



Perceptual and Acoustic Correlates of Voice in COVID-19 Infection

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Abstract

According to the information published by the World Health Organization in 2020, coronavirus disease, abbreviated as COVID-19, is an infectious disease caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) virus. The virus is reported to result in mild to moderate respiratory illness, significantly affecting vocal mechanisms. The present study explored the effects of a recent COVID-19 infection on perceptual, self-reported outcomes, and acoustic measures of voice. The study was conducted on 25 COVID-19-infected patients and was compared against a group of age- and gender-matched healthy individuals. Perceptual evaluation, self-reported voice outcomes using Voice Handicap Index (VHI-10), and acoustic analysis were conducted on the two groups of participants. The results revealed significant differences in perceptual and acoustic parameters of voice between the two groups.

Keywords

- ▶ vocal symptoms
- ▶ COVID-19
- ▶ acoustic measures
- ▶ perceptual measures

Introduction

The year 2020 marked the emergence of a global pandemic, COVID-19, affecting people's physical, social, mental, emotional, and professional lives. COVID-19, an infectious disease caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) virus, results in the most common symptom of upper respiratory tract infection (URTI) in most patients.¹ Most symptoms of COVID-19 are related to pathological changes in the upper and lower respiratory systems, which predict the coexistence of voice-related difficulties in people affected by COVID-19.^{1,2}

The effect of COVID-19 on the respiratory system has both direct and indirect impacts on the voice of the infected individuals. The pulmonary system is reported to be the most affected in most cases of COVID-19 globally.¹ Patients with COVID-19 experience breathlessness as a major symptom, and it is closely linked to reduced pulmonary vital capacity. Dyspnea can lead to lower breath support for voice production or sustaining speech. Phlegm and dry throats were the most common signs and symptoms reported during

COVID-19 infection.¹ Another vocal sign in COVID-19 patients is dysphonia, which may also be one of the first and most persistent signs of the onset of COVID-19. The laryngeal system may manifest edema, erythema, and congestion during the inflammation. The discovery of high expression of the COVID-19 receptor angiotensin-converting enzyme 2 on the vocal folds is also linked to dysphonia in these cases.^{3–5} There is also evidence of variations in the vocal parameters of cepstral peak prominence (CPP), harmonics-to-noise ratio (HNR), and standard deviation F0 (F0SD) during acoustic analysis.⁶ A recent study explored the perceptual phonatory characteristics (auditory perceptual evaluation and maximum phonation duration [MPD]) in 364 COVID-19-recovered participants and reported that phonasthenia, reduced MPD, and dysphonia were reported more in COVID-19-recovered participants than healthy controls.⁷ The shreds of evidence help link the phonatory abnormalities in COVID-19 to the involvement of the crucial subsystems of speech (phonatory and respiratory).⁷ There have been explorations on the pulmonary and phonatory functions of COVID-19 after its onset in 2020. A recent report

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highlighted respiratory system–related difficulties in COVID-19 patients at the end of hospitalization.⁸ Currently, although the threat of COVID infection has reduced drastically, there are still reports of new and emerging variants that may also have effects on the voice production mechanism similar to the earliest variants of COVID-19. In this scenario, it is essential to explore the effect of COVID-19 on the phonatory system as individuals are resuming their professional and personal activities after the infection, which may be crucial in predicting future voice-related problems, too. Additionally, India was reported to witness all the variants of COVID-19, including alpha, beta, eta, kappa, delta, and delta AY.² However, there is paucity of evidence documenting voice characteristics during and after COVID-19 in the Indian subcontinent. To our knowledge, very limited studies have reported vocal characteristics immediately after the recommended isolation period. The present study aimed to examine the effect of COVID-19 infection on the perceptual and acoustic correlates in the voice of individuals infected by COVID-19 within a cluster immediately after the isolation period of 7 days. The clinical implication of this study would be to have preliminary data evidence to create an awareness about voice-related changes post-COVID-19 infection and plan an appropriate interdisciplinary protocol to treat the vocal symptoms if deemed necessary. The objectives of the study were to explore the perceptual changes, self-reported outcomes, and acoustic changes in the voice of individuals infected by COVID-19 immediately after the isolation period and compare it with the control group.

Method

The study followed a case-control research design wherein two groups (experimental and control) of participants were recruited. Ethical clearance was obtained before the commencement of the study from the ethical committee of the parent institute in adherence with the Declaration of Helinski.⁹

Participants

Two groups of participants were recruited for the study: experimental and control. The participants for the experimental group were from within a COVID-19 cluster from a single quarantine zone in the university campus. Because of the COVID-19 restrictions, only females were selected for the present study by purposive sampling due to ease of recruitment and access to voice recording by the investigators. The cluster during January 2022 was generalized as an omicron viral variant.¹⁰ However, the laboratory reports did not specify the virus variant. Individuals with a history of voice problems or respiratory infections that were not resolved at least 2 months before the COVID-19 infection onset were excluded from the study. The control group consisted of age- and gender-matched individuals. The participants in the control group did not have any vocal pathology in the past or recent upper respiratory infections (within 6 months). Informed consent was taken from all the participants before the study was conducted.

Procedure

The participants were recruited through purposive sampling. The participants in the experimental group were instructed to fill out a voice-related symptom questionnaire, following which they were subjected to a voice recording in a sound-treated room.

Voice Symptom Questionnaire

The participants were instructed to complete a voice-related symptom questionnaire on the Google Form platform. The questionnaire probed into the general and vocal symptoms experienced by the participants during the COVID-19 infection. The questionnaire contained two sections: section A documented the demographic details of the participants and section B probed into the general symptoms experienced during fever, vocal symptoms experienced, and details of hospitalization. The Voice Handicap Index (VHI-10),¹¹ which has 10 questions to document the participants' self-perception of the functional, physical, and emotional changes related to their voice, was used. It has a 5-point rating scale ranging from 0 (never) to 4 (always). A score of greater than 11 is considered abnormal.

Perceptual and Acoustic Evaluation

A sustained phonation task (vowel /a/) recording was taken from the participants in the control and experimental groups. The recordings were taken in a sound-treated room with an ambient noise level of less than 25 dB using Pentax Medical Multi-Dimensional Voice Program (MDVP) interface and software (Kay Elemetrics Corporation, Lincoln Park, NJ, United States). The sampling rate of 44,100 Hz was kept constant for all the recordings. The vocal recording data from the experimental group were collected on the seventh day after testing positive for SARS-CoV-2.

The voice recordings of phonation underwent a perceptual analysis using the GRBAS scale,¹² and the MPD was also measured. The GRBAS scale is a 4-point clinician-rated perceptual rating scale to rate the Grade, Roughness, Breathiness, Asthenia, and Strain in voice, where 0 refers to normal and 3 refers to severe. Three experienced speech-language pathologists performed the perceptual evaluation, and an average of their rating was obtained for the GRBAS scores. Cronbach's alpha revealed a high inter-rater reliability between the three ratings of GRBAS ($\alpha = 0.88$). MPD is a clinical aerodynamic test to estimate the respiratory–phonatory coordination. The patient is instructed to take a deep breath, sustain the phonation of /a/, /i/, or /u/ vowel, and the average of three trials is compared with normatives.

The phonation voice recordings underwent acoustic analyses using MDVP and parameters including fundamental frequency (F_0), mean intensity (I_0), jitter (%), shimmer (dB), noise-to-harmonics ratio (NHR), amplitude perturbation quotient (APQ), and pitch perturbation quotient (PPQ) were extracted.

Analysis

The data from the questionnaire, VHI-10, perceptual evaluation, and acoustic parameters were analyzed statistically in

the JASP 0.16.3.¹³ The data from the voice-related symptom questionnaire underwent descriptive statistical analysis. The acoustic and perceptual analysis data were subjected to normality testing using the Shapiro–Wilk test. The data were non-normally distributed ($p < 0.05$) and underwent a nonparametric Mann–Whitney U test to explore the differences in each acoustic parameter and perceptual measure between the experimental and control groups.

Results

The data revealed that 93% of the experimental and control groups belonged to the age group of 18 to 30 years and 7% belonged to the age group of 30 to 40 years (experiencing no symptoms of menopause). Nearly 76% ($n = 19$) of the participants in the experimental group and 84% ($n = 21$) in the control group were from Dakshina Kannada district of Karnataka. Out of the total, 40% ($n = 10$) of the participants had a graduation degree and 56% ($n = 14$) had completed PUC (preuniversity course). None of the participants were professional voice users or had a history of professional voice usage ($n = 0$).

Voice Symptom Questionnaire and VHI

The data from the symptom questionnaire in the experimental group revealed that 88% of the participants were symptomatic. Cough ($n = 22$, 84%) was the most prominent general symptom reported, and dry throat and frequent throat clearing were the common vocal symptoms of COVID-19. The descriptive analysis of the other variables related to the general infection course and symptoms is given in ►Table 1 and ►Fig. 1.

It was found that the maximum number of general symptoms reported by a single participant was 11, and the minimum was 0, with a median (interquartile range [IQR]) of 5.0 (3.00). On the other hand, the maximum number of vocal symptoms reported by a single participant was eight and the minimum was 0, with a mean of 2.93 (± 1.41). Nearly 72% ($n = 18$) of the experimental group reported voice-related problems during and after COVID-19 infection. The most and least reported vocal symptoms during COVID-19 are detailed in ►Fig. 2. Spearman's correlation coefficient was computed to explore the linear relationship between the general and vocal symptoms of COVID-19. The results revealed a moderate positive correlation between the general and vocal symptoms in the experimental group ($r = 0.706$).

The maximum total score of the VHI-10 reported by a single participant was 18 and the minimum was 0, with a mean of

2.53 (± 7.07) in the experimental group, whereas the mean score of VHI-10 in the control group was 0.64 (± 1.18). The data were, however, not normally distributed, with few extremely high values indicating individual variation of the self-perception of change in voice. Although the mean scores were increased in the experimental group, there was no statistically significant difference in VHI-10 scores between the two groups in the Mann–Whitney U test ($U = 234.5$, $p > 0.05$).

Perceptual Analysis

The mean scores of the perceptual parameters of the GRBAS scale were higher in the experimental group for the grade, roughness, and breathiness components, indicating perceptual deviations in voice than in the control group (►Table 2).

The results of the Mann–Whitney U test revealed statistically significant differences in the overall grade ($U = 96.5$, $p < 0.001$), breathiness ($U = 162.5$, $p < 0.001$), and roughness ($U = 99.5$, $p < 0.001$) components of the scale. However, no statistical significance was obtained for the components of asthenia ($U = 325$, $p = 0.65$) and strain ($U = 288$, $p = 0.46$). The raincloud plots of MPD for the two groups are given in ►Fig. 3. It was clear that MPD also differed significantly between the two groups ($t = 5.48$, $p < 0.05$ for /a/; $t = 3.94$, $p < 0.05$ for /i/; $t = 4.40$, $p < 0.05$ for /u/) where it was reduced in the experimental group.

Acoustic Analysis

The mean, median, and standard deviation of the measured acoustic parameters for the experimental and control groups are given in ►Table 3.

Since the data from the acoustic analysis were not normally distributed, each acoustic parameter was compared between the experimental and control groups using the Mann–Whitney U test in JASP 0.16.3. The results revealed statistically significant differences in mean intensity, shimmer, NHR, APQ, and PPQ between the experimental and control groups ($U = 530$, $p < 0.05$ for IO; $U = 59$, $p < 0.05$ for shim; $U = 49.5$, $p < 0.05$ for NHR; $U = 71$, $p < 0.05$ for APQ; and $U = 196$, $p < 0.05$ for PPQ). The effect size was large for shimmer ($r_{tb} = 0.81$) and NHR ($r_{tb} = 0.84$), medium for IO ($r_{tb} = 0.69$) and APQ ($r_{tb} = 0.77$), and small for PPQ ($r_{tb} = 0.37$).

Discussion

COVID-19 existed as a worldwide pandemic since late 2019 and was linked to several physiological, physical, socioemotional, and psychological complications. The present study aimed to explore the effects of the SARS-CoV-2 viral infection on the perceptual, acoustic, and self-reported measures of voice and compare it with a group of the noninfected healthy control group. However, due to the small sample size and the study design, the results may not be easily generalized to the population for the following findings.

The results of the voice symptom questionnaire in the present study showed that frequent throat clearing was the most commonly reported vocal symptom during COVID-19 within the cluster, followed by dryness in the throat (56.7%)

Table 1 Factors related to the general infection course

Variables	Yes	No
Symptomatic	88% ($n = 18$)	12% ($n = 7$)
Hospitalization	32% ($n = 8$)	68% ($n = 17$)
Voice problems during COVID-19 infection	84% ($n = 21$)	16% ($n = 4$)

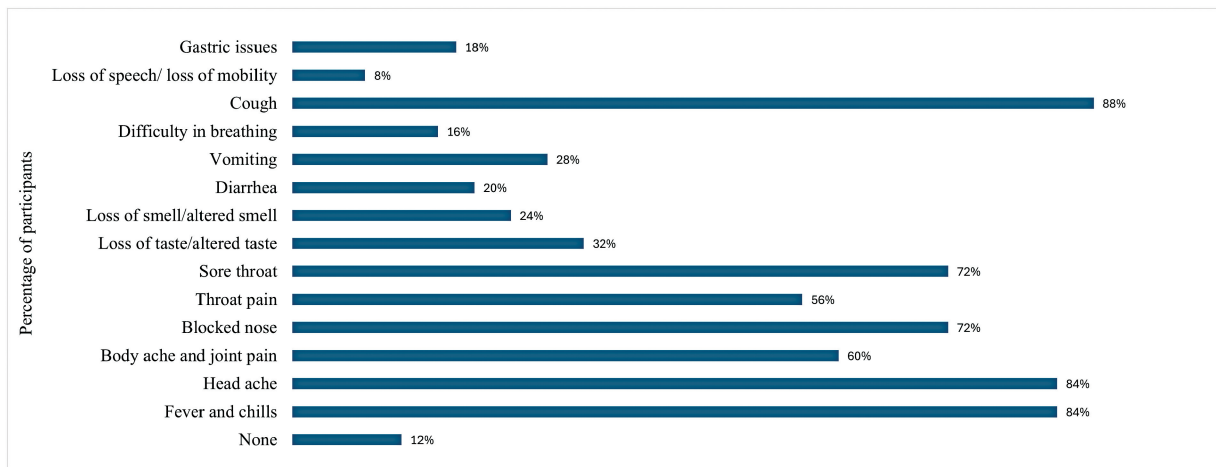


Fig. 1 Reported general symptoms associated with COVID-19 infection.

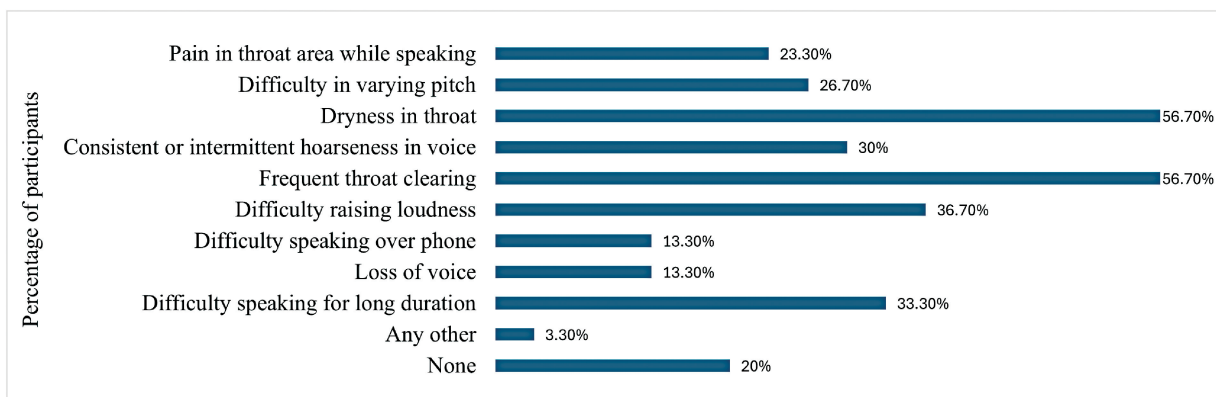


Fig. 2 Reported voice-related symptoms associated with COVID-19 infection.

Table 2 Results of descriptive statistics of perceptual analysis using GRBAS

Variables	Mean		SD		Median		IQR	
	C	E	C	E	C	E	C	E
G	0.28	1.00	0.46	0.28	0.00	1.00	1.00	0.00
R	0.24	0.72	0.44	0.46	0.00	1.00	0.00	1.00
B	0.04	0.76	0.2	0.52	0.00	1.00	0.00	1.00
A	0.00	0.40	0.00	0.20	0.00	0.00	0.00	0.00
S	0.00	0.04	0.00	0.20	0.00	0.00	0.00	0.00

Abbreviation: IQR, interquartile range; SD, standard deviation.

and difficulty in raising loudness level (36.7%). These symptoms align with other studies on vocal symptoms in COVID-19 cases.⁶ The experimental group showed a significant moderate positive correlation between general COVID-19 symptoms and voice-related symptoms. This may suggest that as the severity of COVID-19 infection in an individual's body increases, the number of vocal symptoms also increases. The most commonly reported vocal symptom in the present study was frequent throat clearing and dryness in the throat, followed by difficulty raising loudness and speaking for long hours. Other studies documenting the symptoms of COVID-19 in India have also reported a similar hierarchy of voice-related symptoms.² Since

the study analyzed the vocal characteristics immediately after the isolation period, the reminiscences of the infection in the body might have contributed to the greater vocal symptoms reported. Moreover, most of these symptoms are related to URTI and lower respiratory tract infections (LRTIs), which were reported as the leading cause of voice-related changes in COVID-19 cases.¹⁴ The mean VHI scores were higher in the experimental group than in the control group; the change in voice was not handicapping for most participants in the experimental group. This may be attributed to the fact that the lockdown period had limited the extent of vocal demands and the resulting vocal loading.

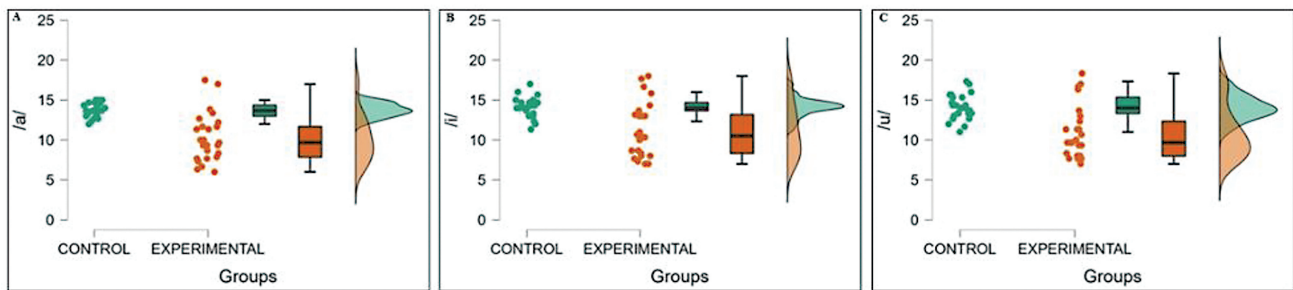


Fig. 3 Raincloud plots of maximum phonation duration (MPD) for /a/, /i/, and /u/ for the experimental and control groups.

Table 3 Mean and standard deviation of acoustic parameters in experimental and control groups

Parameters	Mean		Median		SD		IQR	
	C	E	C	E	C	E	C	E
F0	168.64	147.85	186.60	123.00	54.75	54.36	99.30	84.00
I0	65.09	55.03	65.20	52.00	3.52	7.11	5.00	6.90
Jitt	0.35	0.89	0.30	0.44	0.17	1.7	0.28	0.36
Shim	4.91	12.53	4.91	12.53	1.87	5.71	1.90	10.49
NHR	0.01	0.2	0.01	0.13	0.008	0.2	0.002	0.28
APQ	2.97	6.95	2.80	6.93	1.07	3.02	1.58	5.00
PPQ	0.18	0.51	0.16	0.25	0.10	0.99	0.10	0.20

Abbreviations: APQ, amplitude perturbation quotient; IQR, interquartile range; NHR, noise-to-harmonics ratio; PPQ, pitch perturbation quotient; SD, standard deviation.

The higher mean scores and statistically significant differences in overall grade, breathiness, and roughness in the experimental group obtained on the auditory perceptual assessment using GRBAS aligned with previous findings, which reported significantly increased breathiness in COVID-19 patients compared to controls.¹⁵ The MPD also differed substantially between the experimental and control groups, which was reduced in the experimental group. This could be delineated as an effect of respiratory insufficiency, which was not far from expectation.¹⁵ The results are in line with a previous study that compared acoustic, perceptual, and self-reported outcomes of COVID-19-recovered patients with normal,¹⁴ where the results revealed lower MPD, increased VHI-10 scores, decreased voice-related quality of life (V-RQOL), and a mild change in perceptual voice parameters in COVID-19-recovered patients.¹⁴

The acoustic analysis results infer that mean intensity, shimmer, NHR, APQ, and PPQ were higher in the experimental group compared to the control group. It can be interpreted that amplitude-related measures have shown significant differences between the two groups. This difference in amplitude measures could be due to the predominance of vocal fold inflammation due to repeated cough episodes, respiratory distress, and breathing difficulty in the participants.^{6,16} An increased NHR was also noted in the experimental group, which can be linked to the presence of an increased noise component in the spectrum.¹⁷ The recurrent throat clearing and dry cough reported by the participants in the present study might contribute to air leakage and incomplete vocal fold closure, increasing spectral

noise.¹⁸ This has been well supported in the previous studies that concluded that the increased spectral noise results in the voice being perceived to be breathy.⁶

Summary and Conclusion

The physiology of normal voice production is dependent on the efficient coordination between the respiratory, phonatory, articulatory, and resonatory systems. In COVID-19, due to the infection of these subsystems, especially the respiratory and phonatory systems, there is an effect on the vocal mechanism that was evident in the cases of the current study because of the reported perceptual symptoms, findings of perceptual evaluations, and the deviations in the acoustic parameters of the experimental group as compared to the control group. However, no significant vocal handicap was reported by the participants. The experimental group was found to have a significant reduction in the MPD, indicating respiratory insufficiency in COVID-19 infection. The study also revealed significant differences in the experimental group's mean intensity, perturbation measures, and NHR than the control group. These early changes in voice parameters are generally aggravated by vocal loading and may lead to secondary voice disorders, like muscle tension dysphonia, in order to compensate for the imbalance of the subsystems. Hence, using a multiparametric voice assessment protocol should be considered to identify voice disorders in the patients post-COVID-19 infection so that monitoring and managing the vocal symptoms become more effective while minimizing the chances of vocal handicap.

Limitations

The current study could only generate baseline information on the immediate effects of COVID-19 on voice in the Indian scenario due to the study design and sample size. A longitudinal study design with a larger sample size will help document the long-term vocal symptoms in this population, which will also give insight into developing the protocol for treatment.

Authors' Contributions

All the authors have contributed equally to the conduction and writing of the research study.

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None.

Conflict of Interest

None declared.

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