Chapter 15
Vibratory characteristics of selected pathological female and male vocal folds. Evidence from HSDI

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Abstract

Laryngeal images obtained from HSDI of pathological voices were examined with customized software that delineated glottal edges and used the Hilbert transform based method of analysis to provide objective quantification of glottal perturbation; transformed glottal cycles provided visual patterns on the overall vibratory dynamics. Vibratory patterns in voice-disordered groups vary with pathology and severity. They may show exaggerated, mixed, or deviant vibratory patterns from the normal speaker patterns. Perturbation levels in moderately to severely pathologic speakers were also above the limits of the young and the majority of elderly speakers.

Keywords: HSDI, vocal cord vibration, glottal area waveform, female voice

Aim

The relationship between vocal fold (VF) vibration and voice quality (VQ) has been the source of numerous investigations [1-5]. While this research suggested that several acoustic and physiologic features might be used to differentiate voices, a direct acoustic relationship to accurately differentiate dysphonias has not been established. In Chapter 1, we reported on these relationships for normal voice in groups of females and males using HSDI and image processing methods.

Here we examine pathological voices using the same technology and methods. The specific aim of this study was to characterize dysphonic voices based on deviations from normal in terms of periodicity, perturbation, and open-closed timing characteristics.

Introduction

Information about VF vibration is crucial in understanding the mechanism of normal and abnormal voice production. The relationship between VF vibrations and VQ in dysphonic voices is not clear-cut. Historically the relationship between the two has been studied with various techniques such as acoustic, aerodynamics, and LVS [6-11]. With the exception of LVS, these techniques provided information regarding voice output from both the vocal tract and the glottal source. The main drawback in using these techniques is that the glottal source information has to be inferred by subtracting the vocal tract filter effect [12]. In conditions of aperiodic voices, these inferences are hard to make and understanding glottal characteristics for disordered voices remain problematic [13].

The one exception, LVS, introduced a novel way of visualizing the rapid VF vibrations and opened new doors to the study of vocal function [6-8, 14-17]. It uses a stroboscopic light that flashes at periodic intervals of VF fundamental frequency to reconstruct an
illusion of a still image. A slow motion image can be obtained by flashing the strobe lights at intervals that slightly offset the glottal fundamental frequency. Although useful in studying normal and periodic vocal vibrations, LVS easily misses details of cycle-to-cycle events, especially in dysphonic voices in which aperiodicity is the main characteristic [7-8].

High-speed imaging on the other hand enables visualization of each cycle, but until recently was not clinically practical. In the last four decades, a substantial amount of information on VF vibratory dynamics has been obtained from the analysis of laryngeal images acquired from high-speed photography. Among the earliest and most useful works were those by von Leden et al. [18-20], whose works on high-speed cinematography image analysis of a few minutes of vibration provided the initial bases of understanding of VF vibration. Despite the impressive amount of information obtained from their studies, the equipment used then was clinically impractical (see Chapter 5 in Volume I of this publication).

During the last decade new state-of-the-art technology using solid-state cameras and digital imaging has been introduced for laryngeal imaging [9, 21-23]. The newer digital imaging technology has not only drastically reduced the size of the camera, but has also made the equipment more user-friendly by incorporating tools for simultaneous capturing of the acoustic and laryngographic signals. In addition, recent advances in digital image analysis techniques and improved computer storage capability have recently spurred a resurgence of interest in using high-speed digital imaging (HSDI) for studying VF vibrations in the clinical population [24-28].

Unfortunately for clinical users, the database of normal speakers on which to compare laryngeal disorders is scarce. It is unknown for example how VF imaged with this technique differ by age or gender. Also unknown is how VF vibration differs with changes in phonatory tasks in speakers without voice complaints. Without this information, identification of what is normal and disordered is problematic.

Methods

Subjects were grouped based on voice severity judged by a consensus of three expert judges using the GRBAS perceptual voice evaluation scale developed by Hirano [14]. Four-point equal appearing intervals to reflect normal, mild, moderate and severe were assigned to several descriptors of voice quality such as grade (G), roughness (R), breathiness (B), asthenia (A), and strain (S). All subjects were previously examined and diagnosed by board-certified otolaryngologists and speech pathologists (with a minimum of five years experience in treating voice disorders). After a full record of physical and voice history was obtained, the subjects were instructed regarding the recording procedure and the protocol. The procedure followed was identical to that used for the normal subjects as described in Chapter 1 of this volume.

Results

Vibratory patterns from pathology speakers

Vibratory characteristics from speakers with voice pathology differ within and across disorders. The pathologies included non-specific dysphonia, VF cysts, VF nodules, laryngeal papilloma, adductor spasmodic dysphonia, unilateral VF paralysis with diplophonia, and muscle tension dysphonia (Table 1).
Table 1. Profile of the 10 subjects with voice pathology bydiagnosis and severity.

<table>
<thead>
<tr>
<th>Laryngeal / vocal pathology</th>
<th>Sex</th>
<th>Age</th>
<th>GRBAS</th>
<th>Voice Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Non-specific dysphonia*</td>
<td>F</td>
<td>35</td>
<td>00000</td>
<td>Normal</td>
</tr>
<tr>
<td>2 Left VF cyst</td>
<td>M</td>
<td>32</td>
<td>00000</td>
<td>Normal</td>
</tr>
<tr>
<td>3 VF cyst</td>
<td>F</td>
<td>19</td>
<td>21211</td>
<td>Mild-moderate</td>
</tr>
<tr>
<td>4 VF cyst</td>
<td>F</td>
<td>41</td>
<td>11211</td>
<td>Mild-moderate</td>
</tr>
<tr>
<td>5 Right VF nodule</td>
<td>F</td>
<td>35</td>
<td>22212</td>
<td>Mild-moderate</td>
</tr>
<tr>
<td>6 Adductor spasmodic dysphonia*</td>
<td>F</td>
<td>46</td>
<td>21113</td>
<td>Mod-severe</td>
</tr>
<tr>
<td>7 Diplophonia-UVP</td>
<td>M</td>
<td>42</td>
<td>23321</td>
<td>Mod-severe</td>
</tr>
<tr>
<td>8 Respiratory Pappilloma</td>
<td>F</td>
<td>38</td>
<td>33112</td>
<td>Mod-severe</td>
</tr>
<tr>
<td>9 Respiratory Pappilloma</td>
<td>M</td>
<td>33</td>
<td>33333</td>
<td>Mod-severe</td>
</tr>
<tr>
<td>10 Diplophonia-MTD*</td>
<td>F</td>
<td>39</td>
<td>32213</td>
<td>Mod-severe</td>
</tr>
</tbody>
</table>

* no identified lesion

From the analysis of their GAW, regardless of pathology, speakers with mild voice symptoms showed patterns largely overlapping with normal young and elderly speakers (Figure 1). Speakers with moderate and severe symptoms vary in their vibratory patterns, as they: 1) may exhibit more exaggerated vibratory patterns of breathiness or pressedness or both; 2) may tend to align more to pattern IV (non-specified); or 3) may show unique vibratory features described previously. Perturbation levels in moderate to severe cases exceeded the limits of normal young and the majority of elderly speakers (Figures 2 and 3).

Two speakers with intermittent diplophonia from different pathology (one with muscle tension dysphonia (MTD) with no structural abnormalities, and another with unilateral vocal cord paralysis (UVFP) provided useful vibratory information. In the first case of MTD, the GAW showed changes in the character of the VF vibration from the normal voice to the ‘diplophonic’ voice (Figure 4a).

Prior to the change, GAW showed a uniform breathy-like voice waveform (Figure 4b). At the point of change, frequency and amplitude of the cycles changed into two distinct bands (Figure 4c-e). The glottal area waveform showed bicyclic pattern of vibration, which can be better demonstrated from the montaged series shown in Figure 4f. In the first cycle, opening of the glottis started from the anterior and continued toward the posterior. Afterward, maximum opening closure began from the posterior to the anterior. However, in the next cycle opening began from the medial to lateral. In the third cycle, the pattern was repeated with opening from the anterior to the posterior. This alternate pattern of vibration could be seen throughout the entire phase of the diplophonia.

The Nyquist plot showed two concentric rings that reflected the double tones produced (Figure 4g). The frequency difference between the two tones was 45 Hz. In a series of examinations, it was confirmed that the appearance of the rings was associated with the perceived quality of the diplophonic voice with a predominantly strain character on GRBAS score. The perturbation plot showed the distinct separation in terms of frequency and amplitude during the diplophonic stage (Figure 4h).
Figure 1. Nyquist & perturbation plots and image series for (A) a male singer with left VF cyst and (B) a female singer with no visible pathology. Both subjects had voice complaints but perceptually normal voices. Nyquist for both showed pressed voice patterns but normal perturbation.

Figure 2. Nyquist plots, image series, and GAW of VF cysts or nodules producing moderate voice symptoms. GAW for (A) and (B) indicated a more open glottis and Nyquist plots showed a more breathy voice pattern. GAW for (C) showed a longer closed phase with a mixed pattern of pressedness and breathiness in the Nyquist plot.
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Figure 3. Nyquist & perturbation plots and GAW of sustained /i/ phonation from two young subjects with moderate to severe voice symptoms caused by Respiratory Papillomatosis. Nyquist plots and perturbation values for (A) a female showing exaggerated pressed voice and (B) a male with exaggerated breathy voice patterns.

In the speaker with UVFP the GAW showed 3-period cycles repeating itself with a certain regularity. Inspection of a series of 10-11 cycles showed that the first two cycles shared the same frequency but had different amplitudes, whereas the 3rd cycle had almost the same amplitude as the second cycle but differed in the frequency (Figure 5a-b).

The Nyquist plot looks like a spiral from three concentric bands and the perturbation plot shows clearly the three clusters of amplitude and frequency—two clusters sharing the same frequency and another two sharing the same amplitude (Figures 5c-e).

Perturbation values in these two dysphonic voices were high compared to normal speakers (jitter of up to 14% and shimmer of up to 30%). Unlike the previous case of MTD, the Nyquist did not show any pressed vibratory pattern but rather the larger scatter associated with breathiness. Thus, these two examples of diplophonia with different perceptual qualities also have very different Nyquist plots, which highlight the unique features of each voice.
Figure 4. (a) GAW from 2000 frames of images from one subject with moderate to severe symptoms of diplophonia caused by MTD. The enlarged view of the segment (b) preceding the diplophonia showing periodic vibration and (c) during the diplophonic voice quality showing the bicyclic vibration. (d) Frequency variation plot showing the sudden change in the cycle-to-cycle frequency. (e) Enlarged view of the frequency variation during the diplophonic phase. (f) Image series of the alternating open-close glottal behavior during the diplophonic phase. (g) Nyquist plot illustrating the two concentric rings and (h) perturbation plot showing the two separate clusters of frequency and amplitude, also during the phase of diplophonia.

Adductor Spasmodic Dysphonia

The vibratory patterns in a case of adductor spasmodic dysphonia showed signs of voice irregularities, voice stoppages, and spasms (Figure 6). These VQ features have been described previously [29]. GAW during the spasmodic episodes showed features of interrupted phonation of variable durations. During the phonatory segments there were initial overpressure in the vibratory cycles that rapidly gave way to a more open glottal configuration. Toward the end of the phonatory segment however the amplitude of the cycles gradually decayed and vibrations halted. At this juncture, VF remained stationary in the phonatory position. After some duration of time, the vibratory amplitude began to rapidly build up again and the cycles of activities repeated throughout the phonation. Jitter was 25% and shimmer was 18%.
**Figure 5.** (a) GAW from a subject with diplophonia caused by unilateral VF paralysis (UVFP); (b) image series showing the 3-cycle pattern illustrated by the GAW; (c) cycle-to-cycle frequency variation plot showing the separation of the frequency bands; (d) perturbation plot; and (e) Nyquist pattern showing the tricyclic vibratory behavior.

**Figure 6.** (a) GAW from a subject with adductor spasmodic dysphonia; (b-d) enlarged view of the GAW taken from different parts of the phonation segment following and preceding the voice break; (e) Nyquist and (f) perturbation plots for part of phonation.
Discussion

The present study indicated that speakers with minimal voice symptoms, but whose voices were perceived as normal, showed vibratory patterns similar to normal speakers. However, those with mild-to-moderate voice symptoms demonstrated vibratory patterns of exaggerated normal patterns of pressed and/or breathy voice patterns. Speakers with more severe pathology demonstrated vibratory patterns that deviated altogether from normal in terms of periodicity, perturbation, and open-close timing characteristics. These findings were consistent with long established views that voice qualities were to a large extent determined by the vibratory behavior at the glottal level [30]. It also suggested that the measures of periodicity, open-closed timings, and perturbation as obtained with the present analytic technique were reliable measures of voice severities.

Data from the present study of speakers with voice pathology highlighted the usefulness of using a single visual pattern to represent salient vibratory features. Several researchers had also suggested the use of patterns rather than single features to reflect disordered voices [4, 31]. Visual patterns should be useful for clinicians as the patterns could easily be compared with control normals. Serial patterns during the course of treatment could also be used for tracking treatment progress.

Conclusions

The present studies demonstrate the use of HSDI technique in investigating the vibratory characteristics of pathology speakers. Vibratory patterns in voice-disordered groups vary with pathology and severity. They may show exaggerated, mixed, or deviant vibratory patterns from the normal speaker patterns. Perturbation levels in moderate to severe pathology speakers were also above the limits of the young and the majority of elderly normal speakers.

References


