Reliability of speaking and maximum voice range measures in screening for dysphonia

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RELIABILITY OF SPEAKING AND MAXIMUM VOICE RANGE MEASURES IN SCREENING FOR DYSPHONIA

ABSTRACT

Speech range profile (SRP) is a graphical display of frequency-intensity interactions during functional speech activity. Few studies have suggested the potential clinical applications of SRP. However, these studies are limited to qualitative case comparisons and vocally healthy participants. The present study aimed to examine the effects of voice disorders on speaking and maximum voice ranges in a group of vocally untrained females. It also aimed to examine whether voice limit measures derived from SRP were as sensitive as those derived from voice range profile (VRP) in distinguishing dysphonic from healthy voices. Ninety dysphonic females with laryngeal pathologies and 35 control females participated in this study. Each subject recorded a VRP for her physiological vocal limits. In addition, each subject read aloud the North Wind and the Sun passage to record a SRP. All the recordings were captured and analyzed by the Soundswell's computerized real-time phonetogram Phog 1.0 (Hitech Development AB, Sweden). The SRPs and the VRPs were compared between the two groups of subjects. Univariate analysis results demonstrated that indiviual SRP measures were less sensitive than the corresponding VRP measures in disciminating dysphonic from normal voices. However, stepwise logistic regression analyses revealed that the combination of only two SRP measures was almost as effective as a combination of three VRP measures in predicting the presence of dysphonia (overall prediction accuracy: 93.6% for SRP versus 96.0% for VRP). These results suggest that in a busy clinic where quick voice screening results are desirable, SRP can be an acceptable alternate procedure to VRP.

Key words: dysphonia, voice range profile (phonetogram), functional continuous speech, maximum vocal capacity

INTRODUCTION

The voice range profile (VRP) is the official term proposed by the Voice Committee of the International Association of Logopedics and Phoniatrics (IALP) in 1992 to denote the two-dimensional graphical display of an individual's maximum phonational intensity range against his/her maximum phonational frequency range. Traditionally, VRPs are obtained by asking the individuals to sustain a vowel, usually /a, i or u/, as soft and then as loud as possible across their own maximum frequency range. Such VRP recorded reflects the individual's physiological vocal limits or capacity and, therefore, it is regarded as a test of maximum performance [1]. Alternative terms that have been used in the literature include phonetogram [2-4], phonetography [5], voice profile [6], phonational profiles [7] and voice area [8].

The literature has documented the clinical usefulness of VRP measures to distinguish pathological voice from normal voice [9-12], to document voice changes following vocal fatigue [13] and to evaluate changes in voice impairment severity following voice therapy [4, 14, 15]. However, there are three issues in relation to the VRP recording procedure which may limit its clinical application. The first issue relates to the amount of time involved in obtaining a VRP. The literature suggests that it takes around 20 minutes [16] to half-an-hour [17] to obtain a satisfactory VRP. In this regard, Titze and his colleagues [17] attempted to save the clinicians' time by proposing the use of fully automated procedure to elicit VRPs. In that automated procedure, explanations and instructions for the VRP recording procedure were presented by videotape. The VRPs were elicited and recorded by an automated computer program. Therefore, there were no clinicians involved in the recording procedure. The authors compared the vocal limit values that were elicited using the fully automated procedure to the traditional clinician-assisted procedure in 20 vocally untrained subjects. However, their results failed to indicate a clear and systematic preference of recording procedure on VRP data.

The second issue relates to the reliability and validity of the voice ranges obtained. Several authors have discussed different procedural factors which can lead to high inter- and intra-subject variability of the vocal frequency and intensity limits elicited (see, for example, Coleman, [18] and Gramming et al.[19]). It is, therefore, of no surprise that various investigators have attempted to study the effects of tasks on elicitation of maximum phonational frequency range [20-22] and maximum phonational intensity range [23, 24]. These studies aim to standardize the procedures for eliciting true vocal limits. Unfortunately, the results are yet inconclusive as to which recording procedure can reliably elicit the true frequency and intensity ranges.

Finally, traditional VRPs are recorded using sustained phonations which are considered as highly simplified speech behavior and a singing voice [25]. Therefore, whether traditional VRP can adequately reflect an individual's functional speech performance is of concern [1]. Some investigators have adopted the concept of VRP to obtain a two-dimensional graphical representation of the frequency-intensity interaction during functional speech activities. Instead of using sustained phonation, the profiles are obtained using connected speech, such as counting, performing a monologue or oral reading [26-28]. Currently there is no standardized term for the frequency-intensity plot obtained from this procedure. Previous investigators labeled them as speaking VRP [28] and in more recent studies as speech range profile [26, 29]. The speech profile can be obtained in shorter amount of time than traditional VRP, thus it is a more cost-effective assessment procedure in clinical routine.

Hacki [28] recorded voice profiles from four dysphonic individuals with laryngeal pathologies using singing, speaking and shouting voices. The shapes and sizes of the voice profiles were compared to those of a professional singer and a female without vocal training; both of them were vocally healthy. He found reduced voice profile sizes in most of the dysphonic cases across the three voice modalities. In another study, Ternstrom and his colleagues [27] evaluated the effects of body massage on speaking voice range in a group of vocally healthy subjects. In their study, participants' speech range profiles were elicited by reading aloud a standard text and were analyzed using the Phog 1.0 program. Results revealed a significant increase of speech profile area after a 30-minute body massage, suggesting an increase of speaking voice ranges. Their results suggested that speech profile area could be a sensitive measure to detect voice changes.

The studies reviewed above suggest the potential clinical applications of speech range profiles. However, these studies are limited to qualitative case comparisons and vocally healthy participants. Whether these findings can be generalized to the voice-disordered population has yet to be proved. Therefore, the aim of the present study was to systematically evaluate the effects of voice disorders on the maximum and speaking voice ranges. The second aim of the study was to examine whether voice limit measures derived from connected speech are as sensitive as those derived from sustained vowel prolongation in distinguishing dysphonic voices from healthy voices. In this study, voice range profile (VRP) refers to the frequency-intensity plot of an individual's physiological voice limits and speech range profile (SRP) which are defined here as the graphical plot of an individual's frequency-intensity interactions during connected speech production.

METHODS

Participants

Ninety dysphonic Cantonese females with laryngeal pathologies (Table 1) participated in this study. In addition, 35 Cantonese females with normal voices served as control subjects. The dysphonic participants were recruited from the Voice Clinic at the University of Hong Kong and two public hospitals in Hong Kong. They had not received any voice treatment at the time of testing. Participants with previous vocal and speech training, neurological disorders, and severe respiratory problems were excluded from this study. All the participants passed a hearing screening test of 20 dB at hearing threshold levels 0.5, 1.0, 2.0, 4.0 and 8.0 kHz. The mean age of the dysphonic group was 37.07 years (standard deviation=8.76, range=20 to 53 years) and the control group was 36.03 years (standard deviation=8.85, range=22 to 52 years).

Put Table 1 here

Procedures

All the voice samples were recorded directly into the Soundswell's computerized real-time phonetogram (Phog 1.0, Hitech Development AB, Sweden) using a head-mounted professional grade, condenser microphone (AKG Acoustics C420, Austria) which was adjusted to maintain a constant 5cm distance from the subject's mouth corner. In order to follow the 30 cm mouth-to-microphone distance recommended by the Union of European Phoniatricians (UEP) [8], the microphone was calibrated before testing such that the intensity level picked up at the 5 cm mouth-to-microphone distance would be equivalent to the intensity level picked up by the microphone positioned 30 cm away from the mouth.

Prior to the actual recording, subjects were asked to practice pitch gliding five times as vocal warming up to facilitate the production of maximum vocal performance. Each subject recorded two profiles using her maximum vocal capacity (voice range profile, VRP) and speaking voice (speech range profile, SRP) respectively. The tasks were counter-balanced such that half of the subjects recorded the VRP first, followed by the SRP. The remaining half of the subjects did the recordings in the reverse order. The recording details of the VRPs and the SRPs will be described in the following sections.

Voice range profile (VRP)

The lower VRP intensity contour was obtained before the upper intensity contour to avoid possible laryngeal fatigue [11]. The recording procedure began with the clinician presenting a C_4 tone (261.6 Hz) using the Phog 1.0 program. The subject was asked to sustain /a/ following that tone at her comfortable loudness. Then she had to gradually decrease the loudness until it reached her lowest volume without whispering at that tone. The vowel /a/ was used because of its relatively higher first formant frequency than the vowels /i/ and /u/ that might affect the recording of the low intensity contour [30]. The recording procedure was repeated with musical notes reducing by one semitone at a time down the piano scale until the subject could not sustain her phonation at any further lower frequency. Then, the recording procedure was repeated with musical notes increasing by one semitone at a time up the piano scale starting from C_4 until the subject could not sustain her phonation at any further higher frequency. Every consecutive semitone along the piano scale was used in order to test whether there existed any gap within the subject's VRP, particularly for dysphonic patients with laryngeal pathologies that might present phonation break at a certain semitone point. Each tone was tested three times to ensure the softest possible intensity level has reached [24]. This recording procedure gave rise to the lower intensity contour. Similar procedures were used to obtain the upper intensity contour, in which subjects had to gradually increase the loudness until it reached the maximum loudness at that tone without causing discomfort in the throat across her entire frequency range. Throughout the recording, the clinician provided the subjects with hand-signals to coach them for further lowering / increasing their loudness. Figure 1 shows a sample VRP obtained from a control subject.

Put Figure 1 here

Speech range profile (SRP)

The SRP was recorded by asking the subjects to read aloud the Cantonese passage 'North Wind and the Sun' at their most comfortable pitch and loudness as in daily conversations. Subjects were allowed to practice reading the passage aloud before actual recording. The passage was recorded again if either the clinician or the subjects themselves considered the pitch and loudness used in the recording were different from those of daily conversational speech. Figure 2 shows a sample SRP recorded from the same control subject.

Put Figure 2 here

Data Analysis

All VRPs and SRPs were analyzed by the first author. Four profile boundary points, included the highest frequency (high-F_0), the lowest frequency (low-F_0), the maximum intensity (max-I) and the minimum intensity (min-I), were analyzed from each profile. The max-I point was taken from the highest intensity value of the upper intensity contour. Similarly, the min-I point was taken from the lowest intensity value of the lower contour. The two points where the upper and the lower intensity contours merged at the highest phonational frequency and the lowest phonational frequency gave rise to the boundary points of the high-F_0 and the low-F_0, respectively. The difference between the high-F_0 and the low-F_0 values gave rise to the frequency range (F_0-range). The difference between the max-I and the min-I values gave rise to the intensity range (I-range). In addition, the profile areas were calculated automatically by the Phog 1.0 software for each subject.

Reliability of profile analyzing procedures

Since the analyses of VRPs and SRPs involved visual judgment of the profile boundary points, reliability of the analyzing procedure had to be established. The VRPs and the SRPs from 32 randomly selected subjects were re-analyzed by the first author on a second occasion two weeks after the first analysis. This was to evaluate the intra-judge reliability. These 64 profiles were also analyzed by another judge in order to evaluate the inter-judge reliability.

RESULTS

Reliability of profile analyzing procedures

Pearson's correlation coefficients were used to evaluate the reliability of profile analyzing procedures. Intra-judge reliability coefficients were at least 0.97 (p=0.0001). Inter-judge reliability coefficients were all above 0.99 (p=0.0001) except the VRP low-F_0 that exhibited an inter-judge reliability coefficient of 0.72 (p=0.0001).

Differences between dysphonic and control groups

Table 2 lists the means and standard deviations of the VRP and SRP measures for the dysphonic and control groups, and the results of independent *t*-tests. Such results are summarized and displayed graphically in Figure 3. Figure 3 reveals simplified representations of the VRP and SRP boundaries for the dysphonic and the control groups, as derived from the mean values of the four voice limit measures (that is, the highest and the lowest frequency, the maximum and the minimum intensity) reported for the corresponding profile in Table 2. Because there were seven *t*-tests carried out for both sets of VRP and SRP data, a Bonferroni adjusted *alpha* level of 0.0083 (0.05/7) was applied in each case in order to avoid any possible Type I errors. The dysphonic group demonstrated significantly lower mean high-F_0 than the control group for both VRP and SRP (p=0.0001). The dysphonic group also demonstrated significantly higher mean VRP low-F_0 (p=0.0001) and significantly smaller mean VRP F_0-range (p=0.0001) than the control group. The two groups of subject revealed similar values in the mean SRP low-F_0 and the mean SRP F_0-range.

For the intensity measures, the dysphonic group demonstrated significantly higher mean max-I and min-I for both VRP and SRP. The mean VRP I-range was significantly more limited (p=0.0001) in the dysphonic group as compared to the control group. For the profile areas, only the mean VRP area of the dysphonic group was significantly smaller (p=0.0001) than that of the control group. The mean SRP areas were similar between the two groups of subjects.

<u>Put Table 2 and Figure 3 here</u>

Classification of dysphonic and controls subjects using VRP and SRP measures

Binary logistic regression analyses with stepwise variable selection were employed on each data set to select the optimal combination of measures that could best predict the presence of dysphonia. Table 3 lists the accuracy rates of classifying dysphonic and control subjects using measures selected from the VRP and SRP respectively. Results revealed the combination of three VRP measures, including the VRP area, VRP max-I and VRP min-I, was sufficient to achieve an overall prediction accuracy of 96.1%. For the SRP, the inclusion of only two SRP measures, including SRP F_0-range and SRP max-I, was sufficient to correctly predict 95.6% of dysphonic subjects, with an overall prediction accuracy of 93.8%.

Put Table 3 here

DISCUSSIONS

The voice range profile (VRP) has been frequently used in clinical voice assessments for evaluating voice impairment severity. Recently, there has been an increasing popularity of speech range profile (SRP) to graphically reveal frequency-intensity information during functional speech activities. The present study aimed to evaluate the effects of voice disorders on the maximum and speaking voice ranges in a group of vocally untrained females. It also aimed to examine whether voice limit measures derived from SRP were as sensitive as those derived from VRP in distinguishing dysphonic voices from healthy voices.

Differences between dysphonic and control groups

The dysphonic group demonstrated significantly lower mean VRP high-F_0 and significantly higher mean VRP low-F_0 than the control group. These results corroborate with the previous reports that dysphonic individuals are more limited in their maximum phonational frequency ranges than vocally healthy individuals [9, 11, 31, 32]. The results could be attributed to the increase in vocal fold mass and stiffness associated with the presence of laryngeal pathologies in dysphonic subjects that prevented stretching the vocal folds to phonate at both very high and very low frequencies [9, 10, 33, 34].

The dysphonic group also demonstrated significantly lower mean SRP high-F_0 than the control group. Again, the presence of laryngeal mass lesions in the dysphonic subjects could impact on their highest speaking frequency values. However, the mean SRP low-F_0 of the dysphonic and the control groups were similar. This result might be attributed to the fact that the reading task for eliciting SRP did not demand subjects to push to their physiological vocal limits for the production of the lowest speaking frequency. These findings on the SRP frequency measures also suggest that the high speaking frequency area is more vulnerable to laryngeal mass lesions than the low speaking frequency area.

The mean VRP min-I level of the dysphonic group was significantly higher than that of the control group. This finding is consistent with the existing literature that dysphonic individuals are more limited in phonating at very soft intensity levels when compared to vocally healthy individuals [9, 10, 12]. When phonating at the softest intensity level, the increase in vocal fold mass per unit length associated with the laryngeal mass lesions limits the vocal folds to vibrate at a very low airflow [12]. Therefore it requires dysphonic individuals larger adductory force to initiate vocal fold vibration. This elevates the phonatory threshold pressure and hence the VRP min-I.

Interestingly, the mean VRP max-I of the dysphonic group was significantly greater than that of the control group. The VRP max-I level is related to the threshold of the vocal folds to withstand phonating at very high subglottal pressure. One would expect dysphonic individuals are more limited in phonating at very loud intensity levels than vocally healthy individuals. An observation from the present study suggested that the control subjects were more conservative than the dysphonic subjects in phonating at very loud levels probably because they did not want to damage their voice or create any discomfort to their throats by phonating at very loud volume.

Both mean SRP max-I and min-I values for the dysphonic group were elevated in a similar fashion as those of the VRP. This indicates that dysphonic subjects as a group read the text with louder volume than the control group. As all subjects included in this study were screened for normal hearing, the findings of louder voice used in dysphonic subjects were unlikely to be related to any hearing difficulties encountered by the subjects. The findings correlate to the general observations that voice patients tend to speak with greater phonatory effort to compensate for their poor harmonic-to-noise ratio and to be heard. The louder voice used in the dysphonic subjects may also be an indicator of their vocal abusive behaviors.

Profile area indicates the size enclosed by the upper and lower intensity contours. Mathematically, it is a function of frequency and intensity range. Due to the reduced VRP F_0-range and I-range in the dysphonic group, it seems logical that the dysphonic group demonstrated significantly smaller VRP area than the control group. However, the SRP areas of the two groups of subjects were similar and were not significantly different. Again, the comfortable nature of the SRP task without pushing the subjects to their maximum performance might have contributed to the results.

Classification of dysphonic and controls subjects using VRP and SRP measures

The sensitivity and specificity of the VRP data in the present study (97.8% and 91.4% respectively, see Table 3) were both higher than those reported in Heylen et al. [9]. In their study, a combination of age and three VRP measures including the lowest intensity, the highest frequency and the slope of the upper contour were adequate to classify a group of 136 dysphonic children and 94 healthy children with sensitivity and specificity of 90% and 83% respectively. In the present study, the use of a warm-up task prior to recording and clinician's hand-signals as coaching were incorporated with the attempt to enhance reliability and validity of the VRP measures.

Heylen and his colleagues [9] advocated the use of multiple salient VRP measures to retain its two-dimensional representation and to enhance its power to differentiate dysphonic from healthy voices. It is apparent that this notion also applies to SRP. Results of univariate analyses discussed in the previous section indicated that individual SRP measure in isolation was not as sensitive as the corresponding VRP measure in distinguishing dysphonic from normal voices. However, such discriminating power increased when combining several SRP measures. Binary logistic regression analyses revealed that with two SRP measures (SRP F_0-range and SRP max-I) could best achieve an overall prediction accuracy of 93.6%. This overall prediction accuracy was slightly lower than that of VRP (96.0%) (see Table 3). With the comparable prediction accuracy, SRP is almost as efficient as VRP in predicting for the presence of dysphonia.

CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

In conclusion, the present findings support the speech range profile (SRP) as a valuable clinical tool to differentiate dysphonic from normal voices. The SRP itself takes no more than five minutes to obtain. The shorter administration time and simpler methodological procedure of the SRP lends itself to application as a screening tool for dysphonia. Based on the present findings, we suggest that in a busy clinic where quick screening results are desirable, SRP would be an acceptable alternative to traditional VRP for screening the presence of dysphonia. As a screening tool, the VRP recording procedure would be too time-consuming. Nevertheless, because the SRP and the VRP tasks reflect different extents of vocal demand from the individual (SRP: comfortable speech; VRP: physiological vocal limits), the VRP can be used to further reveal any deficits over the individual's entire frequency and intensity range.

It is acknowledged that only vocally untrained females were recruited in the present study. Further studies are warranted to examine whether the present results can be generalized to the male population as well as individuals with vocal training. Another limitation relates to the recording procedure of SRP. In the present study, SRPs were obtained using the subjects' habitual voice in a reading task under a sound-treated setting. Further studies can be extended to elicit SRP under different communicative situations (e.g., classroom settings) for a more functional evaluation of voice use.

Some authors have reported in their studies that voice profiles obtained using connected speech tasks could exceed the physiological vocal limits obtained from traditional voice range profile procedures using sustained vowel prolongation [26, 28]. In the recent paper by Emerich et al. [26], the voice limits of stage and studio readings of *all* the actors included could go beyond their own physiologic VRP boundaries. Similar observations were also noted in the study by Hacki [28]. It appears that the traditional way of eliciting VRP using sustained vowel prolongations may not always reliably elicit true physiological voice limits. We agree with these authors and recommend further investigations of the feasibility of using connected speech to obtain an individual's voice limits.

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Table 1. Types of laryngeal pathologies in the dysphonic group

Laryngeal pathologies	Number of dysphonic subjects
Vocal nodules	41
Thickened vocal fold(s)	28
Chronic laryngitis	8
Vocal fold edema	5
Vocal polyp	2
Vocal fold palsy	2
Miscellaneous/unspecified	4
Total	**90**

Table 2. Means and standard deviations of voice limit measures, as derived from voice range profile (VRP) and speech range profile (SRP) of the dysphonic and control groups.

Measures	Dysphonic (N=90)		Control (N=35)		Independent-t Tests		
	Mean	SD	Mean	SD	t	df	p-level
			Frequency measures (Hz)				
Highest frequency							
VRP	854.98	251.25	1232.85	221.42	-7.79	123.00	0.0001*
SRP	297.75	50.00	336.06	51.07	-3.82	123.00	0.0001*
Lowest frequency							
VRP	127.65	20.99	115.01	12.00	4.21	105.82	0.0001*
SRP	130.65	18.83	134.89	12.33	-1.47	94.05	0.14
Frequency range†							
VRP	32.36	6.39	40.89	3.73	-9.26	104.16	0.0001*
SRP	14.21	3.07	15.69	2.48	-2.53	123.00	0.01
			Intensity measures (dBA)				
Maximum intensity							
VRP	109.28	5.18	105.66	6.12	3.33	123.00	0.001*
SRP	94.57	5.55	85.37	3.52	11.03	97.01	0.0001*
Minimum intensity							
VRP	60.64	7.41	48.91	3.12	12.45	122.17	0.0001*
SRP	74.23	6.12	66.66	3.31	8.87	110.25	0.0001*
Intensity range							
VRP	48.63	8.06	56.74	6.29	-5.35	123.00	0.0001*
SRP	20.33	3.23	18.71	3.30	2.50	123.00	0.01
			Profile areas (dBA x semitones)				
VRP	931.47	266.31	1421.80	232.23	-9.57	123.00	0.0001*
SRP	173.17	41.28	185.77	45.26	-1.49	123.00	0.14

† Frequency range was measured in semitones.

* Significant at 0.0083 level (2-tailed).

Table 3. Accuracy rate in classifying subjects using selected voice limit measures, as derived from voice range profile (VRP) and speech range profile (SRP)

Profile	Number of subjects		Percentage of subjects	Overall
	Observed	Predicted	correctly classified	accuracy rate
VRP†				
Dysphonic	90	88	97.8%	
Control	35	32	91.4%	96.0%
SRP#				
Dysphonic	90	86	95.6%	
Control	35	31	88.6%	93.6%

Note: † Selected VRP measures include the profile area, the max-I and the min-I.

Selected SRP measures include the F_0-range and the max-I.

FIGURE CAPTION

Figure 1. Sample computer screen of the Soundswell's Phog 1.0 program showing the voice range profile (VRP) recorded from a control subject.

Figure 2 Sample computer screen of the Soundswell's Phog 1.0 program showing the speech range profile (SRP) recorded from the same subject.

Figure 3 Simplified representations of the VRP and SRP boundaries for the dysphonic and the control groups, as derived from the mean values of the four voice limit measures (that is, the highest and the lowest frequency, the maximum and the minimum intensity) reported for the corresponding profile in Table 2.

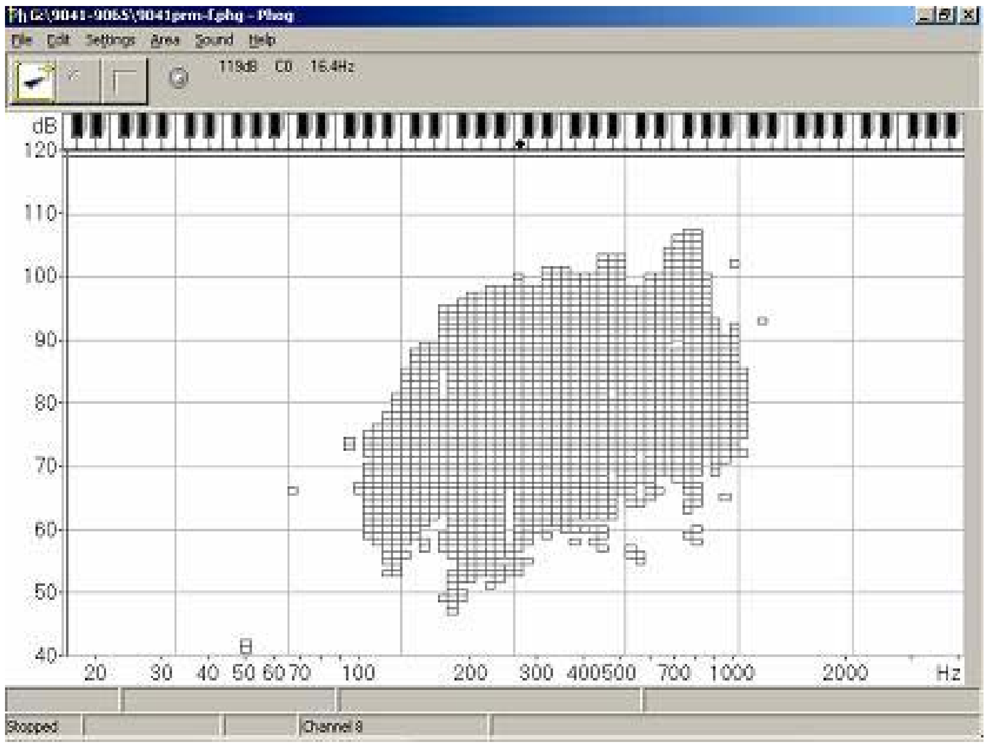

Figure 1. Sample computer screen of the Soundswell's Phog 1.0 program showing the voice range profile (VRP) recorded from a vocally untrained female.

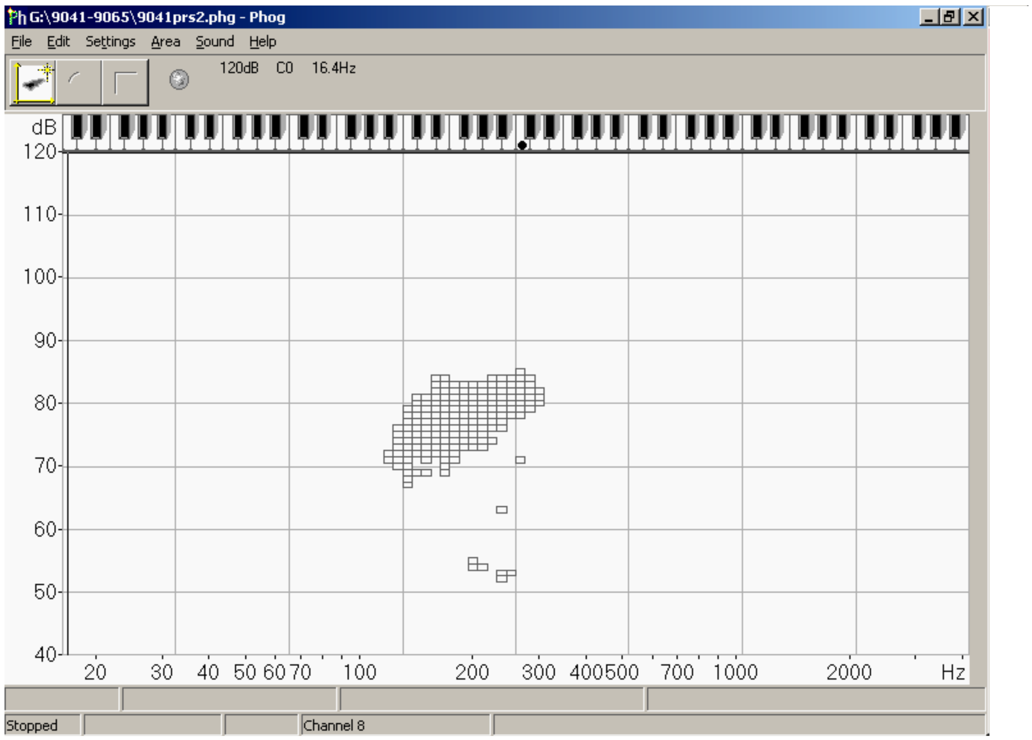

Figure 2 Sample computer screen of the Soundswell's Phog 1.0 program showing the speech range profile (SRP) recorded from the same female control.

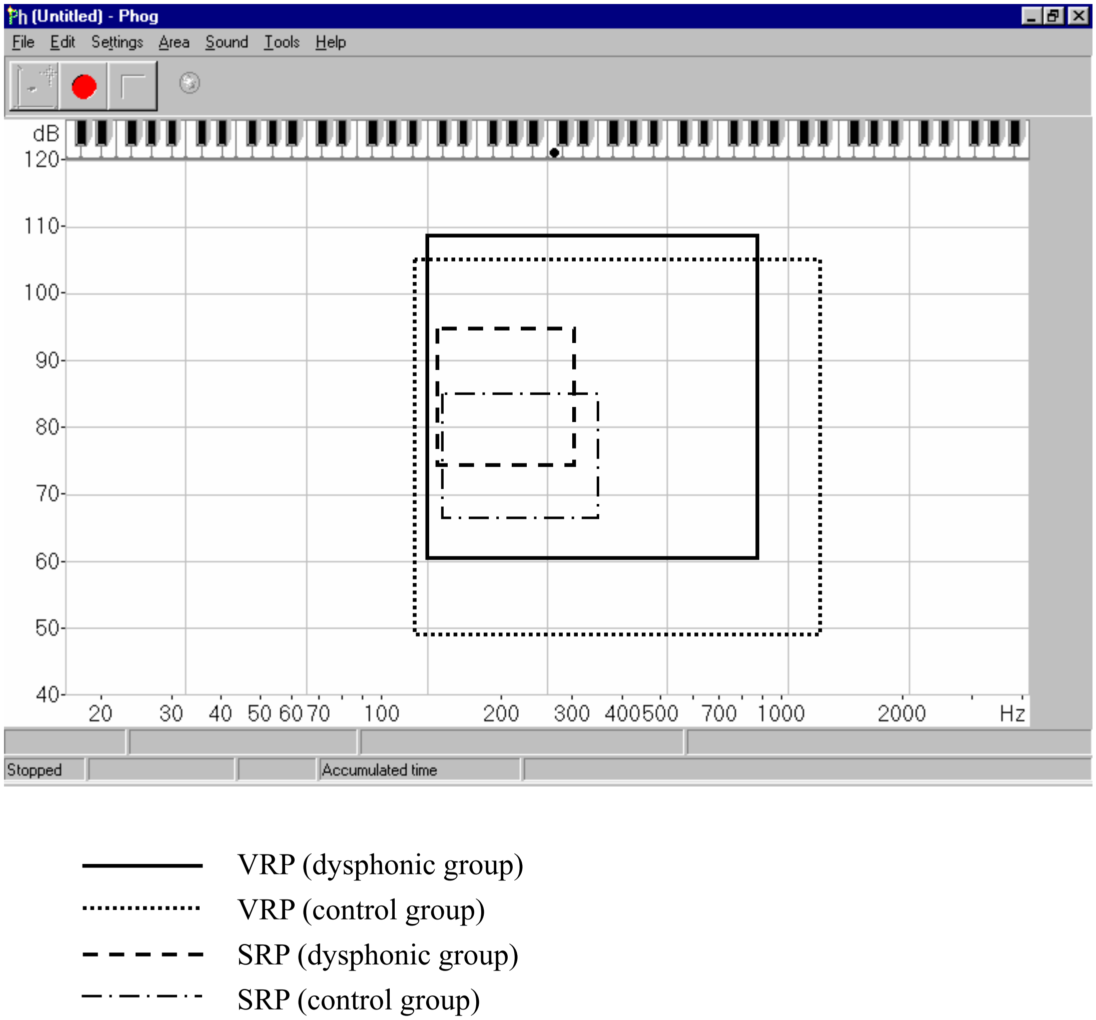

Figure 3 Simplified representations of the VRP and SRP boundaries for the dysphonic and the control groups, as derived from the mean values of the four voice limit measures (that is, the highest and the lowest frequency, the maximum and the minimum intensity) reported for the corresponding profile in Table 2.