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Behind the Headset: Predictive Accuracy of Patient-Reported Outcome Measures for Voice Symptoms in Call Centers

Detrás de los auriculares: precisión predictiva de las medidas de resultados informadas por el paciente para los síntomas de voz en *call centers*

Adrián Castillo-Allendes[1, 2], **Lady Catherine Cantor-Cutiva**[2], **Eduardo Fuentes-López**[3], **Eric J. Hunter**[2]

[1] *Department of Communicative Sciences and Disorders; Michigan State University; East Lansing; Michigan; United States.*

[2] *Department of Communication Sciences and Disorders; The University of Iowa; Iowa City; United States.*

[3] *Department of Health Sciences; School of Medicine; Pontificia Universidad Católica de Chile; Santiago; Chile.*

Correspondence
Adrian Castillo-Allendes.
Email: casti208@msu.edu

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Abstract

Objective. This study examines factors predicting self-reported voice symptoms in call center workers.

Methods. Multivariate analysis and predictive modeling assess personal, work-related, acoustic, and behavioral factors. Generalized Linear Models (GLMs) and Receiver Operating Characteristic (ROC) curves are employed.

Results. Age and sleep patterns impacted voice quality and effort, while workplace factors influenced symptom perception. Unhealthy vocal behaviors related to tense voice and increased effort, while hydration was protective. Voice acoustics showed diagnostic potential, supported by ROC data. These findings emphasize voice symptom complexity in call center professionals, necessitating comprehensive assessment.

Limitations. This study recognizes its limitations, including a moderate-sized convenience sample and reliance on PROM metrics. Future research should incorporate more objective measures in addition to self-reports and acoustic analysis.

Value. This research provides novel insights into the interplay of personal, occupational, and voice-related factors in developing voice symptoms among call center workers. Predictive modeling enhances risk assessment and understanding of individual susceptibility to voice disorders.

Conclusion. Results show associations between various factors and self-reported voice symptoms. Protective factors include sleeping more than six hours and consistent hydration, whereas risk factors include working conditions, such as location and behaviors like smoking. Diagnostic models indicate good accuracy for some voice symptom PROMs, emphasizing the need for comprehensive models considering work factors, vocal behaviors, and acoustic parameters to understand voice issues complexity.

Declaration of interests
The authors have declared that there is no conflict of interest.

Data availability
All relevant data is in the article. For futher information, contact the corresponding author.

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Contribution of the authors
Adrian Castillo-Allendes: Conceptualization, data curation, investigation, methodology, project administration, software, supervision, writing – original draft, writing – review & editing.
Lady Catherine Cantor-Cutiva: Conceptualization, data curation, formal analysis, investigation, software, supervision, writing – review & editing.
Eduardo Fuentes-López: Conceptualization, investigation, methodology, project administration, software, writing – review & editing.
Eric J. Hunter: Methodology, project administration, supervision, writing – review & editing.

Keywords
Voice symptoms; call center workers; predictive factors; occupational health; self-reported measures.

Resumen
Objetivo. Este estudio examina los factores que predicen los síntomas de voz en los trabajadores de *call centers*.

Métodos. Se utilizan análisis multivariados y modelos predictivos para evaluar factores personales, laborales, acústicos y de comportamiento. Se emplean Modelos Lineales Generalizados (GLM) y curvas ROC.

Resultados. La edad y los patrones de sueño afectaron la calidad vocal y el esfuerzo, mientras que los factores laborales influyeron en la percepción de síntomas. Los comportamientos vocales no saludables se relacionaron con voz tensa y mayor esfuerzo, mientras que la hidratación fue protectora. Los parámetros acústicos de voz mostraron potencial diagnóstico respaldado por datos de ROC. Los hallazgos subrayan complejidad de síntomas vocales en profesionales de centros de llamadas, requiriendo una evaluación integral.

Limitaciones. Este estudio reconoce sus limitaciones, que incluyen una muestra de conveniencia de tamaño moderado y la dependencia de medidas PROMs. Futuras investigaciones deberían incorporar medidas objetivas, además de los autorreportes y análisis acústico.

Importancia. Esta investigación aporta nuevos conocimientos sobre factores personales, laborales y síntomas de voz en trabajadores de *call centers*. El modelado predictivo mejora la evaluación de riesgos y la comprensión de la susceptibilidad individual a trastornos de la voz.

Conclusión. Los resultados muestran asociaciones entre diversos factores y los síntomas vocales reportados. Los factores de protección incluyen dormir más de seis horas y una hidratación constante; los factores de riesgo incluyen las condiciones de trabajo, como la ubicación y comportamientos como fumar. Los modelos de diagnóstico indican una buena precisión para algunas PROMs de síntomas de la voz, lo que subraya la necesidad de modelos integrales que tengan en cuenta los factores laborales, los comportamientos vocales y los parámetros acústicos para comprender la complejidad de los problemas de la voz.

Palabras clave
Síntomas de voz; trabajadores de call centers; factores predictivos; salud ocupacional; medidas autoinformadas.

Introduction
Call center workers represent approximately 25% of the global workforce [1]. Since these workers heavily rely on their voices for performing their job, voice disorders are impacting health issues in this population. Previous research have reported a significant portion of call center workers experiencing voice disorders, with prevalence proportion ranging between 27% and 65% [2,3]. These high prevalences raise red flags about the occupational burden on voice health and its implications for the well-being of this workforce.

Occupational voice users, such as call center workers, are more likely to develop work-related voice disorders (WRVDs) than their non-occupational counterparts [4–7]. This elevated risk is the product of a complex interplay of occupational and individual factors. Environmental factors inside the workplace, including high background noise levels, long reverberation times, and extreme temperatures, contribute substantially to increase this risk [1,3,6]. Simultaneously, individual behaviors like smoking, lack of implementation of voice hygiene practices, and hydration habits also influence the development of voice disorders. While the impact of these personal factors has been extensively scrutinized concerning vocal health, the role of occupational factors in this specific population has been comparatively overlooked. Despite the prevalence of WRVDs among call center workers, scarce data exists regarding the intricate relationship between potential risk and protective factors for vocal health [6,8].

The economic consequences of WRVDs are not only for teachers but also for institutions, and for society in general. Dysphonia, a prevalent voice disorder, substantially burdens the healthcare system, leading to frequent medical visits and costing billions of dollars in lost productivity due to work absenteeism. In the United States alone, the direct annual costs attributed to dysphonia have been estimated as high as US$13.5 billion [9]. Moreover, WRVDs contribute to diminished productivity, increased absenteeism and short-term disability claims [7,10]. Beyond these economic implications, these disorders have far-reaching socio-economic and psychological consequences for the affected workers [6,11]. Although workplace voice screening initiatives help to identify occupational voice issues promptly and assess risk factors, their practical implementation remains a challenge [12].

Patient-reported outcome measures (PROMs) are easy to incorporate as an assessment tool and pivotal in evaluating voice symptoms and associated factors, serving as indispensable tools. Unlike in many other fields, voice-related assessments heavily rely on PROMs to capture subjective experiences and perceptions of individuals, enabling a comprehensive understanding of the multifaceted nature of voice disorders [13]. Moreover, PROMs facilitate the assessment of various dimensions of voice symptoms, encompassing physical, emotional, and functional aspects, thus providing a comprehensive understanding of their impact on individuals' well-being [14]. Furthermore, PROMs offer a standardized and validated approach to evaluate voice-related outcomes, ensuring consistency and comparability of data across different individuals and settings.

This study aimed to assess the predictive value of personal factors, work-related factors, voice acoustic parameters, and self-reported vocal behaviors in detecting self-reported voice symptoms. Predictive modeling provides highly valuable information for defining risky conditions to intervene [15] and, therefore, assure informed decision-making in populations at a higher risk of experiencing voice problems.

Methods

Study design

The data analyzed and presented below represent only a portion of the data collected from a larger cross-sectional analytical study. The primary study collected data, including an acoustic voice assessment of voice recordings, vocal health behaviors from PROMs, and workload information from an interview. The primary study methods and outcome measures are described elsewhere [12]. All procedures complied with the ethical standards of the institutional research committee and the Helsinki Declaration of 1964 and its later amendments. The

primary study had ethical approval from the Institutional Review Board of the Pontificia Universidad Católica de Chile, School of Medicine, and all participants provided informed consent before enrollment in the study.

Participants

The participants were selected through a non-probabilistic method and included call center operators affiliated with a healthcare institution in Santiago, Chile. Participants were recruited at three different locations of the same call center, which provides medical customer service. Notably, Location #3, unlike the other two, operates under the outsourcing modality and their employees were not employees of the healthcare institution. To be included in the primary study, participants had to meet the following criteria: (1) be employed in the location for more than two months, (2) work daytime shifts due to differences in vocal workload and physical fatigue of workers in other shifts, and (3) no report of a previous voice disorder diagnosis due to non-occupational causes.

Voice assessment

The acoustic voice assessment and resultant acoustic voice parameters were obtained from participant voice recordings of (1) steady vowel [a:], produced at a comfortable intensity and pitch, ensuring a minimum duration of at least 5 seconds, and (2) connected speech by reading "The Abuelo" (The Grandfather)" passage. This text, although not phonemically balanced, contains the entire inventory of phonemes of Chilean Spanish [16]. Voice samples were recorded using a portable digital recorder (Tascam DR-40) that was placed at 45°–20 cm from the participant's mouth. The recordings were conducted in a single session during working hours in a quiet room with a background noise of ≤ 30 dB with the participant seated. Background noise was assessed using 'The NIOSH Sound Level Meter app, installed on an iPhone 12. This app is recognized for its high accuracy of ± 2 dBA, comparable to professional sound level meters [17–19].

To obtain MPT values, participants were instructed to phonate the vowel [a:] at their comfortable pitch and loudness levels, following established procedures used in prior studies [20,21]. The assessment consisted of three separate trials for each participant. A stopwatch was used to measure the phonation duration in seconds. To obtain a representative MPT value for each participant, we selected the highest duration recorded among the three measurements.

Using Praat v.6.1.16 software, multiple voice acoustic parameters were obtained from both the steady vowel production, with analysis concentrated on the central stable segment lasting 3 seconds, and the connected speech. The following parameters were obtained from vowel production: Harmonic to Noise Ratio (HNR), Smoothed Cepstral Peak Prominence (CPPS-vowel), jitter, shimmer, and voice breaks. From the connected speech production, the following were obtained: L1-L0 slope, CPPS (CPPS-speech), and alpha ratio (a-ratio).

Vocal health behaviors and voice symptoms

The vocal health behaviors of the participants were evaluated using two PROMs: the Spanish version of the Vocal Handicap Index (VHI-10) [22], and the Vocal Hygiene Behaviors and Symptoms Questionnaire (VHS) [1]. The VHI-10, often referred to as the abbreviated version of the VHI-30, is a widely used self-assessment tool designed to evaluate the impact of voice disorders on an individual's quality of life. It is specifically used to assess the perceived handicap or limitations caused by voice-related issues [23]. The VHS consisted of 21 items

presented in two sections. Section I included 6 questions on vocal hygiene behaviors and environmental factors, and section II included 15 questions on voice symptoms. Responses to the questions were on a Likert scale. In addition, self-perceived vocal symptoms were measured using three visual analog scales (VAS) previously validated by the research group in this population [12]. The participants rated their perceptions about phonatory effort, voice quality, and vocal fatigue using three VAS scales: VAS-1, VAS-2, and VAS-3, respectively.

Work-related factors

To obtain information about the workload of the participants, a structured interview was conducted before collecting the voice sample and PROMs. The interview questionnaire comprised several questions related to work experience, including the number of years working in the field, as well as questions about the participants' work schedule, such as the type of shift, the average number of days worked per week, the average number of hours worked per day, and break times.

Statistical analysis

The statistical analysis was conducted in three steps to investigate changes in 19 dependent variables and their relationship with 20 independent variables. The dependent variables included VHI-10 total score, VAS on vocal effort, VAS on voice quality, VAS on vocal fatigue, and fifteen questions on voice symptoms from the Vocal Hygiene Behaviors and Symptoms Questionnaire (VHS). The independent variables were categorized into four groups: personal factors (biological gender, age), work-related factors (years of experience, working hours, location), voice acoustic measures (MPT, CPPS-speech, CPPS-vowel, a-ratio, L1-L0, fundamental frequency mean, jitter, shimmer, HNR), and vocal behaviors (six questions on vocal hygiene habits from the VHS Questionnaire). The analysis aimed to identify the relationships and predictive value of the independent variables on the dependent variables.

First, exploratory data analysis was performed to investigate the distribution of variables. Descriptive statistics were used to summarize and explore the dispersion of the data. For normally distributed continuous variables, the mean and standard deviation were reported, while variables with a non-normal distribution were summarized using the median and 25^{th} and 75^{th} percentiles. Second, Generalized Linear Models (GLMs) multivariate analyses were used to determine whether the independent variables were associated with differences in the 19 dependent variables. For the Categorical Ordinal variables (fifteen questions on voice symptoms from the Vocal Hygiene Behaviors and Symptoms Questionnaire (VHS), an ordinal distribution with a logistic link function was used. For the Numerical Continuous variables (VAS on vocal effort, VAS on voice quality, VAS on vocal fatigue) and the numerical Discrete variable (VHI-10 total), we used a Gaussian distribution with an identity link function. For the categorical variables, the magnitude of the association was expressed by the Odds Ratio (OR) and its 95% Confidence Intervals (CI). For the numerical variables, the magnitude of the association was expressed by the beta (β) and its standard error (SE). Third, Receiver Operating Characteristic (ROC) curves were used to assess the predictive performance of the multivariate models including the statistically significant associated variables. The area under the curve (AUC) reflects the level of accuracy by which the dependent variables can predict the presence of voice symptoms. An AUC of 0.5 reflects a complete absence of any agreement, an AUC of one (AUC=1) presents a perfect agreement, and an AUC of 0.60-0.80 is considered a fair accuracy. In addition, sensitivity (proportion of call center workers with

voice symptoms who were correctly classified) and specificity (proportion of symptom-free call center workers who were correctly classified) were calculated, using the cut-off value of the dependent variables that resulted in the highest sum score of sensitivity and specificity. In this way, we tested whether the added value of the dependent variables would improve the diagnosis of voice symptoms [24,25]. All statistical analyses were performed employing SPSS 25 (IBM Corporation).

Results

Participants characteristics

The sample consisted of 66 call center operators who voluntarily participated in the study, distributed across three different locations. Specifically, there were 25 participants located in location #1, 10 participants in location #2, and 32 participants in location #3. The mean age of the participants was 39.7 years (SD 10.44), with a sex distribution (sex as a biological factor) of 61 female participants and 5 male participants. All of them identified as cisgender. The participants reported an average weekly working hours of 42.79 hours (SD 6.19), with the majority (70.89%) working 44 hours per week. Furthermore, the participants had an average working experience in telemarketing of 7.46 years (SD 6.30), ranging from 1 to 25 years.

Associated Factors of Patient-reported Outcome Measures of Voice Symptoms

The univariate analysis results, included in the Appendix, highlight the variables that met the inclusion criteria for the multivariate analysis, specifically when their p-values were less than 0.20.

The results of the multivariate analysis for the VHI-10 total, Vocal Effort Score (VAS-1), Voice Quality Score (VAS-2), and Vocal Fatigue Score (VAS-3) are presented in Table 1. The results of the multivariate analysis indicate the following trends: workers from Location #3 (β= -4.80) —those who reported sleeping more than six hours at night rarely (β= -4.79), sometimes (β= -3.95), and always (β= -5.38), individuals using their voice in noisy environments sometimes (β = -5.81) and always (β= -6.41), and those with increased L1-L0 (β= -1.09)— experienced a decrease in VHI-10 total score. However, an increase in the VHI-10 total score was observed among workers reporting occasional use of their voice without taking breaks (β= 5.02) and sometimes smoking more than five cigarettes a day (β = 4.71). The vocal effort score showed an increase among workers with longer working hours compared to their colleagues with shorter hours (β= 1.44) and individuals who reported using their voice without taking breaks sometimes (β= 22.21) and always (β= 38.01). The voice quality score showed an increase with age (β= 0.76) and for workers who reported using their voice without taking breaks sometimes (β= 44.54) and always (β= 56.68). However, there was a notable decrease in voice quality scores among workers stationed at Location #2 (β= -33.74). The vocal fatigue score increased for workers who reported smoking more than five cigarettes a day sometimes (β= 21.58), but the score decreased as the CPPS measured in speech increased (β= -1.96).

Table 1. Multivariate Models for Associations between Individual and Work-Related Factors, Voice Acoustic Parameters, and Vocal Behaviors with PROMs (VHI-10 total, Vocal Effort Score (VAS-1), Voice Quality Score (VAS-2), and Vocal Fatigue Score (VAS-3).

Parameter	VHI-10 total			Vocal Effort Score			Voice Quality Score			Vocal Fatigue Score		
	Multivariate Analysis			Multivariate Analysis			Multivariate Analysis			Multivariate Analysis		
	Beta	SE	P-value	Beta	SE	P-value	Beta	SE	P-value	Beta	SE	P-value
Age				0.76	0.45	0.09	0.79	0.38	0.04*			
[gender=.0]												
[gender=1.0]												
Working hours				1.44	0.72	0.05*	0.68	0.68	0.31	-2.04	1.30	0.12
Years of experience				-1.08	0.89	0.23						
Location 1	Reference Category			Reference Category			Reference Category			Reference Category		
Location 2	-2.48	1.75	0.16	-16.30	16.40	0.32	-33.74	14.18	0.02*	2.29	8.10	0.78
Location 3	-4.80	1.48	0.00*	-14.38	12.30	0.24	-6.14	11.36	0.59	-9.66	5.21	0.06
Drink more than three cups of coffee, tea, or soft drink per day - Never										Reference Category		
Drink more than three cups of coffee, tea, or soft drink per day - Almost Never										5.45	9.02	0.55
Drink more than three cups of coffee, tea, or soft drink per day - Sometimes										5.18	9.36	0.58
Drink more than three cups of coffee, tea, or soft drink per day - Always										2.55	8.58	0.77
Use your voice without taking breaks - Never	Reference Category			Reference Category			Reference Category					
Use your voice without taking breaks - Almost Never	1.68	1.71	0.33	16.77	13.13	0.20	21.50	12.49	0.09			
Use your voice without taking breaks - Sometimes	5.02	1.35	0.00*	22.21	10.79	0.04*	44.54	10.21	0.00*			
Use your voice without taking breaks - Always	1.93	2.11	0.36	38.01	15.72	0.02*	56.68	13.45	0.00*			
Drink more than two liters of water a day - Never	Reference Category			Reference Category								
Drink more than two liters of water a day - Almost Never	-1.85	1.80	0.31	1.46	14.95	0.92						
Drink more than two liters of water a day - Sometimes	-1.09	1.56	0.49	-6.53	13.64	0.63						
Drink more than two liters of water a day - Always	-0.80	1.74	0.64	-19.02	13.93	0.17						

Parameter	VHI-10 total			Vocal Effort Score			Voice Quality Score			Vocal Fatigue Score		
	Multivariate Analysis			Multivariate Analysis			Multivariate Analysis			Multivariate Analysis		
	Beta	SE	P-value	Beta	SE	P-value	Beta	SE	P-value	Beta	SE	P-value
Smoke more than five cigarettes a day - Almost Never	1.58	2.39	0.51	30.68	21.13	0.15				-8.58	10.52	0.42
Smoke more than five cigarettes a day - Sometimes	4.71	1.72	0.01*	0.03	12.90	1.00				21.58	6.56	0.00*
Smoke more than five cigarettes a day - Always	2.59	1.66	0.12	9.89	13.63	0.47				0.76	5.95	0.90
Sleep more than six hours at night - Never	Reference Category			Reference Category			Reference Category					
Sleep more than six hours at night - Almost Never	-4.79	2.18	0.03*	7.65	16.21	0.64	-13.31	15.64	0.40			
Sleep more than six hours at night - Sometimes	-3.95	1.86	0.03*	13.11	15.13	0.39	1.72	13.49	0.90			
Sleep more than six hours at night - Always	-5.38	2.01	0.01*	12.02	15.17	0.43	-21.00	14.52	0.15			
Use your voice in noisy environments - Never	Reference Category			Reference Category			Reference Category					
Use your voice in noisy environments - Almost Never	-4.09	3.30	0.22	-32.75	25.95	0.21	-28.97	21.92	0.19			
Use your voice in noisy environments - Sometimes	-5.81	3.01	0.05*	-30.65	23.34	0.19	-29.92	21.29	0.16			
Use your voice in noisy environments - Always	-6.41	2.98	0.03*	-31.01	24.78	0.21	-28.03	21.35	0.19			
Fundamental frequency text												
Jitter	1.32	2.47	0.59	12.06	19.70	0.54	33.31	18.00	0.06			
Shimmer				6.30	14.74	0.67				-0.38	3.02	0.90
CPPS in vowel	-0.29	0.29	0.31	-4.55	2.95	0.12						
CPPS in speech	1.26	0.76	0.10	-2.58	6.14	0.68	-1.27	5.82	0.83	-1.96	1.01	0.05*
HNR	-0.15	0.27	0.58	0.80	2.07	0.70	1.91	1.84	0.30			
L1-L0	-1.09	0.24	0.00*									
MPT	0.02	0.09	0.79							0.60	0.39	0.12
Alpha ratio				2.52	2.35	0.28	1.27	2.20	0.56			

Table 2A presents the results of the multivariate models examining the relationships between individual and work-related factors, voice acoustic parameters, and vocal behaviors, concerning perceptions of hoarseness, tense voice, weak voice, and vocal effort. The analysis showed two independent variables that significantly increased the likelihood of self-reporting a tense voice. Specifically, individuals who occasionally (OR=66.10) and consistently (OR=40.61) consumed more than three cups of coffee, tea, or soft drinks per day, as well as those who occasionally smoked more than five cigarettes a day (OR=16.00), reported a higher incidence of a tense voice. In contrast, three variables were associated with a decrease in this perception, indicative of potential protective factors. These variables included occasionally consuming more than two liters of water a day (OR=0.06), occasionally sleeping more than six hours at night (OR=0.05) and having a higher L1-L0 ratio (OR=0.61).

For hoarseness, increased working hours (OR=1.29) and working in Location #1 (OR=21.67), as well as occasionally using the voice without breaks (OR=10.39), were identified as risk factors, indicated by odds ratios greater than one. In contrast, consistent intake of more than two liters of water per day (OR=0.02) and occasional (OR=0.10) night sleep of more than six hours were identified as protective factors, with odds ratios smaller than one.

We identified one protective factor against self-reported weak voice, which was consistently getting more than six hours of sleep at night. Specifically, the odds ratios (OR) were 0.08 for rarely, 0.04 for sometimes, and 0.06 for always. As shown in the Table, one risk factor was identified for vocal effort, where workers who reported drinking more than three cups of coffee, tea, or soft drinks per day sometimes are 24.40 times more likely than those who never engage in this behavior.

Table 2B presents the results of the multivariate models examining the association between individual and work-related factors, voice acoustic parameters, and vocal behaviors with perceptions of unsteady and/or faltering voice, tired voice, voice loss and voice changes, and lack of air when speaking. One self-reported behavior was identified as a potential risk factor for unsteady and/or faltering voice. Workers who use their voice without taking breaks sometimes (OR=14.11) and always (OR=20.40) were more likely to report this symptom than their colleagues without this behavior. In contrast, individuals who reported sleeping more than six hours at night rarely were associated with a potential protective factor (OR=0.10) against voice loss.

Table 2C presents the results of the multivariate models examining the association between individual and work-related factors, voice acoustic parameters, and vocal behaviors with perceptions of lack of air when speaking, foreign body in the throat, phlegm in the throat, and throat clearing when speaking. Workers with more years of experience were more than 16% likely to report a lack of air when speaking (OR= 1.16), as well as those who reported smoking more than five cigarettes a day sometimes (OR= 11.61) and those who reported sleeping more than six hours at night rarely (OR= 36.47). Workers with more years of experience were 16% more likely to report experiencing a lack of air when speaking (OR=1.16). Additionally, those who reported occasionally smoking more than five cigarettes a day (OR=11.61) and individuals who rarely slept more than six hours at night (OR=36.47) were also more likely to report this symptom. Workers with increased values of CPPS in vowels were less likely to report the sensation of a foreign body in the throat (OR=0.70). As with other self-reported symptoms, individuals who occasionally consumed more than three cups of coffee, tea, or soft drinks per day were significantly more likely to report a sense of phlegm in the throat, with an OR of 14.65.

Table 2A. Multivariate Models for Associations between Individual and Work-Related Factors, Voice Acoustic Parameters, and Vocal Behaviors with Perceptions of Hoarseness, Tense Voice, Weak Voice, and Vocal Effort.

Parameter	Tense Voice				Hoarseness				Weak voice				Vocal effort			
	Multivariate Analysis				Multivariate Analysis				Multivariate Analysis				Multivariate Analysis			
	OR	95% LCI	95% UCI	P-value	OR	95% LCI	95% UCI	P-value	OR	95% LCI	95% UCI	P-value	OR	95% LCI	95% UCI	P-value
Age																
[gender=.0]					Reference Category								Reference Category			
[gender=1.0]					0.00	0.00	0.09	0.00					0.24	0.04	1.64	0.15
Working hours	1.14	0.96	1.35	0.13	1.29	1.06	1.57	0.01*					1.05	0.95	1.17	0.32
Years of experience	1.02	0.89	1.17	0.79												
Location 1	Reference Category				Reference Category								Reference Category			
Location 2	15.62	0.65	373.83	0.09	21.67	1.11	424.84	0.04*					1.98	0.27	14.75	0.50
Location 3	0.25	0.04	1.74	0.16	2.16	0.28	16.60	0.46					0.80	0.27	2.35	0.68
Drink more than three cups of coffee, tea, or soft drink per day - Never	Reference Category				Reference Category								Reference Category			
Drink more than three cups of coffee, tea, or soft drink per day - Almost Never	10.67	0.45	255.84	0.14	0.14	0.00	10.42	0.37					4.10	0.35	47.63	0.26
Drink more than three cups of coffee, tea, or soft drink per day - Sometimes	66.10	2.09	2089.29	0.02*	3.01	0.06	151.09	0.58					24.40	1.94	307.57	0.01*
Drink more than three cups of coffee, tea, or soft drink per day - Always	40.61	1.94	850.56	0.02*	0.15	0.00	6.71	0.32					4.30	0.42	44.66	0.22
Use your voice without taking breaks - Never	Reference Category				Reference Category				Reference Category							
Use your voice without taking breaks - Almost Never	3.55	0.33	37.68	0.29	6.07	0.63	58.14	0.12	3.59	0.71	18.26	0.12				
Use your voice without taking breaks - Sometimes	5.82	0.84	40.41	0.08	10.39	1.34	80.67	0.03*	2.95	0.77	11.38	0.12				
Use your voice without taking breaks - Always	4.71	0.29	77.15	0.28	0.73	0.05	11.36	0.83	4.19	0.62	28.24	0.14				
Drink more than two liters of water a day - Never	Reference Category				Reference Category								Reference Category			
Drink more than two liters of water a day - Almost Never	0.38	0.03	4.99	0.46	0.19	0.02	2.03	0.17					0.69	0.14	3.49	0.66
Drink more than two liters of water a day - Sometimes	0.06	0.01	0.70	0.03*	0.22	0.02	1.97	0.18					0.30	0.07	1.32	0.11

Parameter	Tense Voice				Hoarseness				Weak voice				Vocal effort			
	Multivariate Analysis				Multivariate Analysis				Multivariate Analysis				Multivariate Analysis			
	OR	95% LCI	95% UCI	P-value	OR	95% LCI	95% UCI	P-value	OR	95% LCI	95% UCI	P-value	OR	95% LCI	95% UCI	P-value
Drink more than two liters of water a day - Always	0.29	0.02	3.92	0.35	0.02	0.00	0.33	0.01*					0.20	0.03	1.15	0.07
Smoke more than five cigarettes a day - Never	Reference Category								Reference Category							
Smoke more than five cigarettes a day - Almost Never	6.45	0.16	267.44	0.33					0.73	0.08	6.40	0.77				
Smoke more than five cigarettes a day - Sometimes	16.00	1.50	170.69	0.02*					2.44	0.56	10.68	0.24				
Smoke more than five cigarettes a day - Always	0.30	0.03	2.89	0.30					0.94	0.22	3.99	0.93				
Sleep more than six hours at night - Never	Reference Category				Reference Category				Reference Category							
Sleep more than six hours at night - Almost Never	0.06	0.00	1.40	0.08	0.09	0.01	1.16	0.06	0.08	0.01	0.86	0.04*				
Sleep more than six hours at night - Sometimes	0.05	0.00	0.92	0.04*	0.10	0.01	1.01	0.05*	0.04	0.01	0.35	0.00*				
Sleep more than six hours at night - Always	0.07	0.00	1.33	0.08	0.50	0.05	4.82	0.55	0.06	0.01	0.59	0.02*				
Use your voice in noisy environments - Never					Reference Category											
Use your voice in noisy environments - Almost Never					1.50	0.03	77.39	0.84								
Use your voice in noisy environments - Sometimes					12.24	0.33	455.26	0.18								
Use your voice in noisy environments - Always					88.73	2.10	3741.43	0.02*								
Fundamental frequency text					1.02	0.98	1.06	0.31								
Jitter					78.92	1.75	3555.75	0.03*								
Shimmer																
CPPS in vowel																
CPPS in speech					0.53	0.19	1.44	0.21	0.99	0.51	1.93	0.97				
HNR					1.35	0.93	1.96	0.12								
L1-L0	0.61	0.43	0.88	0.01*	1.08	0.78	1.52	0.64								
MPT	1.01	0.90	1.12	0.90												
Alpha ratio	0.90	0.61	1.32	0.58					0.87	0.66	1.15	0.32				

Table 2B. Multivariate Models for Associations between Individual and Work-Related Factors, Voice Acoustic Parameters, and Vocal Behaviors with Perceptions of Unsteady and/or faltering voice, Tired voice, Voice loss, and Voice changes by the end of the day.

Parameter	Unsteady and/or faltering voice				Tired voice				Voice loss				Voice changes by the end of the day			
	Multivariate Analysis				Multivariate Analysis				Multivariate Analysis				Multivariate Analysis			
	OR	95% LCI	95% UCI	P-value	OR	95% LCI	95% UCI	P-value	OR	95% LCI	95% UCI	P-value	OR	95% LCI	95% UCI	P-value
Age	1.01	0.95	1.09	0.68												
[gender=.0]																
[gender=1.0]																
Working hours	1.13	0.95	1.35	0.18	1.03	0.93	1.15	0.55	1.02	0.90	1.16	0.74	0.98	0.89	1.08	0.69
Years of experience	1.06	0.93	1.22	0.37	1.01	0.90	1.13	0.92								
Location 1	Reference Category				Reference Category				Reference Category				Reference Category			
Location 2	1.85	0.15	23.66	0.64	0.27	0.02	3.27	0.30	2.53	0.31	20.89	0.39	2.30	0.22	24.57	0.49
Location 3	1.15	0.18	7.52	0.89	0.19	0.03	1.29	0.09	0.58	0.12	2.85	0.50	0.38	0.07	1.98	0.25
Drink more than three cups of coffee, tea, or soft drink per day - Never					Reference Category				Reference Category				Reference Category			
Drink more than three cups of coffee, tea, or soft drink per day - Almost Never					0.81	0.05	13.37	0.88	1.97	0.10	39.07	0.66	4.27	0.33	54.91	0.27
Drink more than three cups of coffee, tea, or soft drink per day - Sometimes					3.97	0.25	62.63	0.33	7.48	0.36	156.39	0.20	2.69	0.23	31.64	0.43
Drink more than three cups of coffee, tea, or soft drink per day - Always					1.84	0.15	22.29	0.63	5.57	0.37	84.30	0.22	4.08	0.44	38.13	0.22
Use your voice without taking breaks - Never	Reference Category				Reference Category				Reference Category				Reference Category			
Use your voice without taking breaks - Almost Never	2.47	0.29	20.95	0.41	2.55	0.34	18.80	0.36	0.93	0.12	7.11	0.95	2.36	0.36	15.45	0.37
Use your voice without taking breaks - Sometimes	14.11	2.06	96.50	0.01*	4.93	0.81	29.95	0.08	1.39	0.30	6.55	0.68	4.17	0.76	22.97	0.10
Use your voice without taking breaks - Always	20.40	1.03	405.18	0.05*	1.63	0.12	22.73	0.72	3.00	0.26	34.62	0.38	1.74	0.21	14.78	0.61
Drink more than two liters of water a day - Never	Reference Category				Reference Category								Reference Category			
Drink more than two liters of water a day - Almost Never	0.65	0.06	7.05	0.73	0.47	0.07	3.36	0.45					0.77	0.12	4.97	0.78
Drink more than two liters of water a day - Sometimes	0.72	0.08	6.68	0.77	0.87	0.15	5.13	0.88					1.00	0.21	4.81	1.00
Drink more than two liters of water a day - Always	0.70	0.07	6.61	0.76	0.45	0.05	3.90	0.47					0.28	0.04	2.07	0.21

Parameter	Unsteady and/or faltering voice				Tired voice				Voice loss				Voice changes by the end of the day			
	Multivariate Analysis				Multivariate Analysis				Multivariate Analysis				Multivariate Analysis			
	OR	95% LCI	95% UCI	P-value	OR	95% LCI	95% UCI	P-value	OR	95% LCI	95% UCI	P-value	OR	95% LCI	95% UCI	P-value
Smoke more than five cigarettes a day - Never	Reference Category								Reference Category							
Smoke more than five cigarettes a day - Almost Never	0.58	0.02	14.49	0.74					1.61	0.11	22.93	0.73				
Smoke more than five cigarettes a day - Sometimes	9.01	0.93	87.25	0.06					3.54	0.52	24.13	0.20				
Smoke more than five cigarettes a day - Always	0.24	0.02	2.49	0.23					0.35	0.06	2.19	0.26				
Sleep more than six hours at night - Never	Reference Category				Reference Category				Reference Category				Reference Category			
Sleep more than six hours at night - Almost Never	0.13	0.01	1.81	0.13	1.56	0.14	17.12	0.72	0.10	0.01	0.95	0.05*	0.20	0.02	2.18	0.19
Sleep more than six hours at night - Sometimes	0.23	0.02	2.39	0.22	0.61	0.07	5.42	0.66	0.17	0.02	1.17	0.07	0.28	0.04	2.17	0.22
Sleep more than six hours at night - Always	0.13	0.01	1.60	0.11	2.87	0.30	27.49	0.36	0.53	0.07	4.31	0.56	0.52	0.06	4.49	0.55
Use your voice in noisy environments - Never	Reference Category															
Use your voice in noisy environments - Almost Never	0.04	0.00	3.43	0.16												
Use your voice in noisy environments - Sometimes	0.04	0.00	2.52	0.13												
Use your voice in noisy environments - Always	0.03	0.00	2.30	0.11												
Fundamental frequency text																
Jitter	1.96	0.09	44.16	0.67	6.63	0.45	97.29	0.17	2.94	0.24	36.11	0.40	6.52	0.53	80.11	0.14
Shimmer	3.72	0.41	34.02	0.25	3.54	0.31	41.06	0.31	1.30	0.12	14.58	0.83	2.48	0.30	20.50	0.40
CPPS in vowel	0.94	0.60	1.48	0.80	1.16	0.82	1.66	0.40	0.84	0.57	1.22	0.36				
CPPS in speech																
HNR	0.96	0.70	1.33	0.81	0.98	0.73	1.30	0.86	0.94	0.73	1.20	0.62	1.01	0.79	1.30	0.94
L1-L0																
MPT	0.96	0.86	1.06	0.42	0.98	0.88	1.08	0.65								
Alpha ratio	0.94	0.65	1.35	0.72	0.82	0.59	1.14	0.24					0.86	0.64	1.16	0.33

Table 2C. Multivariate Models for Associations between Individual and Work-Related Factors, Voice Acoustic Parameters, and Vocal Behaviors with Perceptions of lack of air when speaking, foreign body in the throat, phlegm in the throat and throat clear when speaking.

Parameter	Lack of air when speaking				Foreign body in the throat				Phlegm in the throat				Throat clear when speaking			
	Multivariate Analysis				Multivariate Analysis				Multivariate Analysis				Multivariate Analysis			
	OR	95% LCI	95% UCI	P-value	OR	95% LCI	95% UCI	P-value	OR	95% LCI	95% UCI	P-value	OR	95% LCI	95% UCI	P-value
Age																
[gender=.0]													Reference Category			
[gender=1.0]													0.00	0.00	0.06	0.00
Working hours	1.09	0.97	1.23	0.14	1.06	0.95	1.18	0.33								
Years of experience	1.16	1.01	1.33	0.03*	1.05	0.96	1.16	0.28					1.17	0.99	1.37	0.06
Location 1	Reference Category				Reference Category				Reference Category				Reference Category			
Location 2	1.81	0.13	24.74	0.66	0.97	0.14	6.81	0.98	0.95	0.16	5.68	0.95	0.06	0.00	0.82	0.04*
Location 3	0.98	0.18	5.29	0.99	0.51	0.11	2.40	0.39	0.75	0.20	2.78	0.66	0.26	0.03	1.98	0.19
Drink more than three cups of coffee, tea, or soft drink per day - Never	Reference Category				Reference Category				Reference Category							
Drink more than three cups of coffee, tea, or soft drink per day - Almost Never	1.16	0.09	14.72	0.91	0.93	0.08	10.70	0.96	1.62	0.17	15.34	0.68				
Drink more than three cups of coffee, tea, or soft drink per day - Sometimes	5.43	0.38	78.14	0.21	7.98	0.63	101.62	0.11	14.65	1.26	170.49	0.03*				
Drink more than three cups of coffee, tea, or soft drink per day - Always	0.31	0.03	3.45	0.34	3.72	0.37	37.30	0.26	2.11	0.29	15.55	0.47				
Use your voice without taking breaks - Never					Reference Category				Reference Category							
Use your voice without taking breaks - Almost Never					1.30	0.24	6.93	0.76	0.40	0.07	2.44	0.32				
Use your voice without taking breaks - Sometimes					1.30	0.35	4.88	0.70	3.03	0.67	13.67	0.15				
Use your voice without taking breaks - Always					0.82	0.12	5.69	0.84	1.96	0.30	12.77	0.48				
Drink more than two liters of water a day - Never	Reference Category												Reference Category			
Drink more than two liters of water a day - Almost Never	0.66	0.08	5.70	0.71									1.40	0.10	20.40	0.81
Drink more than two liters of water a day - Sometimes	3.75	0.44	32.11	0.23									0.81	0.07	9.28	0.87
Drink more than two liters of water a day - Always	2.82	0.29	27.43	0.37									0.02	0.00	0.31	0.01*

Parameter	Lack of air when speaking				Foreign body in the throat				Phlegm in the throat				Throat clear when speaking			
	Multivariate Analysis				Multivariate Analysis				Multivariate Analysis				Multivariate Analysis			
	OR	95% LCI	95% UCI	P-value	OR	95% LCI	95% UCI	P-value	OR	95% LCI	95% UCI	P-value	OR	95% LCI	95% UCI	P-value
Smoke more than five cigarettes a day - Never	Reference Category												Reference Category			
Smoke more than five cigarettes a day - Almost Never	0.35	0.01	10.18	0.54									0.00	0.00	0.20	0.01*
Smoke more than five cigarettes a day - Sometimes	11.61	1.58	85.33	0.02*									0.74	0.11	5.04	0.76
Smoke more than five cigarettes a day - Always	1.39	0.24	8.17	0.72									3.56	0.51	24.76	0.20
Sleep more than six hours at night - Never	Reference Category								Reference Category				Reference Category			
Sleep more than six hours at night - Almost Never	36.47	2.05	648.98	0.01*					0.22	0.02	2.00	0.18	0.95	0.05	20.39	0.98
Sleep more than six hours at night - Sometimes	0.48	0.05	4.33	0.51					0.44	0.07	3.05	0.41	0.03	0.00	0.71	0.03*
Sleep more than six hours at night - Always	2.67	0.27	26.37	0.40					0.54	0.07	3.95	0.54	0.64	0.03	16.02	0.78
Use your voice in noisy environments - Never	Reference Category												Reference Category			
Use your voice in noisy environments - Almost Never	0.44	0.02	12.77	0.63									0.05	0.00	14.38	0.30
Use your voice in noisy environments - Sometimes	2.01	0.09	45.78	0.66									0.22	0.00	52.74	0.59
Use your voice in noisy environments - Always	7.24	0.23	223.93	0.26									2.41	0.01	617.63	0.76
Fundamental frequency text													1.02	0.99	1.06	0.21
Jitter					2.64	0.32	22.06	0.37								
Shimmer																
CPPS in vowel					0.70	0.50	0.98	0.04*								
CPPS in speech					1.23	0.57	2.69	0.60								
HNR					1.08	0.85	1.38	0.52					1.45	1.01	2.08	0.04*
L1-L0																
MPT																
Alpha ratio					0.86	0.64	1.16	0.32								

Some small protective effects for throat clearing when speaking, though statistically significant, were identified among workers who reported working in Location #2 (OR=0.06), individuals who consistently consumed more than two liters of water a day (OR=0.02), and those who occasionally slept more than six hours at night (OR=0.03). However, it is worth noting that an increased HNR was statistically associated with a higher likelihood of reporting this symptom (OR=1.45).

Table 2D presents the results of the multivariate models examining the association between individual and work-related factors, voice acoustic parameters, and vocal behaviors with perceptions of itchy throat, throat hurt when speaking, and dry mouth. A small yet statistically significant effect was found for individuals who occasionally slept more than six hours at night for both itchy throat (OR=0.04) and throat hurt when speaking (OR=0.07). Similarly, workers with more years of experience and those who reported using their voice in noisy environments rarely (OR=0.03) and sometimes (OR=0.02) were slightly less likely to report experiencing dry mouth.

Diagnostic Models for Patient-reported Outcome Measures of Voice Symptoms

Table 3 presents the diagnostic models for PROMs of voice symptoms. The diagnostic accuracy of each model is assessed using the AUC statistic. Interestingly, the model including statistically significant variables from the multivariate analysis (such as consuming more than three cups of coffee, tea, or soft drinks per day, smoking more than five cigarettes a day, sleeping more than six hours at night, and L1-L0) in relation to the VHI-10 total showed the highest AUC value at 0.92, indicating a good level of accuracy.

Three additional models demonstrated good accuracy. The model for tense Voice, including variables such as consumption of more than three cups of coffee, tea, or soft drinks per day, consumption of more than two liters of water per day, smoking more than five cigarettes a day, sleeping more than six hours at night, and L1-L0 as predictor variables, had an AUC of 0.90. The model for hoarseness, which contained seven variables (including two work-related factors, four vocal behaviors, and one acoustic parameter), had an AUC of 0.85. The model for Voice Quality Score, containing three variables (Age, Location, and the practice of using one's voice without taking breaks), yielded an AUC of 0.81.

On the other hand, the model with the lowest AUC (0.64) included two predictive variables (working hours and the practice of using one's voice without taking breaks) for Vocal Effort Score.

These results emphasize the variability in diagnostic accuracy among predictive models for different PROMs associated with voice disorders. Models that encompass a combination of work-related variables, self-reported vocal behaviors, and voice acoustic parameters tend to exhibit higher AUCs in comparison to simpler models.

Table 2D. Multivariate Models for Associations between Individual and Work-Related Factors, Voice Acoustic Parameters, and Vocal Behaviors with Perceptions of itchy throat, throat hurt when speaking and dry mouth.

Parameter	Itchy throat				Throat hurt when speaking				Dry mouth			
	Multivariate Analysis				Multivariate Analysis				Multivariate Analysis			
	OR	95% LCI	95% UCI	P-value	OR	95% LCI	95% UCI	P-value	OR	95% LCI	95% UCI	P-value
Age									0.96	0.91	1.02	0.19
[gender=.0]												
[gender=1.0]												
Working hours									0.90	0.80	1.00	0.05*
Years of experience												
Location 1	Reference Category								Reference Category			
Location 2	0.67	0.08	5.59	0.71					1.85	0.20	17.27	0.59
Location 3	1.07	0.25	4.57	0.93					0.73	0.16	3.45	0.70
Drink more than three cups of coffee, tea, or soft drink per day - Never	Reference Category											
Drink more than three cups of coffee, tea, or soft drink per day - Almost Never	0.96	0.10	8.91	0.97								
Drink more than three cups of coffee, tea, or soft drink per day - Sometimes	2.31	0.23	22.81	0.47								
Drink more than three cups of coffee, tea, or soft drink per day - Always	1.95	0.28	13.63	0.50								
Use your voice without taking breaks - Never					Reference Category							
Use your voice without taking breaks - Almost Never					3.74	0.72	19.36	0.12				
Use your voice without taking breaks - Sometimes					3.43	0.98	11.96	0.05				
Use your voice without taking breaks - Always					1.65	0.28	9.56	0.58				
Drink more than two liters of water a day - Never												
Drink more than two liters of water a day - Almost Never												
Drink more than two liters of water a day - Sometimes												
Drink more than two liters of water a day - Always												
Smoke more than five cigarettes a day - Never												

Parameter	Itchy throat				Throat hurt when speaking				Dry mouth			
	Multivariate Analysis				Multivariate Analysis				Multivariate Analysis			
	OR	95% LCI	95% UCI	P-value	OR	95% LCI	95% UCI	P-value	OR	95% LCI	95% UCI	P-value
Smoke more than five cigarettes a day - Almost Never												
Smoke more than five cigarettes a day - Sometimes												
Smoke more than five cigarettes a day - Always												
Sleep more than six hours at night - Never	Reference Category				Reference Category				Reference Category			
Sleep more than six hours at night - Almost Never	0.13	0.01	1.62	0.11	0.06	0.00	0.80	0.03*	0.40	0.03	4.59	0.46
Sleep more than six hours at night - Sometimes	0.04	0.00	0.37	0.01*	0.07	0.01	0.68	0.02*	0.19	0.02	1.58	0.13
Sleep more than six hours at night - Always	0.23	0.02	2.89	0.25	0.07	0.01	0.75	0.03*	0.39	0.04	3.94	0.42
Use your voice in noisy environments - Never									Reference Category			
Use your voice in noisy environments - Almost Never									0.03	0.00	0.86	0.04*
Use your voice in noisy environments - Sometimes									0.02	0.00	0.67	0.03*
Use your voice in noisy environments - Always									0.09	0.00	2.86	0.17
Fundamental frequency text	0.98	0.96	1.00	0.06								
Jitter	3.88	0.26	58.16	0.33					1.03	0.05	21.51	0.98
Shimmer									1.21	0.17	8.77	0.85
CPPS in vowel									1.12	0.79	1.58	0.54
CPPS in speech	0.84	0.37	1.88	0.66					0.56	0.25	1.26	0.16
HNR	0.95	0.75	1.21	0.70					0.88	0.66	1.17	0.37
L1-L0												
MPT	0.93	0.85	1.02	0.11					0.93	0.85	1.00	0.06
Alpha ratio												

Table 3. ROC Curves for Patient-reported Outcome Measures of Voice Symptoms.

Voice functioning	Parameters	AUC	SE	Cut-off	Sensitivity	Specificity
VHI-10 total	Drink more than three cups of coffee, tea or soft drink per day	0.92	0.04	0.60	0.93	0.67
	Smoke more than five cigarettes a day					
	Sleep more than six hours at night					
	L1-L0					
Vocal Effort Score	Working hours	0.64	0.08	102.22	0.73	0.51
	Use your voice without taking breaks					
Voice Quality Score	Age	0.81	0.06	100.01	0.81	0.63
	Location					
	Use your voice without taking breaks					
Vocal Fatigue Score	Smoke more than five cigarettes a day	0.67	0.08	49.53	0.81	0.51
	CPPS in speech					
Tense Voice	Drink more than three cups of coffee, tea or soft drink per day	0.90	0.06	-1.21	0.92	0.83
	Drink more than two litres of water a day					
	Smoke more than five cigarettes a day					
	Sleep more than six hours at night					
	L1-L0					
Hoarseness	Working hours	0.85	0.06	-1.56	0.93	0.65
	Location					
	Use your voice without taking breaks					
	Drink more than two litres of water a day					
	Sleep more than six hours at night					
	Use your voice in noisy environments					
	Jitter					
Lack of air when speaking	Years of experience	0.68	0.07	-1.30	0.79	0.54
	Smoke more than five cigarettes a day					
	Sleep more than six hours at night					
Foreign body in the throat	CPPS in vowel	0.65	0.09	13.42	0.77	0.47

Voice functioning	Parameters	AUC	SE	Cut-off	Sensitivity	Specificity
Throat clear when speaking	Location	0.68	0.16	-4.13	1.00	0.32
	Drink more than two litres of water a day					
	Sleep more than six hours at night					
	HNR					
Dry mouth	Working hours	0.68	0.11	-2.81	1.00	0.46
	Use your voice in noisy environments					

Discussion

This study aimed to identify the relationships and predictive value of personal factors, work-related factors, voice acoustic parameters, and vocal behaviors on Patient-Reported Outcome Measures (PROMs) of voice symptoms among call center workers. As employed in this study, predictive modeling offers critical insights for identifying risky conditions to intervene, and therefore informed decision-making in populations at a higher risk of experiencing voice problems.

Personal Factors

This study highlights the role of age in determining voice quality and vocal effort, resonating with existing literature. Aging is known to affect various aspects of voice production including loudness, pitch, and voice quality due to structural and functional dynamics of the vocal folds undergoing changes over time [26–28]. For instance, the muscles of the larynx have the potential to atrophy, the elastin fibers of the lamina propria thin with age, and mucous production diminishes, which could lead to variations in voice quality [26]. An observed trend is the decline in perceived voice quality (i.e., poor voice quality) as individuals age, potentially due to intrinsic aging effects on vocal features. This evolution suggests that producing voice might become more effort-intensive with age, stemming from physiological adjustments in the vocal system.

Other personal factors, especially sleep patterns, have emerged as significant determinants of vocal health in our study. Specifically, individuals who managed to secure more than six hours of sleep nightly exhibited noticeable vocal advantages. This observation resonates with findings from a recent meta-analysis on sleep quality, which underscores the interplay between work-related stress, sleep, and vocal health, particularly among college professors. Carrillo-Gonzalez et al. have identified an increased prevalence of voice disorders among teachers associated with elevated stress levels and six hours or less of sleep per day [29]. Such converging evidence accentuates the indispensable role of adequate rest in safeguarding vocal health, especially for those in vocally demanding professions.

Poor sleep quality and sleep deprivation can adversely affect voice quality, potentially contributing to vocal disorders and compromising vocal performance [30,31]. Sleep serves as a recovery period for both the body and the voice, allowing for the healing of minor inflammations and preventing cumulative damage to the vocal cords [32,33].

Work-Related Factors

The workplace environment plays a pivotal role in shaping call center workers' perception of voice symptoms. Our findings suggest a substantial decrease in the Voice Handicap Index (VHI-10) total score among workers from Location #3 (β= -4.80). This finding suggests that working conditions, including environmental and organizational, from this location differ from the other two locations big enough to be associated with difference in the perception of voice handicap [34,35].

It is noteworthy to highlight that Location #3, being the largest call center with the highest worker count among the three locations, introduces variations that could influence the result's interpretation. One plausible hypothesis that may account for notably lower VHI-10 scores compared to the other locations is the unique dynamics in larger call centers like Location #3. These dynamics could include higher employee turnover, shorter average tenure, and potential differences in call types or work processes, all of which could contribute to variations in reported voice symptoms [36]. This demographic shift may be linked to a lower prevalence of pre-existing voice issues compared to more established, long-standing teams at other locations. However, it is important to note that this hypothesis requires empirical testing in future studies to draw more definitive conclusions.

Concerning Location #2, workers are less likely to report voice-related issues than the other two. Its smaller workforce and room size characterize that setting compared to other locations, which could offer different acoustic properties and working dynamics. The more intimate setting might facilitate better individual vocal habits due to less ambient noise and reduced need for vocal strain. The smaller crowd could also translate to less overlapping conversations, allowing workers to maintain a healthier vocal demand response. These factors align with existing literature highlighting the influence of work-related conditions and workplace culture on voice health outcomes [2,12,37].

While our study did not collect detailed data on room acoustics, noise levels, or specific workplace characteristics, it is worth considering that these factors, coupled with demographic and occupational variables, may collectively influence reported voice symptoms. It is worth noting that room size and acoustic characteristics have been associated with vocal comfort and health across various occupational settings [34,35].

Furthermore, our results showed a significant correlation between the number of working hours and vocal effort scores (VAS-1), aligning with previous research concerning vocally demanding professions such as teaching and call center operations [38–40]. Specifically, as the duration of continuous voice usage extends, call center workers report an elevated sense of effort and strain in speech production, a phenomenon similarly observed among teachers post a week of activity [41]. The high vocal health risk in call center environments necessitates accessible self-report tools for tracking voice symptoms, as highlighted in a study focusing on the utilization of visual analog scales (VASs) for this purpose [12]. Vocal rest underscores the importance of interspersing voice usage with regular rest intervals.

Regarding vocal rest, our findings identified that voice usage without intermittent rest was associated with heightened vocal effort, echoing studies emphasizing the protective effect of vocal rest intervals [41]. Vocal rest serves as a recovery period, facilitating the healing of minor inflammations in the vocal cords, thus averting cumulative damage leading to more severe vocal issues [32,42].

Vocal behaviors

Our study identified significant associations between vocal behaviors and voice symptoms. Individuals who occasionally or consistently consumed more than three cups of caffeinated beverages and smoked more than five cigarettes per day had notably higher odds of reporting tense voice quality and significantly higher likelihood of experiencing vocal effort assessed through VAS-3. These findings quantitatively confirm the impact of these behaviors on vocal health [43–45].

Conversely, adequate hydration, a consistent theme in prior research [46,47], was found to be a protective factor against specific voice symptoms. Hydration levels were associated with a decreased perception of throat clearing and hoarseness. These results underscore hydration's potential as a cornerstone in vocal health interventions aimed at reducing throat clearing and hoarseness among call center workers.

Voice Acoustic Parameters

Our results on this aspect suggest an important role of specific voice acoustic parameters for identifying voice symptoms. Particularly, individuals with higher L1-L0 values, indicative of differences in formant and fundamental frequency energy levels [48], exhibited a significant reduction in their VHI-10 total score. This suggests that when L0 (fundamental frequency energy level) surpasses L1 (formant energy level), it may correspond to a more economical vocal production, resulting in fewer voice-related symptoms. This finding highlights the potential of voice acoustic parameters, accessible through tools like Praat, in providing valuable insights into the comprehensive landscape of voice symptoms, and the need of further research to define the cost-effective use of voice acoustic parameters by defining those that differentiate better normal voices from pathological voices.

Also, an interesting relationship was observed between higher CPPS (Smoothed Cepstral Peak Prominence) measured in speech samples (CPPS-speech) and reduced symptoms of vocal fatigue (VAS-3). This implies that those with higher CPPS-speech values tend to exhibit superior voice quality and a diminished self-perceived vocal fatigue. This provides evidence on the potential of CPPS as a dependable acoustic marker for assessing vocal fatigue, which is in line with previous studies that have employed cepstral based voice metrics, including CPPS, to investigate vocal fatigue and other voice disorders. For instance, a 2020 study emphasized the usefulness of cepstral measures, including CPPS, in analyzing vocal fatigue, particularly among individuals with hyperfunctional voice disorders as an early symptom of voice disorders [49]. Furthermore, some studies have explored the distribution of CPPS values as a potential indicator of overall vocal health status and vocal effort, further supporting its utility in evaluating voice quality [48,50,51].

It is worth noting that while CPPS showed a strong association with vocal fatigue, it did not exhibit similar correlations with other symptoms like tense voice, weak voice, or hoarseness. This suggests that CPPS's impact may be specific to vocal fatigue, emphasizing the importance of considering different acoustic parameters tailored to specific voice-related symptoms. This observation harmonizes with the broader body of literature on voice acoustics, emphasizing the utility of objective voice measures in appraising vocal health and vocal demand responses [52–54].

Diagnostic Models for Patient-reported Outcome Measures of Voice Symptoms

The diagnostic models outlined facilitate the understanding of how personal, work-related, and acoustic variables interplay in predicting PROMs of voice symptoms. The model with the highest accuracy (AUC of 0.92) combines lifestyle factors and the acoustic parameter L1-L0, showcasing the composite influence these variables have on the VHI-10 total, a finding in agreement with existing literature on the multifaceted nature of voice disorders [55,56].

The varying accuracy levels across models for Tense Voice, Hoarseness, and Voice Quality Score underscore the potential for tailored diagnostic approaches in assessing different voice symptoms, guiding targeted interventions. The prominent role of lifestyle and work-related factors in these models reiterates the intertwined nature of personal habits, work environment, and voice health, aligning with studies emphasizing lifestyle modifications and ergonomic interventions in promoting vocal health [39].

The inclusion of acoustic parameter L1-L0 in models with higher AUC values hints at the diagnostic value of acoustic parameters, encouraging further exploration into how other acoustic measures could enhance diagnostic accuracy, corroborating literature on the utility of acoustic analysis in voice assessment [57–59]. These findings underscore the benefits of a multidimensional approach to diagnosing voice disorders in occupational settings. The higher accuracy in models with a diverse range of variables suggests a more holistic assessment could provide a more accurate diagnostic framework, aligning with recommendations for integrated assessment approaches in voice research [54,60].

This analysis could set the stage for refining diagnostic models, exploring other predictive variables, and stimulating discussions on the practical employment of these models, not only in occupational contexts but also in clinical settings, to better assess and address voice disorders among individuals in vocally demanding professions and general population, echoing the importance of evidence-based practice in voice care.

Limitations

Our study acknowledges limitations, including a moderate-sized convenience sample and reliance on self-reported measures. To advance this research area, future studies should incorporate objective measures like endoscopic and aerodynamic assessments alongside self-reports and acoustic voice analysis.

Additionally, we emphasized daytime shifts as an inclusion criterion without specifying shift durations to encompass a broader range of call center workers and enhance external validity. Recognizing the relevance of working hour duration to vocal health, future research might consider incorporating specific shift length criteria for a more detailed participant profile and improved analysis of vocal health factors.

Furthermore, comprehensive assessments of room acoustics should be considered to provide a more holistic understanding of call center workers' vocal health. Future investigations should explore factors such as psychological stress, job satisfaction, and vocal fatigue management. Validating and refining diagnostic models with larger sample sizes and a broader range of voice symptoms will enhance their reliability.

Despite these limitations, this study offers valuable insights into voice symptoms among call center workers, laying the groundwork for further research and targeted interventions to improve their vocal well-being.

Conclusion

Our findings offer valuable insights into the factors associated with voice symptoms among call center workers and other occupational voice users, emphasizing the importance of considering personal, work-related, and behavioral elements when assessing and addressing voice-related issues in this vocally demanding occupation.

This study found specific associations between individual and work-related factors with self-reported voice symptoms. Sleeping more than six hours and consistent hydration were identified as protective factors. On the contrary, working conditions, such as location, and behaviors like smoking were identified as risk factors.

Diagnostic models indicate good accuracy for some voice symptom PROMs, emphasizing the need for comprehensive models considering work factors, vocal behaviors, and acoustic parameters to understand voice disorder complexity. Incorporating acoustic measures into diagnostic models could enhance their accuracy and utility in assessing vocal health, highlighting the multifaceted nature of vocal health in occupational voice users. Future research is needed to refine diagnostic models, explore additional influencing factors, and develop evidence-based strategies to address the multifaceted nature of voice symptoms in this occupation. Ultimately, this research contributes to a deeper understanding of voice health in call center settings and strategies to safeguard and improve the vocal well-being of those in vocally demanding roles.

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