Acoustic Signs of Supraglottal Constriction in Pathological Voices

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Abstract

Purpose: This study aims to identify the acoustic signs of supraglottal constriction and effects of some vocal manipulation techniques. It is hypothesized that some task-related acoustic contrasts would differ between voice patients with and without supraglottal constriction due to different vocal tract configurations. **Method:** Classified through videostroboscopic examinations, 30 participants were gender and age-matched to form two comparison groups ("constricted" and "non-constricted"), with five males and ten females in each group. Participants were asked to sustain a vowel (/a/ or /i/) for approximately three seconds in five tasks, including normal-pitch, low-pitch, high-pitch, /m/-onset (i.e., with the consonant /m/ preceding the vowel at normal pitch), and /h/-onset tasks. Acoustic signals were analyzed to extract measures from the mid-portion of the vowel. **Results:** The "constricted" group showed a lack of task-related contrasts on signal-to-noise ratio, singing power ratio, frequency of the second formant, and the amplitude difference between the first formant and the first harmonic. **Conclusion:** Further investigations are needed to assess the predictive power of the proposed task-based acoustic approach for detecting supraglottal constriction.

Introduction

Supraglottal constriction is a type of vocal tract constriction related to the narrowing of the space above the true vocal folds due to movement of supraglottal structures (Stager, Neubert, Miller, Regnell, & Bielamowicz, 2003). As supraglottal cavities, along with nasal and oral cavities, determine the resonance for the sound waves generated at the glottal source, supraglottal constriction may affect some acoustic measures of voice. For example, vocal tract constriction has been found to have an impact on formant frequencies (Chiba & Kajiyama, 1941; Bickley & Stevens, 1986; Fant, 1980; Kent, 1993; Story, Laukanen & Titze, 2000). Changes of the acoustic pressure in the vocal tract due to vocal tract constriction may also affect patterns of vocal fold vibration such as the open time in a glottal cycle (Bickley & Stevens, 1986; Story, Laukkanen, & Titze, 2000). As supraglottal constriction is often found in voice patients with incomplete vocal fold closure or excessive muscle tension, such as those referred to as having "dysphonia due to muscle imbalance" (Coyle, Weinrich, & Stemple, 2001), investigations on the acoustic signs of supraglottal constriction in pathological voices may provide information useful for assessing and modifying its associated voice quality and vocal behaviours.

Assessment of Supraglottal Constriction: Identification of supraglottal constriction normally requires visualisation of the vocal fold movement through videostroboscopy (Stager et al., 2003). As most of the current visual rating scales are not sensitive enough to changes in the positions of the supraglottal structures (Stager et al., 2001), development of more sensitive measures are needed. The acoustic measures most commonly used for general voice evaluation include fundamental frequency (F0), pitch range, loudness, maximum phonation time, and vocal stability. Acoustic measures related to vocal tract configuration may involve a frequency-domain analysis. Firstly, a spectral measure that has been related to voice quality is the amplitude of the first harmonic (H1). The H1-H2 amplitude difference has been found to be inversely related to the perception of harshness/roughness and positively to breathiness (Kreiman & Gerratt, 1998). Secondly, as vocal tract constriction has been shown to have an impact on formant frequencies, measures of formant frequencies may be useful for differentiating between voices with and without supraglottal constriction. Formant frequencies are the spectral envelope peaks representing the resonance characteristics of the vocal tract. It is well recognised that identification of a vowel is based on the relative loci of the first two to three formant frequencies (Peterson & Barney, 1956; Smith & Scott, 1980; Ryalls & Liebermen, 1982; Hillenbrand & Gayvert, 1993). The frequencies of Formant one (F1) and Formant two (F2) have been found to be affected by the forwardness and the height of the tongue, the size of the oral and pharyngeal space, and the overall length of the vocal tract (Baken & Orlikoff, 2000). Specifically, F1 frequency is affected by the space between the glottal level and the point of the highest tongue position and is altered by the tongue height while F2 frequency is associated with the region in the front of the tongue and is altered by tongue retraction and protrusion. Thirdly, a measure of spectral slope termed "singing power ratio" (SPR) can be extracted from a long-time average (LTA) spectrum to reflect the vocal tract effect on the amplification or suppression of the harmonics generated from the voicing source (Pershall & Boone, 1987). The SPR measure is defined as the energy ratio between the highest spectral peak in the 2-4 kHz frequency range, which is the region where the singer's formant is normally located, and that between 0 and 2 kHz (Pershall & Boone, 1987). Having been related to the power of voice projection (Omori, Kacker, Carroll, Riley, & Blaugrund, 1996), the SPR measure can be used to quantify the resonant quality of the singing voice (Lundy, Roy, Casiano, Xue, & Evans, 2000). For example, trained classic singers have been found to exhibit a lower SPR, indicating a relatively higher level of energy around the frequency range between 2 and 4 kHz, as compared with untrained singers (Barrichelo, Heuer, Dean, & Sataloff, 2001) or singers whose voicing techniques may involve counterproductive vocal behaviours such as laryngeal constriction (Burns, 1986; Stone, Cleveland, & Sundberg, 1999).

Research Questions

Are the inter-task variations of the selected acoustic measures affected by "supraglottal constriction"?

Methods

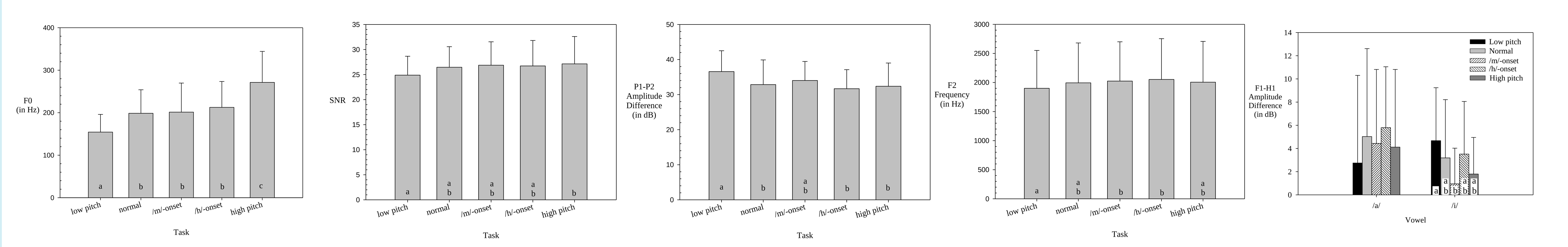
Participants: Fifteen voice patients (5 males and 10 females) identified clinically by the attending speech therapist or otolaryngologist as showing supraglottal constriction and 15 gender and age-matched (within six years of age difference) voice patients as showing "no or very mild constriction" were selected for comparison. The age of the 30 participants ranged from 21 to 79 years. The mean age of the "constricted" group was 42.1 years (SD = 39) and the "non-constricted" group 42.4 years (SD = 35). The voice problems in both "constricted" and "non-constricted" groups were associated with a variety of vocal fold pathologies, including benign mass lesions of the vocal folds, vocal fold paralysis, and functional voice disorders. **Participant's Task:** Participants were asked to sustain a vowel (/a/ and /i/ respectively) for approximately three seconds at a constant loudness level in five different tasks, including normal-pitch, high-pitch, low-pitch, /m/-onset (i.e., vowel preceded by the consonant /m/ at normal pitch), and /h/-onset (i.e., vowel preceded by the consonant /h/ at normal pitch) tasks. Three trials were recorded for each task.

Instrumentation: The acoustic recording system included a headset microphone (AKG C420) and a mixer (Eurorack MX602A). The output of the microphone amplifier was connected to an A/D converter (National Instrument DAQCard-AI-16E-4) via a SCB-68 68-pin shielded connector box. The connector box contained a low-pass filter for the acoustic signals to be low-passed at 20 kHz. The sampling rate for signal digitization was set at 44.1 kHz. Locally developed algorithms written in MATLAB 12 (The Mathworks, Inc.) was installed in the laptop for signal acquisition. The TF32 software (Milenkovic, 1987) was used to extract acoustic measures.

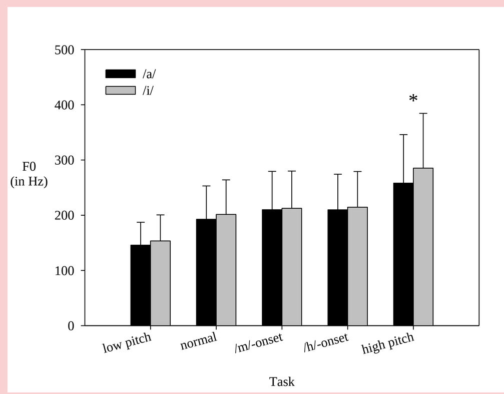
Measurement: The time-based measures employed in this study included F0, percent jitter (%jitter), percent shimmer (%simmer), and signal-to-noise ratio (SNR). The frequency-based measures included F1 and F2 frequencies, the amplitude differences between the first two harmonics ("H1-H2 "), between F1 and H1 ("F1-H1"), and between the spectral peak in the frequency range from 0 to 2 kHz and that in the frequency range from 2 to 4 kHz ("P1-P2 amplitude difference" or SPR).

Results

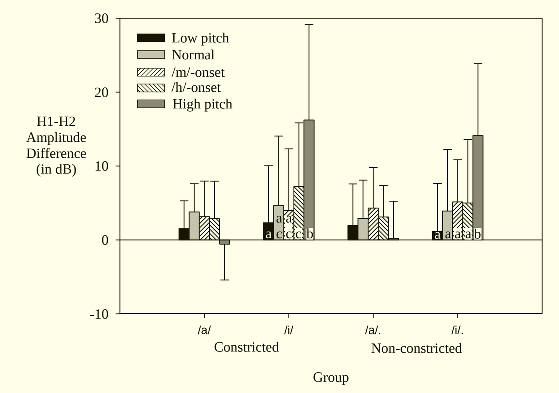
"Non-constricted" Group:



"Constricted" Group:



Summary: Results from a series of two-way (vowel by task) Repeated Measures Analysis of Variances revealed that the task effect was more evident in the "non-constricted" group than in the "constricted" group. For both "constricted" and "non-constricted" groups, there was a significant task effect on F0 and H1-H2 amplitude difference. However, a significant task effect was found only in the "non-constricted" group but not in the "constricted" group for SNR, F2 frequency, F1-H1, and SPR ("P1-P2 amplitude difference"). These findings indicate that supraglottal constriction may be characterized by a lack of task-related acoustic contrasts on these measures. Statistical results of the experimental measures showing a significant task or vowel by task interaction effect were illustrated in figures.



Conclusion

Supraglottal constriction may have a causative or reactive association with voice disorders. Identification of task-related vocal changes symptomatic of supraglottal constriction may assist in the development of an efficient monitoring tool for managing voice problems. The present findings indicate that most task-related acoustic contrasts could be found in voice patients without supraglottal constriction but not in those with supraglottal constriction. Therefore, the acoustic measures shown to be affected by task in the "non-constricted" group alone may have the potential to be used as an objective screening tool for the detection of supraglottal constriction. Specifically, a lack of consistent between-task variation in the measure of SNR, SPR, F2 frequency, and F1-H1 amplitude difference may be taken as a sign of the presence of supraglottal constriction. The lack of the context-related (i.e., isolated vowels vs. vowels preceded by /m/ or /h/) acoustic contrasts in the "constricted" group may be related to the confounding factors related to the altered vocal tract configuration immediately above the larynx. Follow-up studies are needed to assess the sensitivity and specificity of the identified acoustic measures employed in this task-based approach for the detection of supraglottal constriction.

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