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Immediate acoustic effects of straw phonation exercises in subjects with dysphonic voices

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Abstract

This study sought to measure any acoustic changes in the speaking voice immediately after phonation exercises involving plastic straws versus phonation exercises with the open vowel /a/. Forty-one primary school teachers with slightly dysphonic voices were asked to participate in four phonatory tasks. Phonetically balanced text at habitual intensity level and speaking fundamental frequency was recorded. Acoustical analysis with long-term average spectrum was performed. Significant changes after therapy for the experimental group include the alpha ratio, L1–L0 ratio and ratio between 1–5 kHz and 5–8 kHz. The results indicate that the use of phonatory tasks with straw exercises can have immediate therapeutic acoustic effects in dysphonic voices. Long-term effects were not assessed in this study.

Key words: *Dysphonia, long-term average spectrum (LTAS), resonance tube, semi-occlusion, voice analysis, voice therapy*

Introduction

Exercises with partial occlusion or lengthening of the vocal tract have been widely used in voice therapy for both the singing voice and the speaking voice. The goal of these exercises is to produce an increase in input impedance of the vocal tract (1). While the techniques vary, occlusion is typically within the front part of the oral cavity or at the lips. Tasks include phonating with nearly occluded lips, producing voiced fricatives, stop consonants, nasal consonants, lip trill, tongue trill, y-buzz, or phonating into narrow hard-walled tubes of varying diameters and length as an extension of the vocal tract (2–5). Some vocal exercise programs are based on vocal tract semi-occlusions such as the Lessac–Madsen Resonant Voice Therapy method by Verdolini (6) and Stemple's Vocal Function Exercises (7).

Resonance tubes are used in two ways: leaving the distal end open to air or submerging the distal end in water. In both cases the tube acts as an artificial extension of the vocal tract. The name 'resonance tube' comes from the strong sensations of vibrations that are felt in the lips and face during phonation into these tubes (8). A more widely available alternative to resonance tubes is using plastic straws. According to Titze two types of straws can be used: very narrow 'stirring' or coffee straws, or the wider 'drinking' straw (9,10).

Such exercises have been used by people with normal voices as vocal warm-up or for voice training (11–14) to achieve a clear, bright, and resonant sound (5). In the therapeutic field, resonance tubes have been applied in cases of both hyperfunctional dysphonia and hypofunctional dysphonia (15–17). Resonance tubes have also been used to treat unilateral vocal fold paresis and other vocal pathologies (18). Moreover, some authors suggest that exercises on voiced fricatives increase breath management in singing (19) and may improve breathing in general (20,21). Phonating into tubes has also been used in speech therapy for the treatment of hypernasality (15,16,22).

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While there are little to no experimental data regarding the effects of vocal tract semi-occlusion, there are theoretical and experimental studies that have considered the effects of what is often referred to as vocal tract loading (3,23–31). Authors have proposed that the vocal tasks such as narrow anterior constriction or an artificial lengthening of the vocal tract induce an increase in vocal tract impedance, specifically resulting in changes in the inertive reactance (3,31) which may favorably impact the vocal fold vibration (3,29,31–33). Increased inertive reactance changes the glottal flow amplitude and pulse shape (31,34–36). Furthermore, the oscillation threshold pressure is reduced by increased vocal tract inertance (31). According to Story et al. (3) this occurs when F0 approaches F1. Therefore, phonating at a frequency at or near the first formant may allow for an efficient voice production that could possibly be associated with lower effort.

Vocal tract impedance appears to impact at least two components of voice source function: 1) glottal flow pulse, and 2) vibrational characteristics of the vocal folds. The acoustic pressures propagating in the vocal tract affect the glottal flow pulse shape and hence the overall harmonic energy in the acoustic output signal. The second component is the mechano-acoustic interaction of the vocal tract pressures which influence the vibrational characteristics of the vocal folds (3).

Titze (37) discussed a computer simulation study which suggests that phonation can be made more efficient through impedance matching between the voice source and the vocal tract. Impedance matching can be accomplished by using therapy techniques involving either semi-occlusion of the lips or a combination of adjustments in vocal fold adduction and epilaryngeal constriction.

Epilaryngeal constriction can be accomplished by narrowing the lower part of the vocal tract. This change may lower the phonation threshold pressure, which is the minimum subglottal pressure required to initiate and sustain phonation (33). Low values of threshold pressure suggest ease of phonation. In the same study, Titze also noted an increased skewing of the glottal flow waveform (faster cessation of the flow) leading to strengthening of the higher harmonics and an increase in sound pressure level (SPL).

Titze et al. (9) also observed a lower amplitude and a lower relative closed time of the glottis on an EGG signal when phonation into straws was compared to traditional vowel phonation. With narrow straws, it is possible to use the high subglottal pressures needed in singing, while having minimal collision of the vocal folds. What drives the vocal folds is the transglottal pressure, i.e. the difference between the subglottal and the supraglottal pressure. A downstream occlusion increases the supraglottal pressure and hence reduces the transglottal pressure. High subglottal pressures are not necessarily needed in singing; instead rather moderate transglottal pressures are optimal, reducing the need for adductive force. This is consistent with Laukkanen et al. (27). Occlusion of the vocal tract makes it possible to lower the transglottal pressure (which is desirable) even if the subglottal pressure is high. So with narrow straws, the control of subglottal pressure to achieve low values becomes less crucial and easier to manage for less trained voice users.

Bickley et al. (24) reported similar findings in their study of EGG waveforms produced by six subjects using hard-walled tubes at the lips during voicing. For constrictions with cross-sectional areas smaller than 0.1 cm^2, the open phase of the glottal cycle was shown to increase by over 20% relative to the unconstricted segment. Similar increases were reported for the same six subjects during production of voiced fricative consonants. Constrictions with areas greater than 0.2 cm^2 had little effect on altering the open phase duration, thus vocal fold oscillation. Vocal fold oscillation was influenced by articulatory or artificially imposed supraglottal constrictions. Gaskill and Erickson (38) studied the effect of a voiced lip trill on estimated glottal closed quotient (CQ) of the electroglottographic signal in classically trained singers and vocally untrained participants. Most participants showed a tendency for a reduction in CQ during the lip trill, with a more pronounced change in the untrained participants.

Laukkanen et al. performed several studies (25,27,2) with subjects phonating into resonance tubes of varying lengths and diameters. Changes in several different variables both during and after tube phonation were reported across these studies, including glottal waveform shape, laryngeal height, glottal efficiency, laryngeal resistance, and perceived vocal effort.

According to Laukkanen et al. (27) the average laryngeal muscle activity assessed with electromyographic signals was the same or lower during phonation using a resonance tube compared to during vowel phonation. These results suggest that during sufficiently increased impedance of the vocal tract the laryngeal muscle activity tends to decrease and that it also stays lower in vowel phonation immediately after exercising.

Aderhold (39) described improvements in vocal resonance following exercises of phonating while holding one's hand at the lips, partially covering the mouth. Furthermore, Aderhold suggested that in resonant voice there should be only a narrow pathway between the tip of the tongue and the alveolar ridge. Similarly, Lessac (5) promoted the use of the 'y-buzz' for vocal training which is a closed front vowel with a tight linguopalatal constriction and narrow spacing between the upper and lower teeth; the lips are also slightly protruded. The 'y-buzz' is said to provide a rich vocal quality in the *lower* ranges of the voice, protect against strain and 'throatiness', and induce a relaxed vocal production.

The goal of the present study is to determine any measurable acoustic changes in the speaking voice immediately after phonation exercises involving straws, in subjects with slight dysphonia.

Method

Demographics

Forty-one primary school teachers with slightly dysphonic voices volunteered for this study (25 women and 16 men) and were included. Subjects were recruited from five different schools. The grade of dysphonia was assessed using the GRBAS scale by one of the authors of this article (M.G.) who has more than ten years of experience in voice clinics. All participants were rated grade 1 for the degree of both dysphonia (G) and breathiness (B) on the GRBAS scale. The average age of subjects was 35.78 years, with a range of 23–58 years. All subjects denied a history of vocal therapy prior to enrollment in this study. Participants were divided into two groups: an experimental group ($n=24$) and a control group ($n=17$). All of them were asked to attend a single recording and training session lasting no more than 30 minutes. This session included voice recordings for both groups. For the experimental group, the session included voice training with straw phonation exercises, whereas for the control group, the session included voice training with the open vowel /a/.

Voice recordings

Subjects were recorded twice (before and after vocal exercises) during a read-aloud task of a 242-word phonetically balanced text, at habitual intensity level and speaking fundamental frequency. The duration of each recording was approximately 90 seconds. A Tascam Pre-amplifier plus an analog/digital converter, model US-122L, and a condenser microphone Samson, model MM01, were used to capture the voice samples before and after voice therapy. This microphone was selected on the basis of the manufacturer's specifications including a flat frequency response from 20 to 20,000 Hz. The microphone was positioned 10 cm from the mouth of the participants, who remained seated on a stool. Recording took place in a soundproof booth, and samples were recorded digitally in a WAV format at a sampling rate of 44.1 KHz with 16 bits/samples quantization. The capture and recording of voice signals were made using the software Goldwave V5.57 installed on a Sony Vaio laptop Y-210. Participants were asked to produce the same vocal intensity during recordings pre and post vocal training. Intensity level was controlled by one of the experimenters of this study using a sound level meter (American Recorder Technologies, model SPL-8810). This is crucial, since SPL is not linearly correlated to the spectral envelope; an increase in SPL does not correspond to the same increase in decibel at all frequencies of the spectrum. Audio signal was calibrated using a 220 Hz tone at 80 dB produced with a sound generator for further sound level measurements. The SPL of this reference sound was measured with the sound level meter, also positioned at a distance of 10 cm from the generator.

Phonatory tasks

For the experimental group, exercises consisted of a sequence of four phonatory tasks performed with plastic commercial stirring straws of 3 mm inner diameter and 22.8 cm in length. The straw was maintained a few millimeters in between the rounded lips, so that no air would leak from the mouth, and the free end was kept in the air as an extension of the vocal tract. Participants were aware that nasal air leaking should be prevented during the exercises. They also were asked to feel perceptible vibratory sensations in the alveolar ridge, face, and head areas. Titze (40) affirmed that when the energy conversion process at the glottis is efficient, the vibrations are distributed all over the head, neck, and thorax. When the energy conversion process is poor, the vibrations are likely to remain more local. He also states that a more likely resonance is a reinforcement of vocal fold vibration by an inertive vocal tract, which feeds energy back to the source of sound, thereby strengthening its harmonic content. Since the irradiation orifice from the straw is so small that very little sound can escape, participants were asked not to try to create a loud sound during the exercise sequence.

For the control group, exercises consisted of a sequence of four phonatory tasks with the open vowel /a/. The phonatory tasks were the same performed by subjects from the experimental group.

Phonatory exercises included:

1. To phonate a sustained vowel-like sound into the straw using their habitual speaking pitch and volume. The vowel /a/ was used for participants from the control group instead of phonation into a straw.
2. Ascending and descending glissandos into a straw through a comfortable vocal range. No

specific minimum or maximum fundamental frequency was asked for.

3. Pitch and loudness accents into a straw using the respiratory support mechanism, mainly abdominal muscles contraction. This exercise was explained through practical demonstration, and the accents were performed in an upward F0.
4. Singing the melody of the song 'Happy Birthday' into the straw.

Before training, one of the authors provided individual demonstrations and verbal descriptions of each phonatory task. Participants had an opportunity to ask questions. Although subjects had been provided with examples of each exercise, they were instructed to produce their own versions. The sequence of straw exercises used in this study was based on the sequence proposed by Titze (10).

The duration of the complete exercise sequence was 10 minutes for both experimental and control groups. Each task was performed for 2.5 minutes so participants were able to perform each phonatory exercise several times. Subjects were allowed to breathe freely whenever they needed. Immediately after training the second recording was collected for which the subjects were asked to read the same 242-word phonetically balanced text at a habitual intensity level.

Samples were edited with the software Goldwave, version V5.57. The recording amplitude level was controlled with the waveform signal to assure a stable audio signal between samples pre and post training. Acoustical analysis with long-term average spectrum (LTAS) was performed.

Acoustic analysis

Long-term average spectrum is widely accepted as a powerful and effective tool for assessment of both glottal source and vocal tract filter characteristics in the quality of a voice. It is a fast Fourier transform-generated power spectrum whose properties can be compared with a Gaussian bell curve using spectral moments analysis (41). This analysis provides a means of viewing the average frequency distribution of the sound energy in a continuous speech sample. LTAS has been applied in different kinds of studies such as speaker recognition (42,43), voice qualities (44), voice disorders (45,46), aging voice (47,48), evaluation of techniques of voice therapy (41,49,50), and gender differences (51–54).

In the LTAS window, the acoustical variables in this study were the level difference between the F1 and F0 regions (L1–L0), that is, the level difference between 300–800 Hz and 50–300 Hz, which provides information on the mode of phonation; the ratio between 1–5 kHz and 5–8 kHz, which may provide information about noise in the glottal source (breathy voice quality) (55); and the alpha ratio, that is, the level difference between 50–1,000 Hz and 1–5 kHz, which provides information on the spectral slope declination. Hypofunctional voice production and soft phonation are typically characterized by a small alpha ratio, whereas alpha ratio is relatively large in hyperfunctional and loud voice production. Alpha ratio has been found to change significantly during a vocally loaded work-day (56,57).

The LTAS spectra for each subject were obtained automatically by Praat program, version 5.2 Praat (58). For each sample the Hanning window and a bandwidth of 100 Hz were used. At least 80 seconds of each sample were analyzed. To perform the LTAS, unvoiced sounds and pauses were automatically eliminated from the samples by Praat software using the pitch-corrected version with standard settings (47). Since we are interested only in the phonatory source, it is necessary to eliminate voiceless sounds such as fricatives, which otherwise would mask the high-frequency content of the voiced sound (59).

Because loudness variations can affect the intensity in higher spectrum partials, the amplitude values of the spectral peaks were normalized to control for loudness variations between subjects. This process was accomplished automatically by assigning the intensity of the strongest partial a value of 0 and each subsequent partial a proportional value compared with this peak intensity. Speaking fundamental frequency and equivalent sound level (Leq) were also measured before and after voice training with stirring straw and vowel /a/ for the experimental and control groups, respectively.

Statistical analysis

Descriptive statistics were calculated for the variables, including 95% confidence intervals for means. Paired *t* test for means was used to determine the statistical significance between pre and post treatment measures, and unpaired *t* test to compare experimental versus control group measures (pre and post treatment difference). In addition, Pearson correlation coefficient (*r*) was calculated for the pre and post treatment difference, to analyze the correlation between the variables and observe their relationship. An alpha of 0.05 was used for the statistical procedures (this 'alpha' is not the same as the spectral alpha ratio discussed in previous sections). Stata 12.1 (StataCorp, 2008; College Station, TX: StataCorp LP) statistical software was used for analysis.

This study was approved by the research ethics committee of the School of Communication Disorders of the Austral University of Chile.

Table I. Pre-treatment, post-treatment, and confidence intervals for mean values for acoustic measures of LTAS in the experimental group.

Variable	Pre-treatment (mean (95% CI))	Post-treatment (mean (95% CI))	*P* value
Alpha ratio	–21.8 (–22.8; –20.7)	–18.59 (–20.08; –17.1)	< 0.0001
L1–L0 ratio	–1.95 (–3.1; –0.7)	0.13 (–1.1; 1.3)	0.0001
1–5/5–8 ratio	–9.27 (–10.9; –7.5)	–10.79 (–12.3; –9.2)	0.0257

Results

Table I shows pre-treatment, post-treatment, and confidence intervals for mean values of acoustic measures of LTAS of the experimental group. The mean alpha ratios were –21.8 dB and –18.59 dB, respectively, for pre-treatment and post-treatment voice samples. The mean L1–L0 values were –1.95 and 0.13 dB, respectively, for pre-treatment and post-treatment. The mean ratio between 1–5 KHz and 5–8 KHz were –9.27 and –10.79 dB respectively, for pre-treatment and post-treatment.

We found a correlation of 37.9% between alpha and L1–L0 ($r = 0.3791$, $P = 0.0677$), a 10.1% correlation between alpha and 1–5/5–8 ($r = 0.1018$, $P = 0.6359$), and a 12.6% correlation between L1–L0 and 1–5/5–8 ($r = 0.1266$, $P = 0.5555$).

Table II shows pre-treatment, post-treatment, and confidence intervals for mean values for acoustic measures of LTAS of the control group. The mean alpha ratios were –21.75 and –21.06 dB, respectively, for pre-treatment and post-treatment voice samples. The mean L1–L0 values were –0.007 and 0.42 dB, respectively, for pre-treatment and post-treatment. The mean ratio between 1–5 kHz and 5–8 kHz were –9.15 and –9.57 dB respectively, for pre-treatment and post-treatment.

Figure 1 and Table III show the results of LTAS parameters when comparing experimental group versus control group pre- and post-treatment differences. Statistically significant differences between the experimental group (3.22 [2.17; 4.26]) and the control group (0.69 [–0.21; 1.59]) for alpha ratio ($P = 0.0008$) were found. Also, significant differences between the experimental group (2.09 [1.13; 3.04]) and the control group (0.43 [–0.65; 1.52]) for L1–L0 ratio ($P = 0.0229$) were found. No statistically significant differences between the experimental group (–1.51 [–3.03; 0.01]) and the control group (–0.42 [–1.34; 0.50]) for 1–5/5–8 kHz ratio ($P = 0.2580$) were found.

Tables IV and V show pre-treatment and post-treatment mean values and confidence intervals for speaking fundamental frequency by gender in experimental and control groups.

The pre-treatment and post-treatment mean Leq and individual values are summarized in Tables VI and VII for experimental and control groups, respectively. The mean Leq measured for the experimental group were 79.03 ± 0.59 dB and 78.23 ± 0.57 dB, respectively, for pre-treatment and post-treatment voice samples. The mean Leq measured for the control group were 79.92 ± 0.79 dB and 80.27 ± 0.73 dB, respectively, for pre treatment and post treatment. The decrease shown for the experimental group was statistically significant ($P = 0.0101$). There were no statistically significant differences between pre and post treatment for the control group ($P = 0.2851$).

Discussion

The present investigation examined acoustical variables of the LTAS as possible objective markers of voice changes after a single session of voice training with straw phonation exercises. To examine whether the three acoustical variables of LTAS were sensitive to perceived voice improvement after voice therapy, this investigation compared pre-treatment and post-treatment voice samples of patients with dysphonia, using several parameters: The alpha ratio, or the level difference between 50–1,000 Hz and 1–5 kHz, which provides information on the spectral slope

Table II. Pre-treatment, post-treatment, and confidence intervals for mean values for acoustic measures of LTAS in the control group.

Variable	Pre-treatment (mean (95% CI))	Post-treatment (mean (95% CI))	*P* value
Alpha	–21.75 (–23.06; –20.43)	–21.06 (–22.55; –19.56)	0.1235
L1–L0	–0.007 (–1.02; 1.01)	0.42 (–0.64; 1.50)	0.4093
1–5/5–8	–9.15 (–10.66; –7.64)	–9.57 (–11.003; –8.14)	0.3478

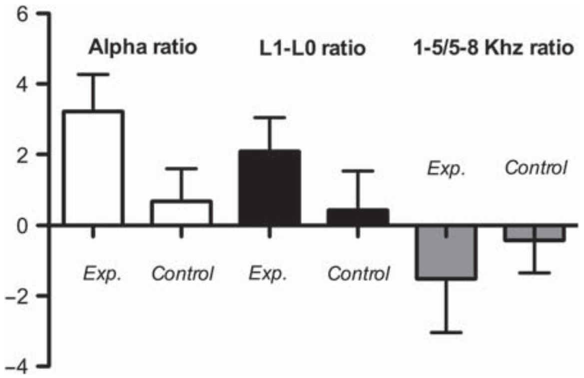

Figure 1. LTAS acoustic parameters, means, and 95% CI for pre- and post-treatment difference, control versus experimental group comparison.

declination; the (L1–L0) ratio, that is, the level difference between 300–800 Hz and 50–300 Hz, which provides information on the mode of phonation; and the ratio between 1–5 kHz and 5–8 kHz which may provide information about noise in the glottal source (breathy voice quality) (55).

Inspection of the results from the experimental group revealed that the alpha ratio and the change in L1–L0 values increased significantly with perceived voice improvement after successful behavioral management ($P = 0.001$). The ratio between 1–5 kHz and 5–8 kHz decreased significantly ($P = 0.0257$). These data suggest a clear immediate effect on spectral characteristics after one single session of vocal exercises with stirring straws.

Results from the control group showed no significant difference between pre and post treatment for alpha ratio, L1–L0, and 1–5 kHz and 5–8 kHz. The comparison of this difference (pre and post) with the difference in the experimental group was statistically different (greater pre/post difference for experimental group) for alpha ratio and L1–L0. No statistically significant difference between the experimental group and the control group for 1–5/5–8 kHz ratio ($P = 0.2580$) was found. Therefore, it is possible to assume that straw phonation exercises produced a greater positive effect than exercises with the open vowel /a/ on the spectral slope declination and mode of phonation in speaking voice analysis in the present study.

There are several methods to measure the difference between the average sound pressure level of stronger regions of the spectrum and the average sound pressure level of the weakest region. This measurement then yields the slope of the LTAS. The alpha ratio, or difference between 50–1,000 Hz and 1–5 kHz, is one of the measures initially proposed by Frokjaer-Jensen and Prytz (60). A high value (more steep) would indicate that F0 and the lower harmonics dominate the spectrum and the curve drops more sharply; and when these values are low, the slope is less pronounced. These measures are related to hypofunctional voices and hyperfunctional voices, respectively. In the present study, a less steep slope was represented by the highest value (less negative, or closer to positive values) because numbers used include negative sign (–). This is the reason why a less steep slope was obtained after voice therapy with increased alpha and L1–L0 ratios.

The different values of alpha ratio are related to the modes of phonation. A hyperfunctional adjustment of the vocal folds produces more intense harmonics by increasing the closed phase of the vibration cycle. This increased velocity of the closed phase results in a modification in the glottal flow wave shape. On the other hand, during phonation with hypoadduction, the harmonics' lost intensity is replaced by noise (61). According to Verdolini et al. (4) and Titze (40), the 'resonant voice' is rich in harmonics, with a lower alpha ratio (less steep spectrum).

Since participants from the experimental group did not increase mean Leq during recordings pre and post vocal training, spectral changes in this study after straw phonation exercises should not be attributable to a total sound level increment, i.e. due simply to a louder voice after treatment. Possibly, the change in alpha ratio in this study (less steep fall of the spectrum slope) after straw exercises may be explained physiologically by an increased skewing or tilt of the glottal flow wave. This suggests a faster closing time of the vocal folds in relation to the open time produced by the use of semi-positions of the occluded vocal tract (3). This would facilitate phonation and produce a strengthening of the higher harmonics (32). The amplitude of higher harmonics is particularly sensitive to the phase velocity of the

Table III. LTAS acoustic parameters means and 95% CI for pre- and post-treatment difference in control versus experimental group comparison.

Pre- and post-treatment difference	Control group	Experimental group	*P* value
Alpha ratio	0.69 (–0.21; 1.59)	3.22 (2.17; 4.26)	0.0008
L1–L0 ratio	0.43 (–0.65; 1.52)	2.09 (1.13; 3.04)	0.0229
1–5/5–8 ratio	–0.42 (–1.34; 0.50)	–1.51 (–3.03; 0.01)	0.2580

Table IV. Pre-treatment and post-treatment mean values, and confidence intervals for F0 by gender in the experimental group.

Gender	Pre-treatment (mean (95% CI))	Post-treatment (mean (95% CI))	*P* value
Male	130.83 (104.50; 157.16)	129.33 (108.26; 150.40)	0.752
Female	226.55 (218.67; 234.44)	224.72 (217.80; 231.64)	0.3336

closing phase of the vibration cycle, i.e. the speed at which the air-flow decreases at the end of the open phase. For example, the faster the speed of closure, the greater the subglottic pressure, and the more intense high harmonics of the spectrum. In other words, the more suddenly the air-jet is interrupted, the higher the sound intensity will be, particularly in the high-frequency components. These physiological and acoustic changes contribute to the production of a perceptually more resonant and bright sound. In this regard, Verdolini (4,62) showed that resonant voice requires an almost abducted or almost adduced position of the vocal folds, noting also that the supra-glottic adjustments contribute to this glottal configuration and therefore the enhancement of the glottal spectrum. Through these physiological and acoustic events it may be stated that the voice can be produced more economically and efficiently. Titze (37) attributed this economy and efficiency to the greatest vocal interaction between the source and filter due to the use of therapeutic techniques that involve semi-occlusion. In a subsequent study, Titze notes that this phonatory economy would be produced by increasing the input impedance of the vocal tract, which affects the shape of the glottal flow pulse and alters the oscillatory characteristics of the vocal folds (63). In this way, the resonant voice may be defined as any production in which the vocal tract assists the sound source in producing acoustic energy. In a study similar to the present one, using two semi-occluded vocal tract exercises (finger kazoo and phonation into tubes), Sampaio (64) demonstrated the immediate effects of both techniques. There were similar positive results in evaluating post-treatment samples both acoustically and perceptually. Auditory perceptual evaluation indicated improvements after phonation into resonant tubes, and in the self-assessment evaluation subjects produced a more resonant voice after one single session with semi-occluded vocal tract exercises. In addition, a decreased fundamental frequency was found in acoustic analysis. In our study, the speaking fundamental frequency showed a decrease after training in both experimental and control groups. However, this difference did not reach statistical significance (see Tables IV and V).

In the present study, all participants were perceptually assessed with slight breathiness according to the GRBAS scale before vocal exercises. In breathy voice quality, with incomplete glottic closure of the vocal folds, the main features of the LTAS are: low energy concentration in the region of 0.4–4 kHz, corresponding to the main formants, with a steep slope of the curve to 5 kHz and a high concentration of energy in the region of 5–8 kHz (55). Nolan observed in the spectrum of breathy voices and different types of falsetto that the spectral slope falls abruptly, sharply, up to 3 kHz, and the same occurred in the spectrum of rough voices (65). Hurme and Sonninen also found that in the spectrum of voice disorders due to paralysis of the vocal folds the greatest concentration of energy is above 7 kHz (66). After voice exercises, the alpha ratio had a significant change (less steep fall of the spectrum slope) showing an increased acoustical energy in the high component of the spectrum, more specifically in the range between 1,000 and 5,000 Hz.

The glottal source is directly affected by variations in vocal loudness. The relationship between loudness and spectral envelope has been well documented. When increasing sound pressure level, the gain in dB in the region of high frequencies is greater than in region of low frequencies. The response for all frequencies is not linear (67–71). The LTAS is similar because it is also a spectrum and it is expected to behave in the same way as other spectra (70), resulting in complications when comparing LTAS curves

Table V. Pre-treatment and post-treatment mean values, and confidence intervals for F0 by gender in the control group.

Gender	Pre-treatment (mean (95% CI))	Post-treatment (mean (95% CI))	*P* value
Male	127.6 (117.95; 137.24)	126.5 (118.68; 134.31)	0.6921
Female	234.28 (221.86; 246.70)	231.14 (223.17; 239.10)	0.2026

Table VI. Pre-treatment and post-treatment Leq mean values, and standard deviation for the experimental group.

Participant	Leq pre-treatment (dB)	Leq post-treatment (dB)
1	78.75	77.12
2	80.94	81.56
3	79.73	78.50
4	84.39	82.88
5	81.76	80.13
6	79.21	78.05
7	79.23	80.69
8	78.99	78.43
9	81.19	79.29
10	76.49	78.96
11	75.69	75.31
12	80.65	79.09
13	77.98	75.50
14	83.28	81.98
15	77.99	76.36
16	75.40	76.20
17	76.65	73.44
18	74.83	75.97
19	77.75	78.17
20	76.58	75.83
21	78.82	79.02
22	85.96	84.65
23	74.83	73.55
24	79.78	77.06
Group mean	79.03 ± 0.59	78.23 ± 0.57

of a voice recorded on different occasions, such as before and after therapy. For obtaining comparable LTAS data before and after therapy, Kitzing recommended that patients should read at the same degree of vocal loudness (72). Kitzing and Åkerlund highlighted the need for an investigation of the effect of vocal loudness on LTAS curves (73). All participants in this study were asked to produce the same vocal loudness while recording pre and post training with semi-occluded vocal tract exercises. Moreover, the amplitude values of the spectral peaks were normalized to control loudness variations between subjects. This process was accomplished automatically by assigning the intensity of the strongest partial a value of 0, and each subsequent partial a proportional value compared with this peak intensity.

Table VII. Pre-treatment and post-treatment Leq mean values, and standard deviation for the control group.

Participant	Leq pre-treatment (dB)	Leq post-treatment (dB)
1	83.55	81.79
2	76.07	79.03
3	81.57	82.90
4	82.73	81.24
5	84.23	83.67
6	78.55	79.63
7	74.10	74.87
8	78.33	79.34
9	82.09	81.46
10	79.78	79.97
11	74.86	76.01
12	83.98	84.77
13	78.45	77.51
14	79.04	78.45
15	83.88	84.67
16	80.77	83.11
17	76.75	76.22
Group mean	79.92 ± 0.79	80.27 ± 0.73

The alpha ratio, the slope of the spectrum, should be analyzed with the L1–L0 ratio (the level difference between 300–800 Hz and 50–300 Hz) because an increase of energy in the high region can be compatible with a voice produced with greater tension in the vocal folds and also with a voice that is richer in harmonics (resonant voice). The degree of vocal fold adduction, which is reflected in the relationship between L1 and L0, will complement the slope of the spectrum. Gauffin and Sundberg established correlations between the mode of phonation and the energy level of the fundamental frequency (L0) (61). Thus, in a spectrum of voices that have glottal hyperadduction, L0 is weak, whereas in a spectrum of voices with glottal hypoadduction, L0 is stronger. These variables were also respectively correlated with the perception of a strained voice and breathy voice (55,61). Kitzing (72) noted that a strong L0 and low L1 are present in the spectrum of breathy voices, while a weak L0 and strong L1 are present in strained voice, indicating, respectively, hyperadduction and hypoadduction of the vocal folds.

On other hand, Fischer-Jorgensen (74) used a variety of techniques to study the acoustic characteristics of Gujarati murmured vowels. She considered the high intensity of H1 to be the most salient spectral feature of murmured vowels and conducted a listening experiment to measure the effects of filtering on the perception of breathy vocal quality. High-pass filtering at 230 Hz was used to reduce H1 amplitude by about 25 dB. Contrary to the expected outcome, correct identification of murmured vowels was not significantly decreased. Despite her belief that the relative amplitude of H1 was 'the most obvious and constant feature', the author concluded that no single acoustic feature was sufficient to produce the sensation of breathiness. Klatt and Klatt (53) used a variety of acoustic and perceptual techniques to investigate male–female differences in voice quality. In general, women were judged to be breathier than men. H1 amplitude measures were also generally greater for women than men. Another study (75), the purpose of which was to evaluate the effectiveness of several acoustic measures in predicting breathiness ratings, shows that the relative amplitude of the first harmonic (H1) correlated moderately with breathiness ratings.

Recordings were made of eight normal men and seven normal women producing normally phonated, moderately breathy, and very breathy sustained vowels.

In our study, the mean of L1–L0 values increased from –1.95 dB (pre-treatment) to 0.13 dB (post-treatment), which shows that H1 amplitude was higher before vocal exercises than after. According to evidence of previous cited research, these results would indicate that subjects' voices after voice training were less breathy because the degree of vocal fold adduction increased; thus it can be stated that after one session of vocal exercises with straw, F0 was weaker than samples taken before.

The ratio between 1–5 kHz and 5–8 kHz also was significantly different between voice samples before and after treatment. It decreased from –9.27 (pre treatment) to –10.79 (post treatment). According to Yanagihara (76), a high level of energy between 5.0–8.0 kHz is related to components of noise emission. In a study with 17 voices representing various voice disorders, Hammarberg et al. (55) report that 1–5 kHz and 5–8 kHz ratio may provide information about noise in the glottal source (breathy voice quality).

In addition to the differences before and after treatment for the three ratios calculated in this study, a Pearson correlation coefficient (*r*) was calculated for the pre- and post-treatment measures difference, to analyze the correlation between the variables and observe their relationship. No significant correlation was found between any groups.

In the present study we obtained significant immediate effects on long-term average spectrum (LTAS) analysis after one single session with straw phonation exercises in patients with slight breathiness. However, we do not overlook the possibility that if we were using subjects with a higher grade of dysphonia and breathiness, the results might have been less successful. It is also important to note that the immediate effects obtained do not portend a long-term improvement in the voices of these subjects. These results only show that the exercise sequence we used can produce a short-term effect in voices that are slightly dysphonic.

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