The Design and Assessment of a Multiparametric Model for the Dysphonia Severity Index for Persian-speaking Populations

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Summary: Objectives. In instrumental voice assessment, multiparametric models reflect the multidimensional nature of voice and are therefore better than models that reflect only a single dimension of voice. The Dysphonia Severity Index (DSI) is one of the most common multiparametric models. In voice assessment, race, language, and structural and physiological features affect the acoustic, aerodynamic, and voice range profile measures. Given these differences, this study was conducted to design and evaluate a multiparametric and objective model for assessing the severity of dysphonia in Persian-speaking populations.

Material and Methods. This study examined 300 participants with several types of dysphonia (104 women and 196 men) and 100 healthy individuals (63 women and 37 men). Five acoustic parameters, three aerodynamic parameters, and seven voice range profile parameters were measured for designing the model. Perceptual evaluation was performed using the grade, roughness, breathiness, asthenia, strain scale. The logistic regression analysis was used to determine the factors affecting the DSI and each component's coefficient.

Results. Of the 15 parameters assessed, shimmer, vital capacity, semitone range, and voice onset time of /pa/ remained in the model with their coefficients. This section presents the DSI model for the examined population. The discriminant analysis showed that this combination corresponds to 47.8 of the perceptual assessment: DSI = 0.289 (shimmer) + 0.0001 (VC) − 0.059 (STR) − 13.278 (VOT_Pa).

Conclusion. In this study, the DSI corresponded to the physiological, linguistic, and racial characteristics of the Persian-speaking population with or without voice disorder.

Key Words: Dysphonia Severity Index–Multiparametric assessment–Persian-speaking–Dysphonia–Voice.

INTRODUCTION

Dysphonia is assessed with two general approaches, including perceptual judgment and instrumental assessments.[1] Perceptual judgment involves quantifying dysphonia by listening to the patient's voice and is currently the most commonly used method among therapists due to being convenient and economical.[1] This method is also part of most pathological voice assessment protocols and is particularly important in clinical diagnoses and the assessment of treatment outcomes.[1] Nevertheless, perceptual assessment is one of the most controversial topics in voice research that has shown various limitations, including problems with the reliability and validity of the scale used, especially for pathological voices in the midrange of the scale—mild to moderate dysphonia, for instance.[1] Perceptual assessments are recommended to not be used alone.[2]

Because of the increasing need for quantitative assessments, instrumental assessments have also been subject of extensive research alongside perceptual assessments.[1,3,4] Instrumental assessment involves quantifying dysphonia through acoustic and aerodynamic analyses and physiological measurements.[1,3,4] Extensive research and analyses based on instrumental assessments have shown the need for combining different assessments for addressing the multidimensional nature of voice and increasing the accuracy of analyses.[1,3,4] Several studies have examined the relationship between the acoustic measurements and the perceptual assessment of voice quality; however, they have not led to desirable results.[5–10] Different studies have been conducted on the instrumental assessments used to achieve a model that can perfectly quantify the severity of dysphonia.[11,12]

The Dysphonia Severity Index (DSI) is one of the most common methods for the multiparametric assessment of voice disorders.[3] The DSI was developed by Wuyts et al in 2000 to develop an index for assessing the perceptual quality of voice both objectively and quantitatively. The index was developed by the multivariate analysis of 387 samples (68 normal and 319 dysphonic samples) taken to describe the perceptual quality of voice based on an instrumental assessment. The following 13 parameters were analyzed to extract the predictive parameters of perceptual quality. jitter (%), shimmer (%), noise-to-harmonic ratio (NHR), highest frequency (F0—high) [Hz], lowest frequency (F0—low) [Hz], F0 range [Hz], semitone range, lowest intensity (I—low) [dB], highest intensity (I—high) [dB], intensity range [dB], maximum phonation time (MPT) [seconds], vital capacity (VC) [cc], and phonation quotient (PQ) [cc/s]. A regression analysis was performed on the parameters to obtain their individual weights for differentiating normal from dysphonic voice. The parameters remaining in the DSI model after the analysis included highest frequency, lowest intensity, jitter, and MPT.[1]

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Although many studies have been conducted on the DSI to date, most of them have examined European populations.[13–16] Jayakumar and Savithri conducted a study on 120 Indian subjects to evaluate the effects of geographic and ethnic changes on the DSI; this study reported the normative DSI as significantly lower in the Indian population than in European populations.[17] The results of examining the DSI in this Indian population showed significant differences in the MPT, F0—high, and DSI compared with the norms obtained for European populations; the MPT was lower in the Indian population compared with European populations and the researchers argued that these changes may be due to the differences in the physical structure, especially stature, of Indians compared with Europeans; in addition, F0—high was reportedly higher in the Indian population compared with previous values reported in different studies. The researchers concluded that geographical and ethnic differences affect the DSI and its parameters.[17] In acoustic evaluation, race, language, and structural and physiological features also affect acoustic values.[18] Malki et al found a significant difference in fundamental frequency and jitter and shimmer in adult men and women in Saudi Arabia compared with adult men and women in North America, and argued that the differences reflect the differences in vocal cord tissues and the anatomical differences in the vocal tract and racial features.[19] Xue et al also reported that the differences in the size of the vocal tract in white Americans, African Americans, and the Chinese have caused the differences in their voice characteristics and acoustic values.[20] A research in Persian-speaking populations showed that the harmonics-to-noise ratio (HNR) reported for Iranian women[21] is higher than the ratio reported for Portuguese-speaking Brazilians[22] and English speakers.[23] As noted, the normative values of acoustic parameters differ from one language to another.

MPT and PQ can be used as measures that have significant relationships with the perceptual assessment of the overall degree of hoarseness.[24] A dimension of aerodynamic evaluation that is common among all cultures is that the power of voice comes from the pulmonary system. The increase in mean MPT is associated with a decrease in the mean glottal airflow,[25] and when the intensity of sound increases, the air flow velocity also increases, and aerodynamic values thus differ between different ethnic groups given the various cultural norms in place for the use of sound with low or high intensity, the structure and volume of the lungs, the physiology and dimensions of the vocal cords, and the top of the vocal cords .[26]

Further research on this index and an examination of the potential changes in the remaining parameters of the multiparameter model in other populations thus appear necessary. Cultural differences affecting speech and voice should be considered to improve the accuracy of the assessments, as empirical studies have shown differences between some cultures in the information obtained from voice with regard to the fundamental frequency of sound, spectral measurements, and aerodynamic characteristics.[27–30] Some studies have also been conducted in Iran for normal acoustic measurements,[21,31] but no research has been carried out on the objective predictive parameters of the perceptual quality of voice with regard to the geographic, ethnic, and cultural differences of Iranians with European populations. The present study was therefore conducted to find the predictive parameters of the perceptual quality of voice and to develop a local model for the DSI in Persian speakers.

MATERIALS AND METHODS

The ethical principles of the Declaration of Helsinki were followed throughout the study. The ethics committee of the Social Welfare and Rehabilitation Sciences University also approved the study protocol. The subjects were fully briefed on the study objectives and methods and submitted informed consent forms for participation.

Study participants

The study participants consisted of 300 willing patients with different types of dysphonia (104 women and 196 men) presenting to the Ear, Nose and Throat Clinic of Amiralam Hospital in Tehran, Iran, between November 2014 and June 2015, and a total of 100 healthy samples without dysphonia (63 women and 37 men). The samples without dysphonia had no history of laryngeal injuries, had not used larynx-damaging substances, and did not have a cold or allergies at the time of sampling. None of the subjects had a history of lung disease and they all gave their full consent for participation in the study and spoke Persian. The subjects were at the age range of 18-65, and the mean ± standard deviation of their age was 45.3 ± 12.9 in the dysphonic and 40.3 ± 14.1 in the healthy group.

Perceptual voice assessment

A digital voice recorder, SONY ICD-UX530 (Sony Corporation of America) (with high sensitivity and less noise with a built-in S-Microphone System and a wider recording range), was used to record each subject's voice sample through an interview discussing their voice condition using dialogues. The recorded voice was then presented to a professional speech-language pathologist with more than 15 years of experience in the evaluation and treatment of voice disorders. The score of the G (grade) parameter of the GRBAS scale was measured for each participant based on the total hoarseness of his speech sample. The participants were divided into four groups, including the normal, mild dysphonia, moderate dysphonia, and severe dysphonia groups, based on perceptual judgments and their G (grade) on the GRBAS scale.

Aerodynamic measures

The vital capacity (VC) was recorded for each participant using the Fukuda Sangyo St-250 SpiroAnalyzer (Fukuda Sangyo Inc., Antipolo City, Philippines), which is a valid instrument for aerodynamic assessment and has been used extensively in research.[32–34] The participants were asked to inhale deeply and then blow into the spirometer as long and strong as possible. This experiment was repeated three times and the maximum VC was recorded for each participant. To measure the MPT, the participants were asked to pronounce the vowel /a/ and prolong it as long as possible and to repeat this task three times. The MPT was then recorded for each participant. The PQ was calculated by dividing the maximum VC by the longest MPT.

Acoustic and voice range profile measures

At least a 3-second sample of the person's voice while producing a prolonged /a/ sound at easy pitch and loudness is needed to measure jitter, shimmer, and NHR because the vowel (/a/) enhances the measurement reliability.[35] The subject was asked to produce the vowel /a/ in a habitual pitch and loudness. The recordings were made with an AKG C 410 microphone (Harman International Company, Vienna, Austria). The variables were measured using PRAAT software.[36] The subject was then asked to repeat the syllables /paa/ and /baa/ several times within 5-second intervals at the mark of the examiner's hand to calculate the voice onset time. The voice onset time is marked by the interval between the release of the speech organs and the onset of voicing in millisecond using the spectrogram. A phonetogram was used to assess the subjects' voice range profile. To obtain the voice range profile, the subjects' voice was recorded three times directly into the phonetogram software from the lowest to highest frequency and from the lowest to highest volume (LingCom phonetogram—version 1.x, Forchheim, Germany). Verbal and auditory samples were required for reaching the maximum capacity, and the voice ranges were then extracted.

Statistical analyses

SPSS-19 (IBM Corp., Armonk, New York, United States) was used for the statistical analysis of the data. After testing the fit of the ordinal regression, the logistic regression analysis was used to determine the factors affecting the DSI and the coefficient of each component. Discriminant analysis was used to evaluate the DSI's capacity for distinguishing between different degrees of dysphonia. The level of significance was set at 0.05, and two-tailed tests were used.

TABLE 2.
Testing the Fitting of Ordinal Regression Model to Data

Model	Chi-Square	df	*P* Value
Model fitting	283.51	15	<0.001
Goodness of fit	824.77	1182	1.000

RESULTS

Table 1 shows participants' frequency distribution in terms of their type of dysphonia and the mean and standard deviation of each of the parameters. Table 2 evaluates the ordinal regression model fit and shows that the model is good. Table 3 presents the results of the regression analysis for determining the factors affecting the DSI and the coefficient of each component. According to Table 3, of the 15 variables measured, shimmer, VC, the semitone range, and the voice onset time of /paa/ are the parameters that had significant values ($P < 0.05$) and remained in the model along with their coefficients. The DSI model for the population under study is presented below.

$$\text{DSI} = 0.289\,(\text{shimmer}) + 0.0001\,(\text{VC}) - 0.059\,(\text{STR}) - 13.278\,(\text{VOT\_Pa})$$

To evaluate how much the DSI changes at different dysphonia severities by the total scores of the perceptual quality of voice, the index scores were compared between the normal people and those with mild, moderate, and severe dysphonia. Table 4 presents the results obtained. As shown in the table, the higher is dysphonia severity, the higher become the DSI values.

After the range of the DSI scores was determined, the ability of the index to distinguish between the groups was assessed using the discriminant analysis. Table 5 presents the results

TABLE 1.
Mean ± Standard Deviation of Each Parameters in the Normal, Neurologic, Functional, and Organic Dysphonia Groups

Dependent Variables	Normal Voice M ± SD	Neurological Voice Disorders M ± SD	Functional Voice Disorders M ± SD	Organic Voice Disorders M ± SD
Jitter	0.43 ± 0.21	2.85 ± 3.57	1.37 ± 2.09	1.20 ± 1.61
Shimmer	3.56 ± 1.83	10.78 ± 6.92	8.04 ± 6.29	8.87 ± 5.55
NHR	0.01 ± 0.009	0.27 ± 0.32	0.12 ± 0.20	0.12 ± 0.18
MPT	13.38 ± 5.66	8.87 ± 6.18	10.29 ± 4.99	9.61 ± 4.75
VC	3608 ± 782	3030.53 ± 947.00	3447 ± 736	3512 ± 860.02
PQ	312.13 ± 145.00	540.03 ± 522.42	419.50 ± 226.45	454.97 ± 246.53
LI	62.68 ± 9.53	56.55 ± 10.39	63.18 ± 9.45	60.86 ± 11.50
HI	85.93 ± 7.45	83.66 ± 5.03	84.76 ± 6.33	86.19 ± 3.56
IR	24.35 ± 11.33	27.11 ± 11.65	21.59 ± 9.46	25.32 ± 11.29
LF	166.73 ± 56.36	199.13 ± 214.85	191.24 ± 98.84	151.27 ± 94.59
HF	472.46 ± 176.58	422.58 ± 197.21	395.82 ± 164.20	380.53 ± 159.43
FR	302.57 ± 168.20	224.26 ± 153.52	205.76 ± 146.00	229.14 ± 146.85
STR	17.77 ± 7.69	12.89 ± 8.50	12.56 ± 7.26	14.05 ± 7.38
Vot_ba	0.06 ± 0.01	0.05 ± 0.01	0.06 ± 0.01	0.06 ± 0.01
Vot_pa	0.06 ± 0.01	0.05 ± 0.01	0.05 ± 0.01	0.05 ± 0.01

Abbreviation: FR, fundamental frequency range; HF, highest fundamental frequency; HI, highest intensity; IR, intensity range; LF, lowest fundamental frequency; LI, lowest intensity; SD, standard deviation; STR, semitone range.

TABLE 3.
Results of the Regression Analysis for Determining the Significant Factors and the Coefficient of Each Component

		Estimate	SD	Wald	df	*P* Value
Threshold	[GS = 0]	–3.640	2.738	1.767	1	0.184
	[GS = 1]	–1.912	2.734	0.489	1	0.484
	[GS = 2]	0.120	2.732	0.002	1	0.965
Location	Jitter	0.059	0.158	0.141	1	0.707
	Shimmer*	0.290	0.037	61.152	1	0.000
	NHR	0.970	1.624	0.357	1	0.550
	MPT	–0.042	0.039	1.203	1	0.273
	VC*	0.000	0.000	3.963	1	0.047
	PQ	0.001	0.001	1.464	1	0.226
	LI	–0.046	0.124	0.136	1	0.712
	HI	0.039	0.123	0.100	1	0.752
	IR	–0.046	0.124	0.141	1	0.707
	LF	–0.046	0.043	1.142	1	0.285
	HF	0.043	0.043	0.989	1	0.320
	FR	–0.042	0.043	0.942	1	0.332
	STR*	–0.059	0.029	4.129	1	0.042
	VOT_ba	–7.519	5.497	1.871	1	0.171
	VOT_pa*	–13.172	5.776	5.200	1	0.023

* Significant variables.
Abbreviation: FR, fundamental frequency range; HF, highest fundamental frequency; HI, highest intensity; IR, intensity range; LF, lowest fundamental frequency; LI, lowest intensity; SD, standard deviation; STR, semitone range.

TABLE 4.
Results of the DSI by Dysphonia Severity

Groups	SD ± Mean	Minimum	Maximum	n
Normal voice	–0.46 ± 0.74	–2.26	2.12	100
Mild dysphonia	0.33 ± 1.04	–1.35	5.21	104
Moderate dysphonia	1.08 ± 1.31	–1.65	5.90	103
Severe dysphonia	2.82 ± 2.05	–0.79	8.82	93

Abbreviation: SD, standard deviation.

TABLE 5.
Results of the Discriminant Analysis of the DSI by Dysphonia Severity

	Wilks' Lambda	F	df1	df2	*P* Value
Dysphonia severity index	0.563	102.49	3	396	0.0001

obtained. According to this table, this index can discriminate between these groups. The results show that this index can classify the main groups up to an accuracy of 47.8%. The main groups are those that have been classified by the perceptual score of the DSI.

DISCUSSION

After performing the regression analysis, the components including shimmer, VC, semitone range, and the voice onset time of /paa/ and their coefficients remained in the model.

Wuyts et al designed the DSI in their study using a weighted combination of the following parameters: MPT, highest frequency, lowest intensity and jitter.[1] In their study, one component remained in the aerodynamic evaluations, two components in the voice range profile evaluations, and one in the acoustic evaluations, and at least one parameter was entered into the model from all the dimensions of the evaluations. In the present study, although the components remaining in the model differ with those remaining in Wuyts et al's study, still, at least one parameter was entered into the model from each of the evaluations; that is, one component remained in the aerodynamic evaluations, two components in the acoustic evaluations, and one in the voice range profile evaluations and were entered into the model, suggesting that a single type of evaluation or a single component cannot show the perceptual quality of voice and that the multidimensional nature of voice increases the need for performing multiparametric evaluations.

One of the remaining parameters of the model is the voice range profile; in most dysphonic patients, there are lesions on the vocal cords that limit the speed of vibration of the vocal cords, thus affecting the frequency range and consequently the voice range profile. When the frequency range is calculated in the form of semitone, differences in semitones are shown more clearly. The present findings confirm the hypothesis that different language communities have their own pitch profiles.[37] As observed in the model, owing to the different pitch profiles in different languages, the semitone range in Persian is a better predictor of the overall perceptual quality of voice.

VC is another component that remained along with others, thereby strengthening the hypothesis that respiratory support is a basis for phonation and creates enough energy for producing voice.[38] The results obtained confirm that the reduction in VC leads the individual to resort to compensatory behaviors for producing sound and that increased pressure reduces the perceptual quality of voice and increases dysphonia.

Voice quality can vary between different languages. These differences may be due to different voice behaviors.[39] Some differences in shimmer and jitter are therefore predictable. The fact that shimmer remained in the model indicates that, in the population under study, shimmer is a better predictor of the overall quality of voice alongside the three other parameters.

Giovanni et al developed a protocol consisting of aerodynamic and acoustic parameters as well as jitter, HNR, oral airflow, and voice onset time; with this protocol, instrumental and perceptual evaluations matched by 66.7%.[40] In the present study, the voice onset time of /paa/ seems a reasonable parameter to be involved in the estimation of the perceptual severity of dysphonia. The voice onset time is a common parameter between the cited research and the present study.

Piccirillo et al developed a concept for voice function in which they stressed only the classification of voice into normal and dysphonic. Using the logistic regression, they obtained a weighted combination of subglottic pressure, airflow at lips, vocal efficiency, and MPT to classify voice into normal and dysphonic:

$$\text{Voice status} = -4.5732 + (-0.1621 \times \text{PSG}) + (-0.0075 \times \text{UL}) + (0.1799 \times \text{VE}) + (0.0782 \times \text{MPT})$$

They initially analyzed 14 parameters using the multiple regression analysis and these four components were the ones that remained to distinguish between normal voice and dysphonic voice and are considered necessary for the distinction of normal from abnormal voice. Piccirillo et al also concluded that binary classifications cannot meet clinical or research needs and argued that, in other populations, these components might remain in the model in another form.[11] The components remaining in the model in this study are different from the components obtained by Piccirillo et al, which could be due to the differences in the components under study as well as in the studies' objectives. Moreover, Piccirillo et al focused only on the distinction between normal voice and dysphonic voice, whereas the present study based its classification on the perceptual score.

Wolfe et al evaluated the predictive value of the four parameters of mean fundamental frequency, jitter, shimmer, and HNR in patients with three types of voice disorder, including nodules, vocal cord paralysis, and functional disorder; their results showed that shimmer is correlated with the perceptual score and reported the correlation as 0.54.[41] Their findings regarding shimmer are consistent with the present findings; it thus appears that shimmer is an important component of the perceptual quality of voice. In a study by Bhuta et al, shimmer was reported as a predictor of the perceptual quality of voice score,[42] which is consistent with the present findings. Yu et al found six parameters to be valuable for the protocol of instrumental voice assessment[3]; their results regarding the semitone range parameter were consistent with the present findings. In the present study, the semitone range was found to be associated with predictions about the overall quality of voice.

In one study, Marin et al examined the combination of two analyses for scoring auditory perception and obtained an acoustic model with six variables for the multiparametric assessment of voice quality. The correlation of this model with the mean overall quality of voice was 0.78.[12] As can be seen, shimmer is a common component of the Acoustic Voice Quality Index and the model presented in this study. Other studies have mostly focused on acoustic parameters and thus cannot be compared with the present study, which examines other aerodynamic and voice range profile components.

The DSI scores ranged from −2.26 to 8.82 in the population under study. With an increase in dysphonia and its severity, the scores obtained for different severities of dysphonia also increase.

The discriminant analysis also showed that this index correctly classifies 47.8% of people into groups with different perceptual severities of dysphonia. The greatest reduction in the discriminant analysis pertained to groups with mild or moderate disorder in the midrange of the spectrum and showing a greater overlap. It appears that separating people into less than four groups (three groups of normal voice, mild disorder, and severe disorder) not only increases the ability of the index to differentiate between people in terms of the severity of the disorder but also reduces the accuracy of the index. It seems that the model alone should not be used for evaluations; rather, it should be used along with other evaluative methods.

CONCLUSION

An objective and quantitative model, which incorporates all the components that can predict the overall quality of voice along with their coefficients, has been developed for voice assessment in Persian-speaking Iranians. This model can be used with other evaluations in voice assessments before and after voice therapy and also before and after laryngeal surgery to evaluate the efficacy of the treatment used.

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