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Vocal outcomes after COVID-19 infection: acoustic voice analyses, durational measurements, self-reported findings, and auditory-perceptual evaluations

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Abstract

Purpose The ongoing literature suggests that COVID-19 may have a potential impact on voice characteristics during the infection period. In the current study, we explored how the disease deteriorates different vocal parameters in patients who recovered from COVID-19.

Methods A total of 80 participants, 40 patients with a prior history of COVID-19 (20 male, 20 female) with a mean age of 39.9 ± 8.8 (range, 21–53) and 40 gender and age-matched healthy individuals (mean age, 37.3 ± 8.8; range, 21–54) were included to this study. The data of acoustic voice analyses, durational measurements, patient-reported outcomes, and auditory-perceptual evaluations were compared between the study group and the control group. Correlation analyses were conducted to examine the association between the clinical characteristics of the recovering patients and measured outcomes.

Results Maximum phonation time (MPT) and the scores of both Voice Handicap Index-10 (VHI-10) and Voice-Related Quality of Life (V-RQOL) questionnaires significantly differed between the groups, which was more evident in female participants. The overall severity score of dysphonia was found to be higher in the study group than the control group ($p = 0.023$), but gender-based comparisons reached significance only in males ($p = 0.032$). VHI-10 and V-RQOL revealed significant correlations with the symptom scores of the disease.

Conclusions Patients with a prior history of COVID-19 had significantly lower MPT, increased VHI-10 scores, decreased voice-related quality of life based on the V-RQOL questionnaire, and higher overall severity scores in the auditory-perceptual evaluation. Self-reported voice complaints disclosed close relationships with the symptom scores of COVID-19 disease.

Keywords COVID-19 · Dysphonia · Symptoms · Voice evaluation

Introduction

COVID-19 (Coronavirus Disease 2019) is a recently emerged high-risk infectious disease with a long incubation period that has progressed very rapidly and has become a pandemic affecting millions of people around the world [1]. Since the pandemic outbreak, a growing number of studies have been conducted to investigate the effect of the disease on physical, psychological, and social health [2–4]. More specifically, the disease seems to have the potential of affecting various systems in the human body including the respiratory, gastrointestinal, neurological, cardiovascular, renal, and even reproductive systems [5–8]. Aside from the available data, ongoing studies are still trying to explore the underlying mechanism of these effects.

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The production of the human voice is a complex phenomenon that requires an integrated working model, especially with the respiratory and neurological systems. A problem in these systems may disrupt the integrity and also the functionality of voice production, which further results in a disordered voice [9]. It is well established in the studies that the lung is the primary affected organ in COVID-19 disease and there are disease-specific pathological changes in an infected lung [10, 11]. One of the most important tasks of the respiratory system is to provide airflow for voice production. In severe cases, COVID-19 can significantly affect the respiratory system and cause pneumonia and acute respiratory distress syndrome. It has been reported that people who are infected experience difficulties not only in the inspiratory phase of respiration but also in the expiratory phase [12]. Since the energy source required for phonation is provided by the air exhaled from the lungs, both respiratory phases should have adequate functionality. On the other hand, cough, sore throat, rhinorrhea, sneezing, and vomiting are among the general symptoms of the disease which are closely related to the anatomical structures involved in voice production [13]. These symptoms could cause mechanical alterations on the vocal folds and lead to deterioration in voice quality. Another issue that may have a potential effect on the phonatory mechanism is post-viral vagal neuropathy (PVVN). According to Saniasiaya et al. [14], since it contributes to laryngeal sensory and motor disruptions, PVVN should be considered as an important factor that effecting the voice of patients with COVID-19.

The prevalence of voice disorders (dysphonia) in COVID-19 patients was reported to be between 22.3% and 43.7% [15–17]. To date, several studies have been performed to investigate the vocal characteristics of patients with COVID-19. In a study by Saki and colleagues, significant differences were found in auditory-perceptual parameters (both for CAPE-V and GRBAS) between the patients and healthy volunteers [18]. In another study, it was stated that the Voice Handicap Index-10 (VHI-10) scores were higher in patients and all scores of CAPE-V were significantly worse in patients than in controls [19]. In the target population, Tohidast et al. [20] investigated the voice quality and vocal tract discomfort symptoms and reported higher scores in all parameters of the GRBAS scale and a greater frequency of vocal tract discomfort symptoms than healthy subjects. In their study, Asiaee et al. [21] used acoustic voice analyses to compare the vocal quality of the patients with healthy participants. The results of the study revealed statistically significant differences between the two groups for CPP, HNR, H1H2, F0SD, jitter, and shimmer parameters. In all the above-mentioned studies, only subjective voice assessment methods were used except for Asiaee's study. However, it is well known that both objective and subjective methods should be included in the voice evaluation protocols for better management [22–25]. In a study by Eadie et al. [22], it was mentioned that combining acoustic and auditory-perceptual measurements improved the classification accuracy between dysphonic and normophonic voices by up to 100%. In a more recent study, a multiparameter voice assessment protocol including objective and subjective methods was recommended to the clinicians in the diagnosis and treatment of voice disorders [25].

To the best of our knowledge, there is no previous data evaluating the vocal characteristics of the patients who recovered from COVID-19 in a comprehensive manner that consists of both the objective and the subjective parameters. We, therefore, conducted the present study to compare the vocal outcomes of recovering patients with a control group using acoustic voice analyses, durational measurements, self-reported questionnaires, and auditory-perceptual evaluations.

Materials and methods

Study design

The present study was designed as a case–control study at Prof. Dr. Necmettin Akyıldız Hearing, Speech, and Voice Center. Ethical approval was approved by the institutional review board of Gazi University Clinical Research Ethics Committee (IRB No. 328) and all data of the participants were collected after written informed consents were obtained.

Participants and recruitment

The individuals who recovered from COVID-19 disease were the target population for the current study. The subjects with voice disorders due to any functional, structural, or neurogenic causes, those with any malignancy in the nasal cavity, oropharynx, and larynx, those with a history of surgery in the head and neck region (except for septoplasty), those receiving regular inhaled medication due to any reason, and those with hearing loss were excluded from the study.

A total of 40 recovering patients (20 male, 20 female) with a mean age of 39.9 ± 8.8 (range, 21–53) and 40 gender and age-matched healthy individuals (mean age, 37.3 ± 8.8; range, 21–54) were included to the study. Body mass index (BMI) for all participants was collected and did not differ between the groups. Data of time after infection, day of turning negative polymerase chain reaction (PCR) test, and the VAS (visual analog scale) scores of symptoms experienced during the disease (coughing, difficulty in breathing, tiredness, difficulty in speaking, and pain) were gathered from the

Table 1 Demographic and clinical characteristics of the participants

Variables	SG $n=40$		CG $n=40$		p-value
	Mean ± sd	Range	Mean ± sd	Range	
Age (years)	39.9 ± 8.8	21–53	37.3 ± 8.8	21–54	0.192
BMI (kg/m^2)	26.8 ± 3.8	19.5–34.6	25.9 ± 3.9	18.3–35.4	0.303
Time after infection (months)	8.2 ± 4.3	1–17	–	–	NA
Time of negative PCR (days)	14.1 ± 3.9	7–21	–	–	NA
Symptoms (10-cm VAS score)					NA
Coughing	2.5 ± (2.9)	0–8.7	–	–	
Difficulty in breathing	2.2 ± (3.0)	0–10	–	–	
Tiredness	5.2 ± (3.7)	0–10	–	–	
Difficulty in speaking	1.5 ± (2.4)	0–9.7	–	–	
Pain	5.6 ± (3.7)	0–10	–	–	

SG study group; *CG* control group; *BMI* body mass index; *PCR* polymerase chain reaction; *VAS* visual analog scale; *NA* not analyzed

study population. Table 1 provides the demographic information and clinical variables of all participants.

Recording of voice samples

All voice samples were recorded in a sound-treated room with an ambient noise level of 30 ± 5 dBC using CSL software (Model 3700, Version 3.4.1, 2000–2001 Kay PENTAX, Montvale, NJ). A unidirectional Rode NT1 Cardioid Condenser Microphone (Rode microphones, Torrance, CA) with a frequency response of 20 Hz to 20 kHz (± 2 dB) was placed at the level of participants' mouths with a distance of 15 cm. Recordings were performed with a sampling frequency of 44,100 Hz and 16-bit resolution. Before the voice recordings, an experienced SLP (Speech and Language Pathologist) explained the CAPE-V procedure in detail to each participant. According to the procedure, all individuals were asked to phonate the sustained vowels (/a/ and /i/), read the sentences in the Turkish version of CAPE-V, and perform a running speech sample (at least 20 s of natural conversational speech) using a standard interview question "*Tell me about your voice*" [26, 27]. All voice samples were then saved in.*wav* format on a desktop computer for further analysis.

Acoustic analyses

Voice perturbation measurements [mean fundamental frequency (F0), jitter local, shimmer local, and harmonic-to-noise ratio (HNR)] and cepstral peak prominence (CPP) values were obtained from sustained phonation and connected speech, respectively. F0, measured in Hertz, is defined as the number of vocal cycles produced per second. Jitter local is the average absolute difference between consecutive periods, divided by the average period and shimmer local is the average absolute difference between the amplitudes of consecutive periods, divided by the amplitude [28]. HNR specifies the ratio of harmonic energy to noise energy in an acoustic voice signal. CPP is a frequency-based acoustic measurement obtained from the cepstrum of a sound wave. Since it measures the degree of harmony within a voice sample, the greater value of CPP corresponds to a more periodic voice signal and a greater degree of harmonic energy [29]. Praat software (Version 6.0.17, Paul Boersma and David Weenink, Department of Phonetic Sciences, University of Amsterdam, Amsterdam, Netherlands) was used for all acoustic voice analyses. For perturbation measurements, the mid-vowel segment of the most stable part of the sustained /a/ phonation was used. Because it consists of all voiced phonemes, the CPP values were obtained from the third sentence of the Turkish version of CAPE-V (*"Arda onca yılın ardından aradı*", phonetic transcription; *"Ardʌ ondʒʌ juɫun ʌrdundʌn ʌrʌdu"*) for each participant according to a previously published data which shows the steps and parameter setting in Praat software for the extraction of CPP [30].

Durational measurements

Maximum phonation time (MPT) and s/z ratio values were obtained during sustained phonations. For MPT, participants were instructed to inhale deeply and produce the sound /a/ as long as they could at their usual speaking volume for three consecutive times. The maximum value of the trials was accepted as MPT and noted in seconds. The same method of MPT was used for s/z ratio, the maximum phonation time of sustained /s/ divided to the maximum phonation time of sustained /z/. Before all durational measurements, the examiner performed the task for each individual for proper execution.

The questionnaires

Turkish version of both Voice Handicap Index-10 (VHI-10) [31] and Voice-Related Quality of Life (V-RQOL) [32] questionnaires were used to collect data about the patient-reported outcomes. VHI-10 is a questionnaire that consists of 10 items with a score of spanning from 0 to 40, each item has five possible answers: 0—never; 1—almost never; 2—sometimes; 3—almost always; and 4—always. V-RQOL also has 10 items that are rated on a 5-point scale (1–5) measuring the social-emotional and physical function of the patients with voice disorders. A higher score from the questionnaire indicates greater severity of dysphonia.

Auditory-perceptual evaluation

Auditory-perceptual voice judgments were performed based on the running speech part of voice recordings ("*Tell me about your voice*"). An SLP (primary rater), who has at least 5 years of experience in the evaluation and measurement of voice disorders, blindly assessed all voice samples in accordance with the CAPE-V protocol. To capture intra- and inter-rater reliability, twenty percent of data were selected randomly and repeat judgments were done by the primary rater and a second rater. All parameters namely, overall severity, roughness, breathiness, strain, pitch, and loudness were evaluated by the raters in the sound-treated room using a headphone.

Data analysis

All statistical analyses were performed with the Statistical Package for the Social Sciences (SPSS Inc., Chicago, IL) software version 25. Demographic data and clinical characteristics of the participants were analyzed descriptively. Mann–Whitney *U* test was used to compare age, BMI, acoustic voice parameters (mean F0, jitter local, shimmer local, HNR, and CPP), durational measurements (MPT and s/z ratio), patient-reported outcomes (VHI-10 and V-RQOL), and auditory-perceptual evaluation results between the groups. After the comparisons between the study and the control group, gender-based comparisons were performed to obtain gender-specific values of the related voice parameters. The Spearman correlation analysis was performed to determine the correlations between the clinical characteristic of the participants and the measured outcomes. Two-way random effects, absolute agreement, and intraclass correlation coefficients (ICC) were used to calculate intra- and inter-rater reliabilities for all CAPE-V parameters (overall severity, roughness, breathiness, strain, pitch, and loudness). The ICC results were interpreted as follows: if ≥ 0.90, excellent; if between 0.75 and 0.90, good; if between 0.50 and 0.75, moderate; and if < 0.50, poor [33]. A p value of < 0.05 was considered statistically significant.

Results

Comparisons of acoustic voice parameters between the study group ($n = 40$) and the control group ($n = 40$) did not significantly differ for mean F0 ($p = 0.686$), jitter local ($p = 0.202$), shimmer local ($p = 0.268$), HNR ($p = 0.482$), and CPP ($p = 0.874$). Among the durational measurements statistically significant difference was found for MPT ($p = 0.020$), but s/z ratio did not differ between the groups ($p = 0.201$). VHI-10 scores were significantly higher in the study group (mean ± sd; 2.48 ± 3.81, range; 0–16) than the control group (mean ± sd; 0.95 ± 2.40, range; 0–10). Significantly higher scores for V-RQOL were also observed for the study group (mean ± sd; 12.68 ± 3.56, range; 10–27) than the control group (mean ± sd; 10.95 ± 2.45, range; 10–24). The p values for VHI-10 and V-RQOL scores were obtained 0.002

Table 2 Comparisons of acoustic voice parameters, durational measurements, and scores of the questionnaires between the groups

Parameters	SG $n = 40$		CG $n = 40$		p-value
	Mean ± sd	Range	Mean ± sd	Range	
Mean F0 (Hz)	190.17 ± (61.0)	104.26–309.52	196.42 ± 66.90	102.52–323.44	0.686
Jitter local (%)	0.24 ± 0.13	0.10–0.71	0.20 ± 0.09	0.09–0.44	0.202
Shimmer local (%)	3.52 ± 1.60	1.14–9.09	3.20 ± 1.46	1.18–6.62	0.268
HNR (dB)	24.28 ± 3.07	17.69–29.50	23.95 ± 2.63	19.34–31.44	0.482
CPP (dB)	20.58 ± 1.45	17.64–23.47	20.54 ± 1.39	18.18–23.68	0.874
MPT (s)	16.88 ± 5.40	6.20–32.60	20.14 ± 6.51	7.15–34.56	0.020
S/Z ratio	1.00 ± 0.22	0.51–1.54	0.92 ± 0.18	0.60–1.30	0.201
VHI-10 score	2.48 ± 3.81	0–16	0.95 ± 2.40	0–10	0.002
V-RQOL score	12.68 ± 3.56	10–27	10.95 ± 2.45	10–24	< 0.001

SG study group; *CG* control group; *HNR* harmonic to noise ratio; *CPP* cepstral peak prominence; *MPT* maximum phonation time; *VHI-10* Voice Handicap Index-10; *V-RQOL* Voice-Related Quality of Life

and < 0.001, respectively. Table 2 provides more detailed data of measured outcomes.

Gender-based comparisons were conducted for further analyses of acoustic voice parameters, durational measurements, and scores of the questionnaires. The findings showed that there was no statistically significant difference between the males in the study group and the males in the control group for any parameter. Whereas, comparisons between the female participants showed significantly lower scores for MPT ($p = 0.038$), significantly higher scores were obtained for both VHI-10 ($p < 0.001$) and V-RQOL ($p = 0.001$) questionnaires in the study group than in the control group. More information about the parameters is given in Table 3.

Intra-rater reliability was found 'excellent' for overall severity and roughness, 'good' for breathiness, strain, pitch, and loudness parameters of CAPE-V. Inter-rater reliability was found 'excellent' for overall severity and loudness, 'good' for roughness, breathiness, and strain, and 'moderate' for pitch parameters of CAPE-V. ICC values and interpretation are defined in Table 4.

Comparisons of CAPE-V parameters revealed statistically higher scores in the study group for overall severity ($p = 0.023$), but no significant differences were found for the other parameters between the groups. When gender-based comparisons were conducted for the parameters, the results only showed a statistically significant difference for overall severity parameter in the male participants with a higher score in the study group (mean ± sd; 4.60 ± 11.3, range; 0–50 versus mean ± sd; 0.25 ± 1.11, range; 0–5). Comparisons between the female participants showed no significant differences for any parameters. Comparisons of CAPE-V parameters between the groups are detailed in Tables 5 and 6.

The Spearman analyses revealed significant correlations of both questionnaires with the symptom scores during COVID-19 infection. The score of VHI-10 was significantly correlated with coughing ($r = 0.442$, $p = 0.004$), difficulty in breathing ($r = 0.402$, $p = 0.010$), tiredness ($r = 0.529$, $p < 0.001$), and pain ($r = 0.314$, $p = 0.049$). Furthermore, the score of V-RQOL was significantly correlated with age ($r = 0.368$, $p = 0.020$), difficulty in breathing ($r = 0.412$, $p = 0.008$), tiredness ($r = 0.466$, $p < 0.002$), and difficulty in speaking ($r = 0.329$, $p < 0.038$). The results of correlation analyses for the scores of questionnaires are presented in Table 7. However, no statistically significant correlation of age, BMI, time after infection, time of negative PCR, and symptom scores was found with the other voice-related evaluations (acoustic variables, durational measurements, and CAPE-V parameters).

Table 3 Gender-based comparisons of acoustic voice parameters, durational measurements, and scores of the questionnaires between the groups

Parameters	SG-female $n = 20$		CG-female $n = 20$		*p*-value	SG-male $n = 20$		CG-male $n = 20$		*p*-value
	Mean ± sd	Range	Mean ± sd	Range		Mean ± sd	Range	Mean ± sd	Range	
Mean F0 (Hz)	242.92 ± 32.80	197.93–309.52	256.81 ± 28.45	203.80–323.44	0.149	137.41 ± 26.52	104.26–198.25	136.03 ± 26.48	102.52–192.45	0.758
Jitter local (%)	0.23 ± 0.10	0.10–0.46	0.18 ± 0.07	0.09–0.34	0.056	0.25 ± 0.15	0.10–0.70	0.23 ± 0.09	0.10–0.44	0.947
Shimmer local (%)	3.99 ± 1.84	1.14–9.09	3.22 ± 1.19	1.56–5.39	0.149	3.05 ± 1.20	1.25–5.79	3.19 ± 1.71	1.18–6.62	0.820
HNR (dB)	22.88 ± 3.26	17.69–28.77	23.40 ± 2.55	19.34–27.69	0.495	25.68 ± 2.14	29.72–29.50	24.51 ± 2.66	20.16–31.44	0.096
CPP (dB)	20.44 ± 1.38	18.57–23.47	20.03 ± 1.34	18.18–22.99	0.369	20.73 ± 1.53	17.64–23.45	21.04 ± 1.28	18.77–23.68	0.583
MPT (s)	13.71 ± 2.70	8.71–19.01	16.76 ± 5.07	7.15–25.07	0.038	20.06 ± 5.60	6.20–32.60	23.52 ± 6.10	11.34–34.56	0.060
S/Z ratio	1.05 ± 0.24	0.73–1.54	0.91 ± 0.18	0.60–1.30	0.102	0.95 ± 0.19	0.51–1.30	0.94 ± 0.18	0.64–1.19	0.947
VHI-10 score	2.65 ± 2.73	0–9	0.15 ± 0.67	0–3	< 0.001	2.30 ± 4.72	0–16	1.75 ± 3.17	0–10	0.698
V-RQOL score	12.55 ± 2.50	10–19	10.35 ± 0.74	10–12	0.001	12.80 ± 4.45	10–27	11.55 ± 3.33	10–24	0.127

SG study group; *CG* control group; *HNR* harmonic to noise ratio; *CPP* cepstral peak prominence; *MPT* maximum phonation time; *VHI-10* voice handicap index-10; *V-RQOL* voice-related quality of life

Table 4 Intra-rater and inter-rater agreement for the scores of CAPE-V

CAPE-V parameters	Intra-rater				Inter-rater			
	ICC	95% CI	Classification	*p*-value	ICC	95% CI	Classification	*p*-value
Overall severity	0.933	0.834–0.973	Excellent	< 0.001	0.931	0.826–0.973	Excellent	< 0.001
Roughness	0.961	0.897–0.985	Excellent	< 0.001	0.807	0.510–0.924	Good	< 0.001
Breathiness	0.872	0.682–0.949	Good	< 0.001	0.816	0.535–0.927	Good	< 0.001
Strain	0.798	0.486–0.920	Good	< 0.001	0.758	0.377–0.905	Good	0.002
Pitch	0.865	0.656–0.947	Good	< 0.001	0.659	0.172–0.863	Moderate	0.010
Loudness	0.768	0.430–0.907	Good	0.001	0.925	0.804–0.971	Excellent	< 0.001

CAPE-V consensus auditory-perceptual evaluation of voice

Table 5 Comparisons of CAPE-V parameters between the groups

CAPE-V parameters	SG $n=40$		CG $n=40$		*p*-value
	Mean ± sd	Range	Mean ± sd	Range	
Overall severity	2.63 ± 8.43	0–50	0.13 ± 0.79	0–5	0.023
Roughness	1.98 ± 4.49	0–17	1.00 ± 2.84	0–13	0.345
Breathiness	0.30 ± 1.34	0–7	0.10 ± 0.63	0–4	0.539
Strain	1.28 ± 4.82	0–25	0 ± 0	0–0	0.079
Pitch	0.98 ± 3.56	0–20	0.80 ± 2.26	0–9	0.759
Loudness	0.75 ± 4.74	0–30	0 ± 0	0–0	0.317

SG study group; *CG* control group; *CAPE-V* consensus auditory-perceptual evaluation of voice

Discussion

This study investigated the voice-related parameters in the patients who recovered from COVID-19 disease to compare outcomes with a group of non-infected healthy control cohort. Although several studies have been conducted to reveal the effect of the disease on the human voice, to the best of our knowledge, this is the first study considering this issue in a wide range of assessments including acoustic voice analyses, durational measurements, self-reported outcomes, auditory-perceptual judgments, and clinical symptoms of the subjects.

Although the previous studies have investigated the relationship between COVID-19 and voice-related parameters [18–21], acoustic analyses were discussed only in one study [21]. Asiaee et al. compared the acoustic voice results of 64 patients with 70 healthy participants and stated significant differences in CPP, HNR, H1H2, F0SD, jitter, and shimmer values. However, in our cohort, mean F0, jitter local, shimmer local, HNR, and CPP parameters did not show any difference between the study group and the control group. Furthermore, correlation analysis did not reveal any relationship between the symptom scores during COVID-19 infection and acoustic variables. The logical explanation of the difference between the studies is that all patients included in the previous study were actively infected patients at the time of enrollment. However, in the present study, our study group consisted of individuals who had a previous history of COVID-19 and recovered from the disease. As such, the mean time passed after infection was 8.2 ± 4.3 months (range, 1–17 months) in the study group. Therefore, it could be said that the acoustic voice characteristics of the patients might deteriorate only during the exacerbation of the disease.

Among the durational parameters, only MPT differed between the groups with a lower score in the study group,

Table 6 Gender-based comparisons of CAPE-V parameters

CAPE-V parameters	SG—female $n=20$		CG—female $n=20$		*p*-value	SG—male $n=20$		CG—male $n=20$		*p*-value
	Mean ± sd	Range	Mean ± sd	Range		Mean ± sd	Range	Mean ± sd	Range	
Overall severity	0.65 ± 2.90	0–13	0 ± 0	0–0	0.317	4.60 ± 11.3	0–50	0.25 ± 1.11	0–5	0.032
Roughness	0 ± 0	0–0	0.25 ± 1.11	0–5	0.317	3.95 ± 5.77	0–17	1.75 ± 3.76	0–13	0.182
Breathiness	0 ± 0	0–0	0 ± 0	0–0	1.000	0.60 ± 1.87	0–7	0.20 ± 0.89	0–4	0.515
Strain	0.55 ± 2.46	0–11	0 ± 0	0–0	0.317	2.00 ± 6.36	0–25	0 ± 0	0–0	0.152
Pitch	0.30 ± 1.34	0–6	1.60 ± 3.03	0–9	0.078	1.65 ± 4.82	0–20	0 ± 0	0–0	0.076
Loudness	0 ± 0	0–0	0 ± 0	0–0	1.000	1.50 ± 6.70	0–30	0 ± 0	0–0	0.317

SG study group; *CG* control group; *CAPE-V* consensus auditory-perceptual evaluation of voice

Table 7 Correlations between the characteristics of recovering patients and the scores of questionnaires

	VHI-10		V-RQOL	
	r	*p*-value	*r*	*p*-value
Age	NS	NS	0.368	0.020
BMI	NS	NS	NS	NS
Time after infection	NS	NS	NS	NS
Time of negative PCR	NS	NS	NS	NS
Coughing	0.442	0.004	NS	NS
Difficulty in breathing	0.402	0.010	0.412	0.008
Tiredness	0.529	< 0.001	0.466	0.002
Difficulty in speaking	NS	NS	0.329	0.038
Pain	0.314	0.049	NS	NS

NS not significant; *BMI* body mass index; *PCR* polymerase chain reaction; *VHI-10* voice handicap index-10; *V-RQOL* voice-related quality of life

but it was not related to any of the symptom scores during COVID-19 infection and the time passed after infection. Previous studies have also described a reduction of MPT in COVID-19 patients [18, 21]. Our results combined with prior research indicate that the disease can affect the respiratory system and decrease the duration of phonation in this patient population, which is more evident in females.

In a previous study, the VHI-10 questionnaire was used for patient-reported vocal outcomes and it was stated that the total score was higher in patients with COVID-19, as we found [19]. However, the average total VHI-10 score was found to be 7.31 ± 6.67 which was relatively high from our result (2.48 ± 3.81). We also used the V-RQOL questionnaire and the results showed us that COVID-19 caused a reduction in voice-related quality of life in recovering patients. The possible reason for this difference between the studies may be due to the time of evaluation. While the previous study was conducted with the active COVID-19 patients, our study was conducted with the subjects who recovered from the disease. It is known that the symptoms encountered during the respiratory tract infections such as cough, sore throat, nasal congestion, and rhinorrhea alter the basic characteristics of voice [34]. In our cohort of recovering patients, significant correlations were found especially between the symptom scores during COVID-19 infection and the scores of both VHI-10 and V-RQOL questionnaires. We therefore clearly conclude that exacerbation of the symptoms causes an increase in self-reported vocal complaints and patients with COVID-19 are more likely to have deterioration in voice quality after the infection period.

In the current study, we used the CAPE-V procedure for auditory-perceptual evaluation. All parameters (overall severity, roughness, breathiness, strain, pitch, and loudness) were used for comparisons between the study and the control group. Except for the overall severity ($p = 0.023$), there were no significant differences for the other parameters. Our auditory-perceptual evaluation results are comparable to those from previous studies [18–20]. For example, Saki et al. [18] aimed to investigate the auditory-perceptual characteristics of patients with different severities of COVID-19. In the study, they only used the overall severity parameter of CAPE-V and found significant differences between the subgroups of patients and their healthy counterparts. The overall severity scores of patients with mild, moderate, and severe COVID-19 were reported as 24.55 ± 5.49, 46.31 ± 5.99, and 64.11 ± 6.23, respectively. In another study by Tahir et al. [19], all CAPE-V parameters were reported significantly higher in patients than in healthy controls except for the strain and the pitch parameters. In the study, the mean overall severity score was found 20.29 ± 15.74 which indicates a mild to moderate deviance in voice quality [26]. Compared to the prior results, the findings of the current study revealed a relatively lower score for auditory-perceptual evaluation (2.63 ± 8.43). Because we found a significant difference between the recovering patients and healthy controls in a long-term period after infection, it is possible to conclude that even after the infection the overall severity of dysphonia persists in patients who recovered from COVID-19 disease.

Conclusion

As far as we know, this is the first study that evaluates all voice-related parameters namely, acoustic voice analyses, durational measurements, patient-reported outcomes, and auditory-perceptual evaluations together in a cohort of patients who recovered from COVID-19 disease. The findings showed us that the recovering patients had significantly lower MPT, increased VHI-10 scores, decreased voice-related quality of life based on the V-RQOL questionnaire, and a mild amount of voice deviancy in auditory-perceptual evaluation. However, a similar trend was not observed in acoustic voice analyses between the study and the control group. Correlation analyses showed that symptom scores of the disease have a close relationship with self-reported voice complaints. Since the current study was conducted with the patients who had a prior history of COVID-19, these results suggest that the target population may experience various vocal impairments after the infection period. However, because of the small sample size and a relatively short time of follow-up, the results should be interpreted with caution. Thus, further studies investigating the effect of COVID-19 on human voice with

a larger cohort and longer follow-up period are needed to specify the present findings.

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Declarations

Conflict of interest The authors declare that they have no conflict of interests.

Ethics approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Ethical approval for the study was granted by Gazi University Clinical Research Ethics Committee (Decision number: 328).

Informed consent Broad informed consent was obtained from all parents or caregivers.

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