Exploring the Characteristics of Functional Dysphonia by Multimodal Methods

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Summary: Objectives. To explore the characteristics of functional dysphonia (FD) using multimodal methods.

Methods. A total of 47 FD patients and a group of 22 normal controls were enrolled. Subjective auditory-perceptual assessment of the voice, Voice Handicap Index (VHI) 30, acoustic analysis, psychological scales assessment, surface electromyography (sEMG), nasal airflow and thoracoabdominal studies were performed.

Results. FD was mostly triggered by mood changes. Patient self-evaluation was more serious than auditory-perceptual evaluation and objective acoustic analysis. There was no obvious organic disorder observed under laryngoscope in patients with FD, but there were cases of glottic insufficiency and supraglottic compensation. With regards to sEMG, nasal airflow, chest, and abdomen examination results: (1) sEMG in the normal control group was symmetrical and stable on both sides during rest and phonation, and nasal airflow as well as the chest and abdomen were symmetrical and regular; (2) sEMG in the FD group showed increased recruitment of the sternocleidomastoid muscles, the infra- and suprahyoid muscles, and the cricothyroid muscle, accompanied by prephonation recruitment and postphonation persistence, mainly involving the infra- and suprahyoid muscles; (3) In the FD group, there was shortened inspiratory time, increased chest breathing amplitude, and reduced abdominal breathing, with predominantly chest breathing, and a "breath-holding" phenomenon was observed in some patients, with a significant increase in the number of breaths during the short text task.

Conclusions. FD occurs mainly in middle-aged women, and there are many triggers. The Hamilton Anxiety/Depression Rating Scale scores were higher, and subjective symptoms were more serious than objective evaluation. No obvious organic changes were seen under laryngoscope, and features such as supraglottic compensation and glottic insufficiency were observed; muscle tension was significantly higher than that of the normal control group, and prephonation recruitment and postphonatory persistence were seen in some patients; the breathing pattern was mainly chest breathing, and the times of breaths during the short text task significantly increased. With identification of the characteristics of FD, the therapy could be focused them.

Key Words: Functional dysphonia−Multimodality−Surface electromyography−Nasal airflow−Chest and abdominal breathing.

INTRODUCTION

Functional dysphonia (FD) was characterized by increased vocal effort, altered vocal sound, pitch, and intensity in the absence of explaining organic or neurologic causes.[1] The main treatment method is vocal therapy, experienced speech pathologists can improve patients with FD in the short term, but long-term efficacy remains unclear.[2] Actually vocal therapy has been compared to a "black box", it is difficult to determine the relative effectiveness of one treatment over another, or what "active ingredients" in therapy were associated with positive effects. One of the reasons is due to the lack of etiology-driven therapy process.[3-5] This makes it particularly important to explore the characteristics of FD and discover its possible causes.

Several methods have been proposed to document FD, those assessment methods, however, have disadvantages associated with subjectiveness and comprehensive.[1,6] The process of voice and speech production involves the dynamics, vibration, and resonance of the vocal organs. A mild change in any of these interconnected aspects will cause changes to the voice. This dictates that the assessment of vocal disorders cannot be performed in a single dimension. Behlau et al[7] proposed evaluating FD from multiple aspects, and monitoring the condition using various single perspectives. Reetz et al[8] proposed that FD should be comprehensively evaluated via a combination of acoustic analysis, auditory-perceptual evaluation. Since the three types of evaluation provide different perspectives, they are not mutually interchangeable. When Redenbaugh and Reich[9] used surface electromyography (sEMG) in FD patients for the first time, it was found that sEMG signals in patients with hyperphonic function increased significantly. Khoddami et al[1] found that sEMG is a reliable tool to measure the root mean square (RMS) value, the peak activity, and the activity duration in FD. Both Milutinović and Hocevar-Boltezar[10,11] found that the EMG showed increased muscular activity of the larynx during phonatory tasks. Hixon and Hoit[12] compared breathing abnormalities during phonation with "abnormalities in phonatory dynamics," and proposed

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that the subglottic pressure in patients with phonation disorders appeared to be higher than that of controls. Altman et al[13] found that 98% of FD patients exhibited uncoordinated respiratory support. Lewandowski[4] thought aerodynamic assessment should collected during connected speech and vowel prolongations. Andreassen et al[14] reviewed the current evaluation of FD patients in 2017, and listed a series of inspection methods, based on strobolaryngoscope, sEMG, auditory-perceptual assessment of voice, and supplemented by acoustics analysis and aerodynamics.

Previous studies have proposed multidimensional assessments in patients with phonation disorders, but they are limited to independent studies in multiple dimensions and have their own insufficient. Therefore, a multidimensional, real-time, and specific examination approach is required to achieve a systematic and comprehensive understanding of the condition.

Clinically, multidimensional observations are often carried out in multimodal methods, which are widely used in fields such as computer and automation technology as well as clinical medicine. In recent years, such an approach has developed extensively in the medical field, including neurology, imaging specialties and nuclear medicine.

In this study, data related to voice, sEMG, nasal airflow, and thoracoabdominal breathing signals were collected at the same time, and combined with auditory-perceptual assessment, Voice Handicap Index (VHI) 30, acoustic analysis, psychological scale assessment, etc. Through integrated analysis, a multidimensional exploration of the characteristics of FD was conducted.

MATERIALS AND METHODS

Participants

Patients with vocal disorders treated at the Department of Otolaryngology - Head and Neck Surgery, Beijing Tongren Hospital, Capital Medical University between June 2018 and January 2020 were recruited, with 47 cases of FD and a group of 22 controls. This study included 47 patients with FD, aged 18−80 years, with an average age of 38 ± 17.61 years. There were 14 males and 33 females, with a male:female ratio of 1:2.3, and the female gender was predominant. In the normal control group, there were 22 cases, aged 22−67 years old, with an average age of 33.87 ± 11.97 years. There were 11 males and 10 females. The median duration of FD was 2 (0.5−14) months (Table 1).

TABLE 1.
Basic Information of the Participants

	Gender (n)	Age (years)	Duration (months)
FD	Male 14 Female 33	38 ± 17.61	2
Control	Male 11 Female 10	33.87 ± 11.97	–

Procedure

Subjective auditory-perceptual assessment, VHI-30, psychological scale assessment, acoustic analysis, strobolaryngoscopy

The subjective auditory-perceptual assessment of voice was carried out using the GRBAS score proposed by the Japan Society of Logopedics and Phoniatrics. Voice-related quality of life was assessed using the Chinese-translated version of the VHI-30.[15] The Hamilton Anxiety and Depression Scales were used for psychological evaluation. Acoustic analysis: fundamental frequency (F_0), Jitter, Shimmer, the noise to harmonic ratio (NHR) and the maximum phonation time (MPT) were tested. The acoustic analysis software by the Kay Pentax Company in the United States was used to process and analyze the vowel /a/. Environmental noise was less than 45 dB, the microphone was placed 15 cm away from the mouth during recording, and 2 seconds of the central stable region of phonation was used for analysis. Laryngoscopy was performed with the German XION strobolaryngoscope on all subjects.

Surface electromyographic techniques and airflow measures

Using a multichannel physiological recorder (Australia COMPUMEDICS Greal 48 channel, Signals were sampled at 1000 Hz, bandwidth = 20−500 Hz, 50 Hz notch filter was utilized to eliminate power line noise), the subject's internal and external larynx muscles and shoulder surface EMG, voice signals, chest, abdomen and nasal airflow signals were recorded together. After collection, the signals were exported in EDF format, and wavelet transformation was used to remove noise and electrocardiogram (ECG) interference. *Praat* software was used for signal visualization, labeling and analysis.

Simultaneously record sEMG activation of the internal and external larynx muscles including trapezius (TRA), sternocleidomastoidus (SCM), suprahyoid (SH), infrahyoid (IH), cricothyroidus (CT; trapezius muscle(TRA),sternocleidomastoid muscle (SCM), suprahyoid muscle (SH), infraphyoid muscle (IH), cricothyroid muscle (CT). (Table 2). The participants were asked to sit comfortably on a chair with back support, with the knees and hips in 90°

TABLE 2.
The Position of the Electrodes

Muscles	Position
TRA	Midpoint of C7 to acromion
SCM	Midpoint of sternocleidomastoid to sterno-clavicular joint
SH	Submandibular region with about 1 cm lateral to the neck midline
IH	Lamina of the thyroid cartilage
CT	Cricothyroid space with a distance about 1 cm lateral to the neck midline

flexion. Before electrode placement, the neck surface was cleaned with 75% alcohol pads and shaved (only in men) to reduce electrode-skin impedance.[1]

Chest, abdomen, and nasal airflow: nasal catheters were placed in the nostrils of subjects to detect nasal airflow signals, chest straps and abdominal straps were respectively positioned on the sixth to seventh intercostal spaces of the patient's lower chest and at the umbilicus of the abdomen to record the loudness changes of the patient's chest and abdomen.

Tasks

Testing procedures: with the patient breathing calmly for 30 seconds, the baseline condition and the situation in rest state were observed. The vowel sounds /i/ and /a/ were selected for the phonation task, using various pitches and loudness levels; the short phrase "I am going to Heilongjiang, he is going to Wuxi City" (in Mandarin) , and the short text " North Wind and Sun" (in Mandarin) were used, with 10 seconds rest following each period of phonation to avoid fatigue. The vowels were spoken 3 times, and the best signal was used.[16] Recordings were monitored in real-time for signal integrity and any movement artifact. sEMG index including time domain index (root mean square value, RMS) and frequency domain index (median frequency, MDF). Approximately 2 seconds of the central stable region of phonation was used for analysis.

Statistical analysis

SPSS 26.0 for Mac was used for statistical analysis (SPSS Inc., Chicago, IL). Data that followed the normal distribution were expressed as Mean±SD, and data that did not obey the normal distribution were expressed as the median. The t test and the rank sum test were used for quantitative data. $P < 0.05$ was considered statistically significant.

RESULTS

Clinical characteristics, the subjective auditory-perceptual assessment, VHI-30

FD is mainly induced by quarreling (73.6%), angry and nervous (59.4%), and voice abuse (59.4%). Auditory-perceptual assessment of mild hoarseness (G1) 14 patients (29.7%), moderate hoarseness (G2) 29 patients (61.8%), severe hoarseness (G3/whisper) four patients (8.5%). VHI-30 in FD group (69.56 ± 23.81) was significantly higher than those in the normal control group(4.24 ± 1.78).

Acoustic analysis

Acoustic analysis showed that Jitter and Shimmer in FD patients were significantly higher than those in the normal control group, and maximum phonation time in the FD group was significantly lower than that in the normal control group.

Strobolaryngoscopy

The 47 cases of FD patients showed no obvious organic lesions under strobolaryngoscope; there were 30 cases with supraglottic compensation, and 36 cases with glottic insufficiency.

Psychological scale assessment findings

Based on the Hamilton Anxiety/Depression Scale, there were 26 patients in the FD group with possible anxiety and 25 patients with possible depression.

Surface EMG

Normal control group

In the normal control group, both sides were uniform and symmetrical during rest and phonation. Recruitment was stable during phonation, and there was no significant difference observed with sEMG between /i/ and /a/ and between gender ($P > 0.05$). Prephonation recruitment was present in seven cases (31.8%), lasting 589 ± 247 mm (200−1000 mm). SH and IH (100%) were recruited prephonation, and there was no obvious persistence during phonation (Tables 3 and 4).

Functional dysphonia group

In the FD group, the EMG signal showed recruitment was essentially symmetrical on both sides during rest and phonation. 30 cases (63.8%) exhibited prephonation recruitment, with SH and IH having the largest amplitude, and short and loud phrases were associated with the longest prerecruitment time. Postphonation persistence was present in 22 cases (46.8%). The results of the Wilcoxon rank sum test indicated that prephonation recruitment and the duration of postphonation persistence for each task in the FD group were significantly higher than the normal control group ($P < 0.05$). There was no significant difference observed with sEMG between /i/ and /a/ and between gender ($P > 0.05$).

Time-domain index (RMS) and frequency-domain index (MDF) were studied. There was no significant change in the RMS of TRA. Recruitment was increased significantly for loud as well as high-pitched loud /i/ in SCM as well as in SH, IH and CT for all phonation tasks ($P < 0.05$), and increased as the pitch and loudness of the phonation tasks increased. The trend of short phrase and loud phrase task is the same as that of vowel task. In 15 patients (31.9%), muscle recruitment suddenly increased at the beginning of phonation, decreased slightly thereafter, and then a high level of contraction was maintained. In terms of MDF, a substantial increase was observed only in IH for each phonation task, with no significant changes in the remaining muscles ($P <$ 0.05), and muscle recruitment was not related to pitch and loudness (Tables 5 and 6, Figures 1 and 2).

Nasal airflow and chest and abdominal breathing

The normal control group

Nasal airflow, as well as the chest and abdomen were symmetrical and regular, and there was combined chest and

TABLE 3.
The Root Mean Square (RMS) Value (μV) During Rest and Phonation in the Normal Control Group

Muscle			RMS					
	Rest		Normal	High	Louder	High and Louder	Phrase	Loud Phrase
TRA	0.002 ± 0.001	/i/	0.012 ± 0.001	0.017 ± 0.005	0.018 ± 0.004	0.019 ± 0.006	0.012 ± 0.001	0.014 ± 0.004
		/a/	0.013 ± 0.001	0.016 ± 0.006	0.015 ± 0.005	0.018 ± 0.007		
SCM	0.002 ± 0.001	/i/	0.012 ± 0.003	0.014 ± 0.005	0.015 ± 0.002	0.016 ± 0.007	0.002 ± 0.001	0.004 ± 0.003
		/a/	0.013 ± 0.002	0.014 ± 0.004	0.015 ± 0.004	0.016 ± 0.006		
SH	0.004 ± 0.002	/i/	0.012 ± 0.001	0.015 ± 0.003	0.014 ± 0.003	0.019 ± 0.004	0.014 ± 0.006	0.016 ± 0.004
		/a/	0.012 ± 0.002	0.015 ± 0.004	0.017 ± 0.002	0.017 ± 0.005		
IH	0.002 ± 0.001	/i/	0.014 ± 0.002	0.015 ± 0.005	0.014 ± 0.005	0.018 ± 0.005	0.017 ± 0.007	0.021 ± 0.004
		/a/	0.014 ± 0.001	0.015 ± 0.003	0.016 ± 0.003	0.027 ± 0.004		
CT	0.004 ± 0.002	/i/	0.015 ± 0.007	0.016 ± 0.007	0.016 ± 0.007	0.019 ± 0.005	0.012 ± 0.006	0.016 ± 0.008
		/a/	0.014 ± 0.004	0.018 ± 0.003	0.017 ± 0.004	0.019 ± 0.004		

abdominal breathing in all cases. There were no obvious gender differences in the duration and amplitude of breathing. Nasal breathing was predominant at rest, while oral breathing was predominant during speech. The inhalation time for each phonation task was significantly shorter than that of inhalation at rest, and the amplitude was significantly increased ($P < 0.05$). The duration of exhalation was the same as the phonation duration, and the

TABLE 4.
The Median Frequency (MDF) (Hz) During Rest and Phonation in the Normal Control Group

Muscle			MDF					
	Rest		Normal	High	Louder	High and Louder	Phrase	Loud Phrase
TRA	24.19 ± 5.91	/i/	78.87 ± 12.19	70.74 ± 13.04	74.74 ± 5.74	72.98 ± 18.89	80.43 ± 16.05	82.34 ± 19.62
		/a/	74.79 ± 10.34	71.21 ± 16.83	72.23 ± 10.99	71.12 ± 15.09		
SCM	20.01 ± 7.24	/i/	79.51 ± 19.89	78.79 ± 19.29	79.44 ± 18.63	76.67 ± 19.87	84.09 ± 15.23	88.45 ± 10.81
		/a/	78.94 ± 14.21	78.98 ± 11.29	77.04 ± 20.21	74.34 ± 16.02		
SH	22.49 ± 4.11	/i/	84.92 ± 19.31	86.62 ± 15.56	85.28 ± 15.46	84.19 ± 14.69	89.32 ± 19.56	86.11 ± 15.91
		/a/	86.62 ± 12.11	83.25 ± 18.90	86.02 ± 11.21	83.88 ± 19.23		
IH	24.19 ± 5.68	/i/	89.31 ± 16.81	89.73 ± 15.51	90.11 ± 15.54	88.73 ± 15.73	98.33 ± 20.56	99.85 ± 16.39
		/a/	88.21 ± 13.41	87.95 ± 16.26	87.04 ± 16.39	85.84 ± 17.30		
CT	24.53 ± 5.13	/i/	85.02 ± 18.54	92.29 ± 11.18	85.34 ± 21.01	80.41 ± 18.99	89.46 ± 22.09	94.21 ± 47.02
		/a/	84.37 ± 16.12	93.52 ± 9.03	81.11 ± 19.63	76.85 ± 12.32		

TABLE 5.
The Root Mean Square (RMS) Value (μV) During Rest and Phonation in Functional Dysphonia

Muscle			RMS					
	Rest		Normal	High	Louder	High and Louder	Phrase	Loud Phrase
TRA	0.002 ± 0.001	/i/	0.015 ± 0.001	0.017 ± 0.005	0.018 ± 0.004	0.020 ± 0.006	0.019 ± 0.005	0.023 ± 0.004
		/a/	0.016 ± 0.001	0.019 ± 0.003	0.020 ± 0.002	0.020 ± 0.004		
SCM	0.002 ± 0.001	/i/	0.013 ± 0.003	0.014 ± 0.005	0.020 ± 0.002	0.025 ± 0.007	0.023 ± 0.004	0.023 ± 0.006
		/a/	0.014 ± 0.004	0.015 ± 0.004	0.020 ± 0.004	0.018 ± 0.004		
SH	0.004 ± 0.002	/i/	0.017 ± 0.001	0.021 ± 0.003	0.024 ± 0.003	0.028 ± 0.004	0.027 ± 0.002	0.030 ± 0.005
		/a/	0.021 ± 0.003	0.021 ± 0.004	0.025 ± 0.003	0.025 ± 0.003		
IH	0.002 ± 0.001	/i/	0.020 ± 0.002	0.022 ± 0.005	0.021 ± 0.005	0.024 ± 0.005	0.028 ± 0.004	0.028 ± 0.003
		/a/	0.018 ± 0.003	0.022 ± 0.003	0.025 ± 0.003	0.024 ± 0.003		
CT	0.004 ± 0.002	/i/	0.022 ± 0.007	0.025 ± 0.007	0.025 ± 0.007	0.027 ± 0.005	0.024 ± 0.005	0.025 ± 0.003
		/a/	0.017 ± 0.005	0.021 ± 0.004	0.025 ± 0.006	0.026 ± 0.003		

TABLE 6.
The Median Frequency (MDF) (Hz) During Rest and Phonation in Functional Dysphonia

Muscle			MDF					
	Rest		Normal	High	Louder	High and Louder	Phrase	Loud Phrase
TRA	24.19 ± 5.91	/i/	78.86 ± 12.19	78.12 ± 13.04	81.43 ± 15.74	81.75 ± 18.89	85.25 ± 12.45	88.27 ± 15.30
		/a/	78.23 ± 13.56	76.59 ± 11.03	81.85 ± 14.37	79.76 ± 14.82		
SCM	20.01 ± 7.24	/i/	86.71 ± 19.89	83.37 ± 19.29	84.34 ± 18.63	83.26 ± 19.87	87.48 ± 12.38	86.34 ± 14.82
		/a/	84.44 ± 15.29	87.31 ± 20.32	82.28 ± 17.29	81.62 ± 17.31		
SH	22.49 ± 4.11	/i/	86.96 ± 19.31	85.57 ± 15.56	85.46 ± 15.46	85.39 ± 14.69	90.33 ± 12.59	88.89 ± 15.34
		/a/	88.02 ± 18.34	86.21 ± 13.84	87.18 ± 19.22	83.46 ± 17.93		
IH	24.19 ± 5.68	/i/	100.05 ± 16.8	104.94 ± 15.5	107.99 ± 15.5	107.91 ± 15.7	112.36 ± 16.25	115.33 ± 19.03
		/a/	103.01 ± 15.22	102.74 ± 19.41	109.32 ± 17.88	107.64 ± 19.04		
CT	24.53 ± 5.13	/i/	87.12 ± 18.54	87.76 ± 11.18	87.08 ± 21.01	86.23 ± 18.99	90.34 ± 20.43	89.32 ± 19.72
		/a/	85.88 ± 19.02	82.23 ± 15.39	83.07 ± 17.39	80.54 ± 20.36		

exhalation amplitude was significantly greater than that at rest ($P< 0.05$) . Nasal airflow and the chest and abdominal signals were coordinated while breathing during the short text ($P > 0.05$).

Functional dysphonia group

When breathing at rest, the nasal airflow and chest-abdominal breathing time in the FD group were significantly shorter than those in the normal control group ($P< 0.05$). The chest inhalation amplitude was significantly greater than that in the normal control group ($P< 0.05$) , and the abdominal amplitude was significantly lower than that in the normal control group ($P< 0.05$). Chest breathing was predominant.

During the vowel task, the nasal airflow inspiratory time was significantly shortened ($P< 0.05$) , the amplitude of the chest significantly increased, and the abdominal was significantly reduced, with chest breathing as the predominant type of breathing. The nasal airflow and chest-abdomen signal waveforms were disordered and uncoordinated, and did not change with the alterations to loudness and pitch in the phonation tasks. In patients with prephonation recruitment, the respiratory curve of the nasal airflow was almost straight, similar to a "breath-holding" phenomenon. During the short text task, the nasal airflow and chest-abdomen were not coordinated, and the breathing frequency was significantly higher than that of the normal control group, with the nasal airflow frequency significantly higher than that of chest and abdominal breathing ($P< 0.05$).

DISCUSSION

FD is more common in middle-aged women. Gabriela[13] believes that the prevalence in women is higher than that in men because they bear greater social pressures. Research by Nguyen[17] showed that among female elementary school teachers, the prevalence of FD was significantly higher than that in other populations. The findings in this study are similar to previous results.

Our research showed that one of the FD triggers was related to emotions. The auditory-perceptual assessment and objective assessment in the patients were predominantly mild to moderate, while self-evaluation was mostly moderate to severe, suggesting the problems related to voice had a greater impact on the patient. O'Hara et al[18] reported that FD patients are more inclined toward perfectionism and are more likely to be anxious. Roy and Bless[19] proposed that, compared to those with vocal cord nodules, FD patients are more inclined toward introversion. Kollbrunner and Seifert[20] believed that psychological factors are closely related to FD. At present, the causal relationship between psychological factors and voice disorders is unclear, but psychological evaluation can be used in the diagnosis of FD or as one of the auxiliary treatment methods.

No obvious organic disease under strobolaryngoscope was seen in any of the FD patients. Mucosal wave reduction was observed in some patients, with supraglottic compensation and incomplete glottis closure. The possibility of potential voice diseases could not be excluded.

The results of this study suggest that there is a significant difference in surface EMG during speech between the FD group and normal controls. During the phonation, laryngeal biomechanics require extrinsic and intrinsic control. The extrinsic laryngeal muscle connects the larynx and the surrounding structure. With the hyoid bone as the center, the Extrinsic laryngeal muscle can be divided into the SH muscle group and the hypohyoid muscle group. Extrinsic laryngeal muscle can pull larynx and hyoid bone in four directions: anterior, posterior, cranial, and caudal, and at the same time fix the laryngeal, so that can participate in voice modulation.[21] Our study showed that the recruitment of SH and IH in patients with FD was significantly higher than that in the control group. This may cause uncoordinated rise and fall of the larynx and affect phonation. Redenbaugh and Reich[9] made use of sEMG in FD for the first time, include 7 normal and 7 FD patients measured sEMG of rest, two resisted-force maneuvers, vowel production, and connected speech. Found that FD group has

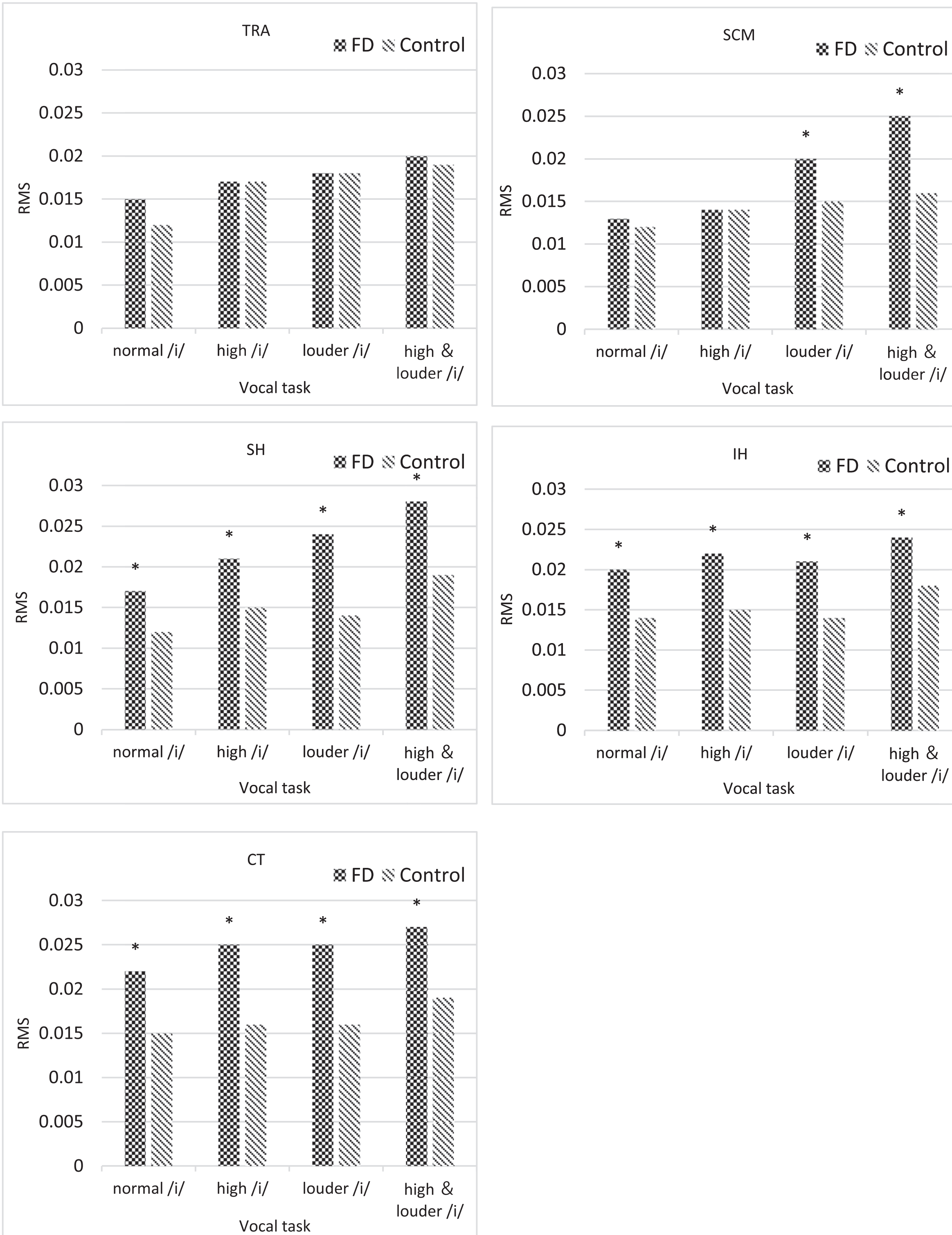

FIGURE 1. The RMS signal (μV) of surface EMG in different muscles during the vowel task in patients with functional dysphonia and the normal control group. **A.** The trapezius muscles in the FD group showed no significant differences in signals in all vowel tasks. **B.** There was a significant increase in the recruitment of the sternocleidomastoid muscles in the FD group for high-pitched and loud high-pitched /i/. **C.** The suprahyoid muscles in the FD group exhibited significantly increased signals in all vowel tasks. **D.** Infrahyoid muscle signals in the FD group were significantly increased in all vowel tasks. **E.** The cricothyroid muscle signals in the FD group were significantly increased in all vowel tasks.

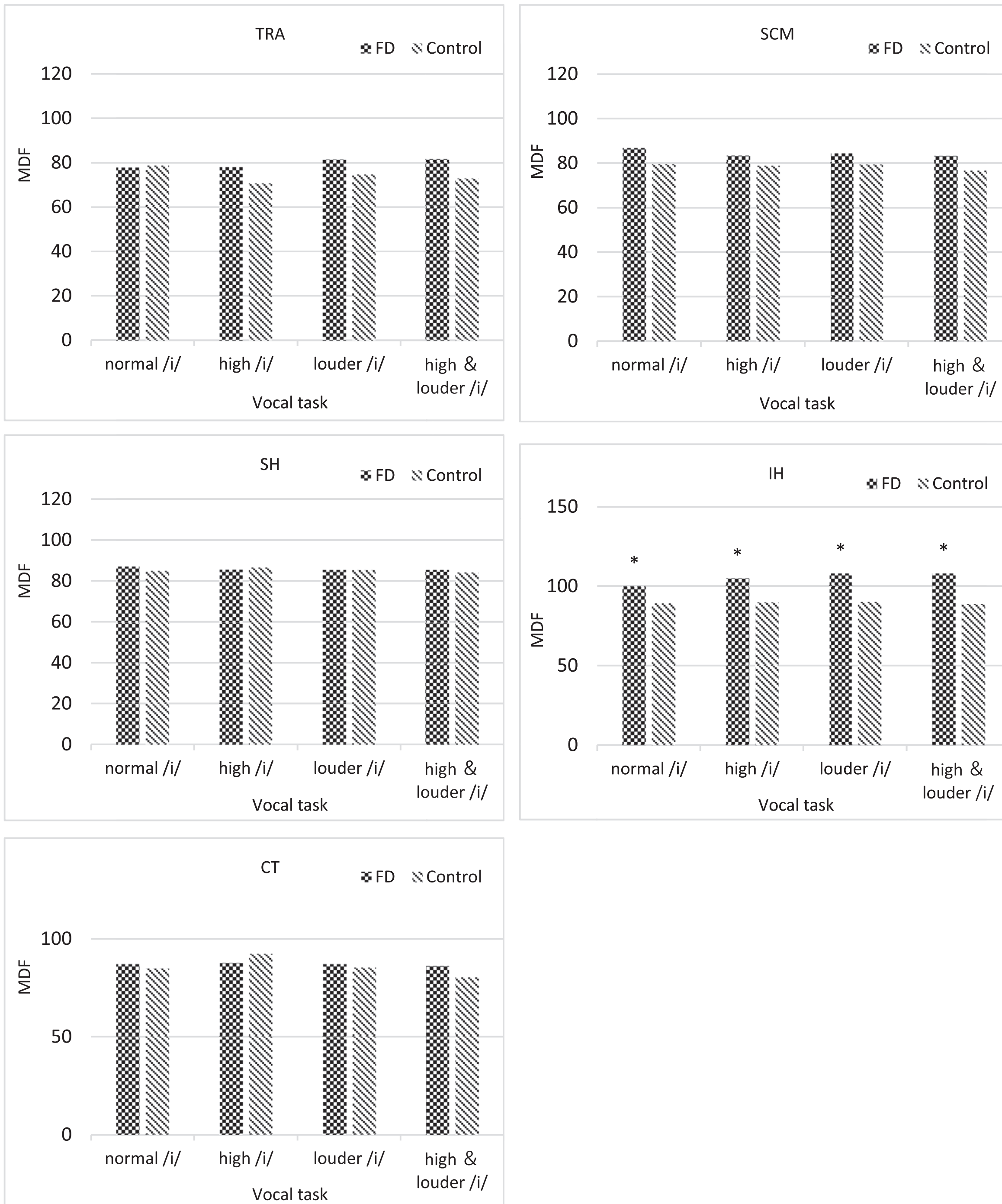

FIGURE 2. Surface electromyogram MDF signals (Hz) in different muscles during the vowel tasks in patients with functional dysphonia and normal controls. **A.** The trapezius muscles in the FD group showed no obvious signal differences in all vowel tasks. **B.** The sternocleidomastoid muscles in the FD group showed no obvious signal differences in all the vowel tasks. **C.** The suprahyoid muscles in the FD group showed no obvious differences in signals for all vowel tasks. **D.** The infrahyoid muscle signals were significantly increased in the FD group in all vowel tasks. **E.** No obvious differences in cricothyroid muscle signals were observed in the FD group in all vowel tasks.

significantly higher muscle electrical active during rest, vowel prolongation and connected speech. Milutinović et al[10] studied the interaction of the activities of different parts of the phonatory apparatus: laryngeal area, thorax and abdomen. Found out that not only the laryngeal muscle was significantly increased during phonation, but also the thorax and abdomen. Hocevar-Boltezar[14] performed sEMG testing in FD patients and normal subjects, and it was found that the signal in normal subjects and FD patients suddenly increased 200−300 milliseconds before phonation, and the signals in normal subjects increased to two to three times of the baseline value, whereas the signals in the perioral and neck muscles of FD patients increased to six to eight times of the baseline value, and a constantly high level was maintained during phonation. Our data were consistent with those in the literature, there was no significant muscle recruitment in the FD group during the rest time. It is noteworthy to notice that some of the patients who present prephonation recruitment also demonstrate "breath-holding" before pronunciation. It is suggested that this type of patients has abnormal respiratory support and over recruitment of the extrinsic laryngeal muscle at same time. It is difficult to conclude whether the poor respiratory support was activated as a consequence of the excessive tension in extrinsic laryngeal muscles, or whether it was responsible for some of the voice disorders.

We also found that in the FD group, the frequency domain index MDF could not distinguish FD patients from normal subjects quite well. In the FD group, only IH recruitment was higher than that of the normal control group, and there was no relationship with pitch and loudness.

In recent years, researches of sEMG in functional phonation disorders have different results. Khoddami et al[1] performed a group of 15 FD patients with sEMG, found that sEMG was a highly reliable tool to register the muscle activity. But it could not distinguish healthy people from FD patients. In another study, Balata[21] found there was lower electrical activity of the extrinsic laryngeal muscles in dysphonic individuals compared with nondysphonic. As a noninvasive test, sEMG has its own characteristics and influencing factors. There are various anatomical characteristics of the studied subject that influence the registration of the EMG activity under the surface electrode, such as thickness of the skin, fatty tissue, the size and properties of the underlying muscles, noise interference, skin resistance.[2] We uses wavelet transform to process sEMG signal to remove interference, well preprepared for the skin to reduce the resistance, allow the patient with sufficient rest time during the pronunciation to avoid muscle fatigue, select multiple groups of muscles, different kind of tasks to get the accurate data.

Well respiratory support is the basis of phonation. Nasal breathing was predominant at rest, and oral breathing was predominant during speech. During speaking, nasal airflow and the duration of chest and abdominal breathing were significantly shortened. The frequency of breathing was relatively fixed at rest, and the duration and amplitude of the inspiratory and expiratory phases were relatively similar. Breathing was different between rest and speech. At rest, the inspiratory and expiratory durations were roughly the same. With regards to breathing during speech, the main function of chest breathing is to ensure sufficient breath volume, and the chest cavity remains expanded until the end of speech. The main function of abdominal breathing is to steadily contract the abdominal muscles and diaphragm, and to maintain constant airflow to facilitate continuous speech.

One of the important reasons for the abnormal respiratory support found in FD patients is the lack of coordination between breathing and phonation. The findings in our study suggest that the respiratory support in the FD group showed obvious disordered nasal airflow, shortened inhalation time, increased chest breathing amplitude, with no increase or decrease in abdominal breathing, and a tendency toward chest breathing. Among the patients with prephonation recruitment, the phenomenon of "breath-holding" before phonation was present. The proportion of abdominal breathing in FD patients was low, with chest breathing being the main form, and abdominal strength was weak. At the same time, we found that the recruitment of the sternocleidomastoid muscles, the IH and SH muscles and the cricothyroid muscle abruptly increased during "breath-holding," and the EMG signals decreased slightly once "breath-holding" had ended. Appropriate breathing is the basis of phonation. Previous studies on hoarseness and breathing have focused on the context of chronic obstructive pulmonary disease and asthma. As early as 1997, Cohn[22] discovered that patients with unexplained hoarseness had abnormal lung function or a positive acetylcholine provocation test. Hamdan[23] conducted a cross-sectional analysis in asthma patients and found that the proportions of main complaints of hoarseness, vocal fatigue, and labored phonation were significantly higher than those in the normal control group. Gilman et al[6] found that subglottic pressure in patients with hoarseness was significantly higher than that in the normal control group, but did not believe that subglottic pressure can distinguish normal subjects from patients with hoarseness. However, large-scale outpatient lung function screening is not only time-consuming, but also adds to socioeconomic burden. In this study, speech, electromyography, nasal airflow, and chest-abdomen signals were combined to evaluate the breathing of patients with FD in a relatively straight-forward and convenient manner.

As the main treatment of FD, vocal therapy demonstrates positive outcomes, but still has a number of limitations in their methodological designs.[5] It is difficult to achieve a comprehensive assessment of FD in a single dimension. We use multimodal methods to explore the characteristics of FD. With identification of the characteristics of FD, the therapy could be focused them, for example, enhance the vocalization with abdominal breath support or relax of the muscles.

There are some limitations in this study: (1) It is necessary to further expand the sample size for the research, and to increase the number of subgroups with FD; (2) This study used MAV for electromyographic standardization, but its applicability to the IH muscles and the cricothyroid muscle is unclear; (3) Psychiatric and psychological factors were present in over half of the patients with FD, so sEMG, nasal airflow, as well as chest and abdomen breathing need to be determined in different emotional states, while avoiding fatigue.

CONCLUSIONS

FD occurs mainly in middle-aged women, and most cases are associated with triggers; Hamilton Anxiety/Depression

Scale scores were higher, and subjective symptoms were more serious than objective evaluations; no obvious organic changes were seen under laryngoscope, but supraglottic compensation and glottic insufficiency were observed; sEMG was bilaterally symmetrical, and could be accompanied by prephonation recruitment and postphonation persistence. It could be seen that the tension of the sternocleidomastoid muscles, the IH and SH muscles and cricothyroid muscles increased; the prephonation inhalation time was shortened, the amplitude of chest breathing was increased, and the amplitude of abdominal breathing was decreased, with chest breathing predominant. Some patients exhibited a "breath-holding" phenomenon, and the number of breaths was significantly higher than that of the normal control group. With identification of the characteristics of FD, the therapy could be focused them, for example, enhance the vocalization with abdominal breath support or relax of the muscles.

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