Voice Quality After a Semi-Occluded Vocal Tract Exercise With a Ventilation Mask in Contemporary Commercial Singers: Acoustic Analysis and Self-Assessments

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Summary: Objective. The current study aimed at investigating the immediate effects of a semi-occluded vocal tract exercise with a ventilation mask in a group of contemporary commercial singers.

Study Design. A randomized controlled study was carried out.

Methods. Thirty professional or semi-professional singers with no voice complaints were randomly divided into two groups on recruitment: an experimental group and a control group. The same warm-up exercise was performed by the experimental group with an occluded ventilation mask placed over the nose and the mouth and by the control group without the ventilation mask. Voice was recorded before and after the exercise. Acoustic and self-assessment analysis were accomplished. The acoustic parameters of the voice samples recorded before and after training were compared, as well as the parameters' variations between the experimental and the control group. Self-assessment results of the experimental and the control group were compared too.

Results. Significant changes after the warm-up exercise included jitter, shimmer, and singing power ratio (SPR) in the experimental group. No significant changes were recorded in the control group. Significant differences between the experimental and the control group were found for ΔShimmer and ΔSPR. Self-assessment analysis confirmed a significantly higher phonatory comfort and voice quality perception for the experimental group.

Conclusions. The results of the present study support the immediate advantageous effects on singing voice of a semi-occluded vocal tract exercise with a ventilation mask in terms of acoustic quality, phonatory comfort, and voice quality perception in contemporary commercial singers. Long-term effects still remain to be studied.

Key Words: Voice–SOVTE–Ventilation mask–Contemporary commercial singers–Vocal warm-up.

INTRODUCTION

Semi-occluded vocal tract exercises (SOVTEs) are widely used in the fields of voice therapy and didactics, aiming at improving vocal economy and efficiency. The rationale and theoretical underpinnings for SOVTEs have been described by Titze.[1] SOVTEs promote an increase in vocal tract impedance, resulting in changes in the inertive reactance,[2–6] with favorable effects on voice production because of a reduction of phonation threshold pressure[5,7] and an increase of skewing of the glottal flow waveform (faster cessation of the glottal flow).[4,5] The increasing vocal tract impedance can affect the glottal function through acoustic-aerodynamic interactions and mechano-acoustic interactions.[2,8,9]

Many different SOVTEs exist and have been described so far. The common feature of these exercises is the reduction of the cross-sectional area of the vocal tract at or near the lips. Some of the most known SOVTEs are represented by lip and tongue trills,[10] hummings,[11] hand-over-mouth,[12] resonance tubes,[13] flow resistant straw,[14] and Lax Vox.[15]

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Andrade et al[16] recently studied various types of SOVTEs by acoustic and electroglottographic (EGG) analysis. According to their results, SOVTEs could be classified into two groups: steady exercises (hand-over-mouth, humming, and straw) and fluctuating exercises (tongue-trill, lip-trill, and Lax Vox). Steady exercises show steady EGG contact quotient and fundamental frequency (F0), and they seem to promote an easier phonation. Fluctuating exercises show fluctuating contact quotient and F0, and they make use of a secondary vibrating source thus obtaining a "massage effect" on the vocal tract and a proprioceptive feedback. In addition to this classification, the cited study shows the benefits of mixing steady and fluctuating SOVTEs, obtaining a massage effect as well as an easier phonation.

Ventilation masks can be used to perform both steady and combined steady-fluctuating exercises (eg, with lip-trills and tongue-trills), thus representing an interesting tool in the field of SOVTEs. A steady vocal tract semi-occlusion can be obtained by putting the mask over the nose and mouth and by closing the junction with the palm of the hand while phonating. The use of ventilation masks to obtain a semi-occlusion of the vocal tract was first proposed by Borragan A.T. (Centro de Foniatria y Logopedia, Santander). The effects of SOVTEs performed with a ventilation mask have not been studied yet.

Various techniques have been used to investigate the effects of these vocal exercises, such as acoustic analysis[17–22] and EGG.[23–28] Some studies have been carried out performing aerodynamic, electromyographic, radiological, or endoscopic analysis.[9,29–35]

Concerning acoustic analysis, some of the most frequently used acoustic measures are perturbation parameters like jitter, shimmer, and noise-to-harmonic ratio (NHR); sound pressure level (SPL); F0; tempo, and vibrato.[36] Long-term average spectrum (LTAS) is another useful analysis which provides information about the spectral energy distribution of a sound. It reflects both the voice source and the vocal tract resonance characteristics.[37,38] Several parameters can be employed to assess the spectral energy balance from an LTAS such as the singing power ratio (SPR), which has been introduced by Omori et al.[39] It is calculated by subtracting the amplitude of the strongest partial between 2 and 4 kHz from the level of the strongest partial between 0 and 2 kHz in the power spectrum. SPR is expressed in dB; it reflects the "ring" of the voice and relates to the resonant quality of the singing voice.[40–42]

In the present study, immediate acoustic and subjective effects of a steady SOVTE with a ventilation mask were investigated in a group of contemporary commercial singers.

METHODS

This randomized controlled study was carried out according to the Declaration of Helsinki. All subjects enrolled in the study gave their informed consent.

Participants

A total of 30 trained contemporary commercial singers (18 women and 12 men) with no voice complaints were recruited. The mean age was 32.40 ± 12.07 years, and the mean singing experience was 12.73 ± 8.33 years. Participants were randomly allocated, on recruitment, to one of the following groups: an experimental group ($n = 15$) and a control group ($n = 15$).

Procedures

Each subject was recorded twice (before and after a vocal warm-up exercise) with a microphone Samson Meteor Mic (Samson Technologies, Hauppauge, NY) connected via USB to a MacBook Pro computer (Apple, Cupertino, CA) running the *Apple Soundtrack Pro software* Version 3.0.1 (Apple, Cupertino, CA). The audio signals were digitized on 16 bit at a sampling frequency of 50 kHz. Participants were asked to produce the same vocal intensity during the recording sessions (before and after warming up). SPL was measured using an ambulatory phonation monitor, model 3200 (KayPENTAX, Montavale, NJ) through an accelerometer attached to the anterior base of the neck of each participant. Before starting each new recording, an SPL calibration was performed using a microphone positioned 15 cm from the subject's mouth. Voice recording was performed in standard conditions, with a mouth-to-microphone distance of 30 cm, quiet environment (<40 dB), and constant gain. No singer had warmed-up the voice before the beginning of the recording session. Each participant was recorded while performing the chorus of the song *Volare* by Domenico Modugno (Bb major for men and G major for women) followed by the sustained /a/ of the word "volare" (C for men, A for women) before and after a warm-up exercise. For both the experimental and the control group, the warm-up exercise consisted of the following phonatory tasks:

- to sing the sustained vowels /a/ /e/ /i/ /o/ /u/ at comfortable pitch and volume, using M1 laryngeal mechanism, according to the register definition of Roubeau et al.[43]
- ascending and descending glissandos on the whole vocal range (from M0 to M3) with the vowels /a/ /e/ /i/ /o/ /u/.
- to sing the chorus of *Volare*, by Domenico Modugno.

The experimental group was asked to perform the described warm-up exercise with a ventilation mask (Ambu UltraSeal Disposable Face Mask, size 6, Copenhagen, Denmark). The mask was put over the nose and mouth of the singer and occluded with the palm of the hand while warming up to create a positive pressure feedback in the vocal tract. Each singer of the experimental group was given instructions before the execution of the warm-up exercise to assure a proper performance and avoid muscle tensions while phonating. The control group was asked to perform the same warm-up exercise without the face mask.

Acoustic analysis

Acoustic analysis was carried out with *PRAAT software* (Version 5.3.57 for Mac, Boersma & Weenick, University of Amsterdam, Amsterdam, The Netherlands).[44] The acoustic parameters used to evaluate voice quality before and after the warm-up exercise were both perturbation parameters (to assess the sound wave regularity variations) and the SPR (to assess resonance quality variations). The perturbation parameters jitter (Jitt%), shimmer (Shimm%), and NHR were calculated on the sustained /a/ of volare. The SPR was extracted from the LTAS of the whole chorus of *Volare*. LTAS were computed with a bandwidth of 100 Hz and a frequency range of 0–24.99 kHz. Mean SPL was also measured before and after warm-up for each singer.

To compare the experimental and the control group, the difference between pre- and post-exercise was calculated for each acoustic parameter (ΔJitt%, ΔShimm%, ΔNHR, ΔSPR, and ΔSPL).

Self-assessment

The recruited singers answered four questions about their perception of phonatory comfort and voice quality immediately after the recording of post-exercise voice samples. Each participant was asked verbatim: "Please, tell how do you feel with (1) vocal emission comfort, (2) sensation of sound projection, (3) harmonic quality of your voice, (4) stability and cleanliness of the sound of your voice." For each question, the possible answers were: (A) better than before the exercise, (B) equal or worse than before the exercise. Each singer was asked if he or she had clearly understood the questions; if not, the questions were discussed with the investigators.

Statistical analysis

Means and standard deviations (SDs) for all acoustic analyses were calculated. Unpaired *t* tests and Fisher exact tests were used to analyze differences in the personal data (age, gender, and singing experience) between the experimental group and the control group, as appropriate. A paired *t* test for means was used to detect statistical differences between acoustic measurements before and after exercise both in the experimental and in the control group. An unpaired *t* test for means was used to compare experimental versus control group measures variations (pre- and post-exercise difference). Concerning self-assessment data, the rates of positive answers for each question were calculated. A Fisher exact test was used to compare experimental and control group mean answer rates. An alpha of 0.05 was considered for the statistical procedures. Statistical analysis was carried out with *GraphPad InStat software* (Version 3.06 for Windows, San Diego, CA, USA).

RESULTS

No statistically significant differences were found regarding age, gender, and singing experience between the two groups of singers.

Acoustic analysis

In the experimental group, means and SDs for the investigated acoustic parameters before the warm-up exercise were Jitt% = 0.13 ± 0.06%, Shimm% = 1.56 ± 0.72%; NHR = 0.0023 ± 0.0017; SPR = 20.71 ± 4.04 dB; and SPL = 89.30 ± 7.05 dB. The respective values after the warm-up exercise were Jitt% = 0.11 ± 0.04%; Shimm% = 1.14 ± 0.43%; NHR = 0.0018 ± 0.0014; SPR = 17.81 ± 3.83 dB; and SPL = 87.65 ± 7.34 dB. Significant statistical differences were found for Jitt% ($P = 0.043$), Shimm% ($P = 0.022$), and SPR ($P < 0.01$). Pre- and post-warm-up mean values of the described acoustic measures with SDs for the experimental group are shown in Table 1.

In the control group, means and SDs for the investigated acoustic parameters before the warm-up exercise were Jitt% = 0.12 ± 0.056%; Shimm% = 1.48 ± 0.95%; NHR = 0.0022 ± 0.0016; SPR = 20.16 ± 4.05 dB; and SPL = 90.06 ± 9.35 dB. The respective values after the warm-up exercise were Jitt% = 0.12 ± 0.057%, Shimm% = 1.47 ± 0.95%, NHR = 0.0023 ± 0.003; SPR = 20.09 ± 2.97 dB; and SPL = 89.53 ± 10.18 dB. No significant differences were found in the investigated acoustic parameters. Pre- and post-warm-up mean values of the described acoustic measures with SDs for the control group are shown in Table 2.

Comparison of the acoustic variations before and after the vocal warm-up in the experimental and the control group showed significant differences for ΔShimm ($P = 0.035$) and ΔSPR ($P = 0.004$), as shown in Figures 1 and 2.

TABLE 1.
Mean Values and Standard Deviations (SDs) of the Investigated Acoustic Parameters Before and After the Proposed Warm-Up Exercise in the Experimental Group

Acoustic Parameter	Before Warm-Up (Mean and SD)	After Warm-Up (Mean and SD)	*P* Value
Jitt (%)	0.13 ± 0.06	0.11 ± 0.04	0.043*
Shimm (%)	1.56 ± 0.72	1.14 ± 0.43	0.022*
NHR	0.0023 ± 0.0017	0.0018 ± 0.0014	0.081
SPR (dB)	20.71 ± 4.04	17.81 ± 3.83	<0.01*
SPL (dB)	89.30 ± 7.05	87.65 ± 7.34	0.201

* Significance.

TABLE 2.
Mean Values and Standard Deviations (SDs) of the Investigated Acoustic Parameters Before and After the Proposed Warm-Up Exercise in the Control Group

Acoustic Parameter	Before Warm-Up (Mean and SD)	After Warm-Up (Mean and SD)	*P* Value
Jitt (%)	0.12 ± 0.056	0.12 ± 0.057	0.906
Shimm (%)	1.48 ± 0.95	1.47 ± 0.95	0.978
NHR	0.0022 ± 0.0016	0.0023 ± 0.003	>0.999
SPR (dB)	20.16 ± 4.05	20.09 ± 2.97	0.870
SPL (dB)	90.06 ± 9.35	89.53 ± 10.18	0.746

Self-assessment

Self-assessment results for the experimental group showed 93% of positive answers (better than before the exercise) and 7% of negative answers (equal or worse than before the exercise) for question 1 (vocal emission comfort); 73% of positive answers and 27% of negative answers for question 2 (sensation of sound projection); 100% of positive answers for question 3 (harmonic quality of the voice); and 87% of positive answers and 13% of negative answers for question 4 (stability and cleanliness of the voice).

For the control group, self-assessment results showed 53% of positive answers and 47% of negative answers for question 1 (vocal emission comfort); 40% of positive answers and 60% of negative answers for question 2 (sensation of sound projection); 40% of positive answers and 60% of negative answers for question 3 (harmonic quality of the voice); and 66% of positive answers and 34% of negative answers for question 4 (stability and cleanliness of the voice).

Significant differences between experimental and control group answer rates were found for question 1 ($P = 0.035$), question 3 ($P = 0.0007$), and question 4 ($P = 0.0078$).

DISCUSSION

The effects of a steady SOVTE with a ventilation mask were investigated in a group of contemporary commercial singers. In the current study, both acoustic and self-evaluation analyses were performed after a steady SOVTE with an occluded ventilation mask. The obtained findings suggest that vocal warm-up with a ventilation mask results in both acoustic and subjective immediate positive effects on voice quality. The investigated acoustic parameters were perturbation parameters (jitter, shimmer, and NHR), SPR, and SPL. Jitter and shimmer are measures of the cycle-to-cycle variations of fundamental frequency and amplitude, respectively, whereas NHR represents the average ratio of the disharmonic spectral energy components (noise) to the harmonic spectral energy components. It includes contributions from both perturbations of amplitude and frequency. The measure correlates with the overall perception of noisiness or roughness in the signal.[45] SPR has been previously described as a parameter related to the resonant quality of the singing voice. Lower SPR values correlate with higher energy in the higher harmonic partials of the spectrum, enhancing the richness and the "ring" of

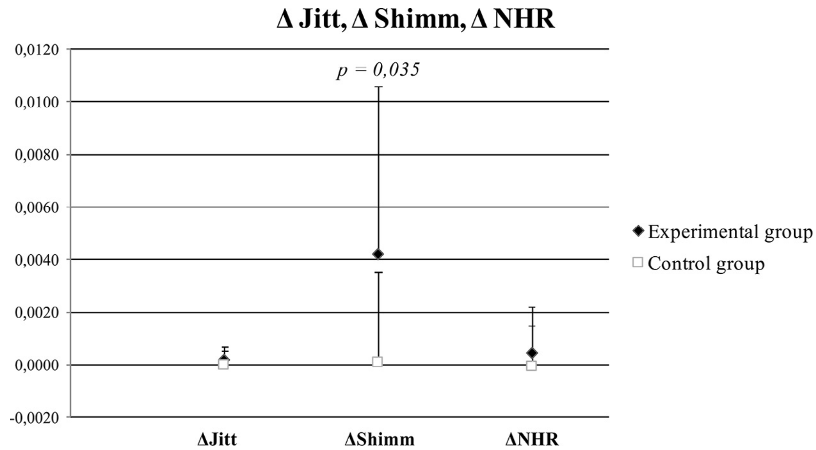

FIGURE 1. Mean Jitter, shimmer, and noise-to-harmonic ratio (NHR) variations after the warm-up exercise (ΔJitt, ΔShimm, and ΔNHR) and respective standard deviations in the experimental group and in the control group.

the voice, thus influencing the perception of voice quality in a positive way.[40] SPL is another very important parameter to be taken into account, because LTAS contour is nonuniformly affected by vocal loudness variation: an increase in intensity does not linearly correlate with an increase in dB of all the frequencies of the spectrum.[46]

At present, no data exist in literature about the efficacy of vocal warm-up with a ventilation mask. The immediate effects of various types of SOVTEs have been widely investigated by several authors, both in dysphonic and non-dysphonic subjects. A previous study by Guzman et al[22] found immediate positive acoustic effects of a straw phonation exercise in subjects with dysphonic voices. A similar study by Costa et al[47] reported subjective significant improvement after a straw phonation exercise indicating an easier and better voice, whereas no significant differences before and after the exercise were found in the acoustic and perceptual assessments. Paes et al[48] showed that the Finnish resonance tube method has immediate positive acoustic and subjective effects on the voices of teachers with chronic behavioral dysphonia.

In the current study, all the investigated acoustic parameters showed an improvement after the warm-up exercise in the experimental group, with significant differences for Jitt%, Shimm%, and SPR. On the contrary, in the control group no significant differences were found, suggesting that the effect of the vocal task itself could be considered negligible. Significant differences were found in pre- and post-exercise variations of Shimm% and SPR between the experimental and the control group as well, confirming a positive immediate acoustic effect of the proposed SOVTE on voice quality in contemporary commercial singers. Because pre- and post-SOVTE SPL mean values were not significantly different, the reported spectral changes (SPR) for the experimental group are not attributable to an increase of voice loudness. The reduction of SPR, which was found significant for the experimental group, could be considered as a result of an increased skewing of the glottal flow wave, with a consequent easier phonation and a strengthening of the higher partials of the spectrum.[1,2] The consequence is higher economy and efficiency in the process of voice production. Titze attributed this effect to a greater acoustic interaction between source and filter

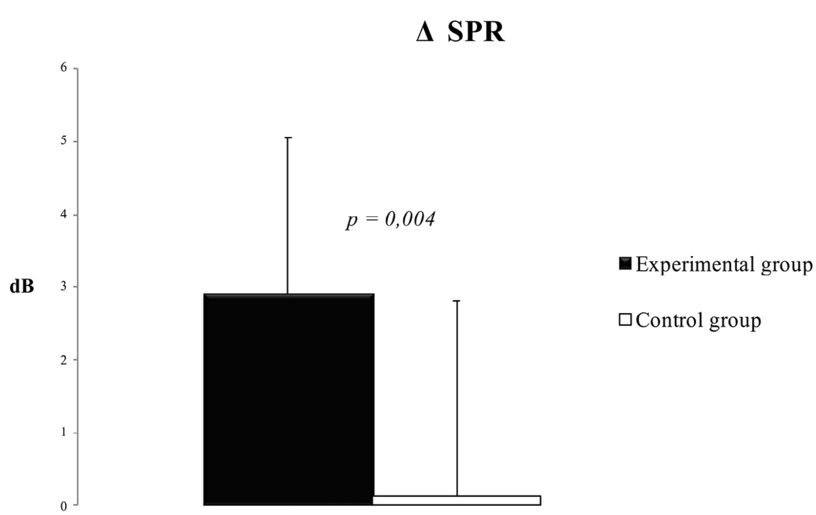

FIGURE 2. Mean singing power ratio (SPR) variations after the warm-up exercise (ΔSPR) and respective standard deviations in the experimental group and in the control group.

when a semi-occlusion is applied to the vocal tract.[5] An increase of the input impedance of the vocal tract affects the shape of the glottal flow pulse and alters the oscillatory characteristics of the vocal folds, thereby the vocal tract would assist and enhance the production of acoustic energy by the sound source.[2,3] The positive effects of impedance matching could be also correlated to electromyographic and aerodynamic findings. In a single-subject study, Laukkanen et al[31] showed that exercises with increased vocal tract impedance promote higher thyroarytenoid muscle activity compared to cricothyroid and lateral cricoarytenoid muscles. Vocal efficiency (calculated as the ratio of oral radiated power to the product of mean pressure to mean airflow) was found higher during and after a bilabial fricative and after tube phonation. Computer modeling results confirmed that higher glottal economy and efficiency would be promoted by a higher thyroarytenoid/cricothyroid ratio when lateral cricoarytenoid activity is tuned for ideal adduction. Some authors carried out computed tomography (CT) and magnetic resonance imaging studies to investigate the macroscopic modifications occurring in the vocal tract during and after SOVTEs.[9,34,35] Their findings could help to relate the positive effects of semi-occlusion postures to morphometric variations of the resonance cavities. For example, a single-subject study on a trained classical singer by Guzman et al[9] analyzed vocal tract and glottal function during and after vocal exercising with resonance tube and straw through CT scanning, acoustic, perceptual and EGG analysis. In particular, CT analysis of the vocal tract during and after the proposed SOVTEs showed a better velum closure, a lowered larynx position, and a widened hypopharynx area. After tube or straw phonation, an increased ratio between the cross-sectional area of the low pharynx and the area of the epilaryngeal tube opening was observed too. These changes could explain the increased singer's or speaker's formant cluster shown by the acoustic analysis. The results indicated that SOVTEs may have vocal training and vocal warm-up effects as they lead to increased vocal efficiency and economy. In a single-subject magnetic resonance imaging and acoustic study by Laukkanen et al[34] similar results were obtained both during and after straw exercising, with an improved velar closure, an increased pharynx/epilarynx transversal area ratio and an increased SPL of the speaker's formant cluster.

In the current study, self-assessment after the proposed SOVTE showed a significant increase in the perception of phonatory comfort, harmonic quality, and stability of the voice for the experimental group. Positive subjective sensations after SOVTEs have been already reported by some authors.[47,48] This effect could be related to changes promoted by these exercises in the vocal tract, such as a lowered laryngeal position and an enlargement of the resonance cavities, thus producing strong somatosensitive biofeedback.[35,49]

The main limitations of the present study were the small number of recruited singers and the lack of medium- and long-term analysis. Future research should include larger number of singers (both classical and contemporary commercial singers) and long-term efficacy analysis. In addition, future studies may focus on the comparison between SOVTEs with a ventilation mask and other steady and fluctuating SOVTEs.

CONCLUSIONS

The results of the present study suggest that a SOVTE performed with an occluded ventilation mask reveals an immediate improvement of voice quality concerning some perturbation and resonance acoustic parameters. In addition, self-assessment shows an immediate significant increase in phonation comfort and sound quality perception. These data suggest that SOVTEs with a ventilation mask may have positive vocal training and vocal warm-up effects in contemporary commercial singers. In the present study, only immediate effects after exercising were analyzed; long-term effects still remain to be studied.

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