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The Effect of Semi-Occluded Vocal Tract Exercise (SOVTE) and Traditional Vocal Warm-up (TVW) on the Vocal Quality of Untrained Female Singers in Malaysia: A Comparison

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ABSTRACT

Vocal warm-up has garnered much research attention these recent years. This study compared the short-term effects of straw phonation (SP) with a traditional vocal warm-up (TVW) on the vocal quality of untrained female singers. It also determined the effect of exercise type on the vocal economy and skill acquisition. Vocal quality was measured using voice range profile (VRP), multi-parametric index, acoustic, and aerodynamic parameters. Eighty participants were randomly recruited and divided into two equal groups to perform vocal warm-ups at a frequency of two 10-minute sessions per day for three weeks. Voice data were collected using Praat and Vocalgrama software, while the statistical results were analysed using Statistical Product and Service Solution (SPSS). As a result, some parameters, i.e., fundamental frequency maximum (F0-max), maximum intensity (max Int) and area of VRP, fundamental frequency (F0), jitter, shimmer, harmonics-to-noise ratio (HNR), and dysphonia severity index (DSI), projected significant changes after three weeks of warming up exercise in TVW group. In the SP group, the participants experienced significant changes in max Int and area of VRP only. Both groups did not exert significant changes to min Int, which indirectly measures phonation threshold pressure (PTP), signifying no improvement for the vocal economy. Participants from the TVW group benefitted the most from vocal warm-ups due to notable improvement in vocal quality, technical singing skills (i.e., skill acquisition), and vocal efficiency. Meanwhile, the SP group only benefitted in terms of enhanced vocal efficiency.

Keywords: Acoustic parameters, aerodynamic, dysphonia severity index, semi-occluded vocal tract exercise, traditional vocal warm-up, vocal quality, voice range profile

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INTRODUCTION

Singing is a highly skilled art that requires coordinated and integrated respiration, phonation, resonation, and articulation (McKinney, 2005). The muscles required for singing can be trained through planned vocal exercises and vocal training programs. Vocal exercises are integral to warming up the voice, correcting vocal faults (e.g., poor breath support can cause pitching intonation & pressed phonation issues; Risdale, 2017), extending vocal range, and acquiring vocal technique (e.g., learning to sing wide intervals, legato, staccato, rapid figurations, & control of dynamics). Vocal exercises are crucial to enhancing vocal quality (McKinney, 2005). Vocal warm-up is vital to prevent vocal fold injury and achieve optimal voice function in both untrained and professional singers (Gish et al., 2012; Milbrath & Solomon, 2003).

Technical/artistic and physiological vocal warm-ups are the two major vocal warm-up types (Behlau et al., 2010; Kang et al., 2019; Portillo et al., 2018). Singing teachers have widely applied traditional vocal warm-ups (TVW), also known as technical/artistic warm-ups, to optimise breath support, voice placement, and vocal timbre (Portillo et al., 2018). On the contrary, speech-language pathologists commonly deploy physiological vocal warm-up exercises as voice rehabilitation exercises. The physiological warm-up prepares a singer's vocal production system for adequate physiological conditions, mainly during or after a performance, to reduce vocal risks and fatigue. Semi-occluded vocal tract exercises (SOVTEs) are among the most common physiological warm-ups carried out by singers. These SOVTEs are designed to improve vocal fold vibration efficiency and physiological conditions and enhance phonation efficiency to achieve resonant voice (Christmann & Cielo, 2017; Portillo et al., 2018). As a result, singers, singing teachers, and speech-language pathologists have begun acknowledging the benefits of vocal warm-ups for voice training and rehabilitation (Portillo et al., 2018).

Despite the wide variety of TVW, it encompasses the following fundamentals: (1) alignment of body position and muscles relaxation, (2) proper inhaling and exhaling techniques, (3) vowel formation, as well as (4) vocal output and placement at different registers, amplitudes, and pitches (Davids & LaTour, 2012; Kang et al., 2019; Stegman, 2003). According to Gish et al. (2012), 70 per cent of voices are highly supportive of the need for TVW sessions to attain easy phonation and flexible voice. Additionally, various acoustic variables, including jitter, pitch perturbation quotient, shimmer, harmonics-to-noise ratio (HNR), and fundamental frequency (F0), have improved following TVW (Amir et al., 2005; Moorcroft & Kenny, 2013; Onofre et al., 2017). Jitter refers to a frequency change measurement within a sample of phonation that varies with strain, stiffness, and vocal fold mass, while shimmer is affected by subglottal pressure and glottal resistance (Robieux et al., 2015).

Andrade et al. (2014) investigated several SOVTEs classified into two categories based on vibratory sources in the vocal tract. Straw phonation (SP) and humming are instances of exercises with a single source of vibration into the vocal tract (i.e., vocal folds), while lip trills and tongue trills are examples of exercises with a secondary source of vibration that should exert a massaging effect on vocal organs (Andrade et al., 2014; Saldías et al., 2020). The effects of SP have been assessed in several studies. Higher mean airflow and spectral energy and decreased oral pressure were observed after SP (Costa et al., 2011; Guzman, Laukkanen, et al., 2013; Manternach et al., 2017). Straw phonation (SP) generates semi-occlusion in the vocal tract. Narrowing the vocal tract increases air pressure above the vocal folds, thus creating positive oral pressure, keeping the vocal folds separated during phonation, and reducing the force of the impact as they meet (Costa et al., 2011; Scearce, 2016; Titze, 2001). This narrowing of the vocal tract promotes a critical feedback mechanism for the vibration of the vocal fold, hence facilitating voice initiation and self-sustained oscillation (Conroy et al., 2014).

These vocal folds introduce a relatively high impedance to the upstream airflow originated by the lungs through the narrowing of the glottis. Increased impedance is imparted unto the vocal tract by narrowing it, which promotes the impedance matching between filter (i.e., vocal tract) and voice source (i.e., vocal folds, Rothenberg, 1981; Story et al., 2000; Titze, 1988, 2001; Titze & Laukkanen, 2007; Titze & Story, 1997). This impedance matching results in time-delayed build-up and release of supraglottal pressure, which feeds energy back into the system by producing in-phase velocity between airflow and supraglottal pressure (Titze, 2006). As a result of the raised inertive reactance (a component of impedance) of the vocal tract, the transglottal pressure is reduced (Bele, 2005; Titze, 2001), thus lowering phonation threshold pressure (PTP). The PTP refers to the least amount of subglottal air pressure required to set the vocal folds into vibration (Titze & Story, 1997), increasing vocal economy and ease of phonation (Bele, 2005; Story et al., 2000; Titze & Story, 1997).

According to Titze (2006), in comparison to the other five progressive exercises (i.e., tongue trills, lip trills, bilabial fricatives, phonation into tubes & humming), SP is the most efficient and easiest to master (Titze, 2006). Therefore, referring to the above considerations, TVW, and SP exercises, along with other identified variables, were investigated in this present study.

LITERATURE REVIEW

This section presents the literature on TVW and SOVTEs by exploring the possible gaps for research and the research findings that can be compared against the outcomes retrieved from this present study. A few studies have reported positive results, as delineated in the following:

Guzman, Angulo, et al. (2013) compared the impact of vocal function exercise (VFE) (vocal training program that consists of SOVTE) with the impact of conventional singing exercises on the voice spectrum in 38 vocally normal pop singers. The study participants were randomly divided into an experimental group (VFE, n=20) and a control group (TVW, n=18). Each participant performed both speaking voice and singing voice tasks. After training on spectral slope declination for the VFE group in both tasks, significant improvements were observed. The singing power ratio (SPR) significantly increased singing voice analysis, while both SPR and alpha ratio significantly increased speaking voice analysis. Significant training improvement in the alpha ratio was noted in the TVW control group after training. As for voice samples, significant variances were found in alpha and SPR for both VFE and control groups (more significant prior-subsequent variance for VFE). The VFE offers a more significantly beneficial effect on the voice spectrum and a decline in speaking voice analysis on a spectral slope than TVW.

Guzman, Higueras, et al. (2013) also examined the acoustic impact of SP on dysphonic teachers using the spectral measure. After SP exercises, spectral tilt was evaluated compared to TVW vowel phonation exercises [a:]. The outcomes showed that SP exercises offered immediate acoustic benefits.

The SOVTEs have been reported to increase voice economy by reducing phonation threshold pressure (PTP) and effort while concurrently increasing or maintaining consistent acoustic output (Guzman, Laukkanen, et al., 2013). The subglottal pressure required to initiate and sustain vocal fold vibration is phonation threshold pressure (PTP) (Fujiki & Sivasankar, 2017). The PTP is affected by several factors, including pre-phonatory glottal width, tissue damping, vocal fold thickness, and mucosal wave velocity (Titze et al., 1995). Additionally, PTP can be influenced by changing several physiological conditions, such as vocal fatigue (Chang & Karnell, 2004) and dehydration (Levendoski et al., 2014), thus, making it one of the most commonly used metrics in examining vocal health and economy. For instance, upon assessing ten male actors and ten female actresses, McHenry et al. (2009) revealed a decrease in PTP after singing TVW (McHenry et al., 2009). Meanwhile, Kang et al. (2019), who involved seven men and 19 women vocally healthy untrained singers, found a significant decrease in PTP within 10 minutes of SP. Furthermore, by employing a non-invasive approach, PTP was closely related to minimum intensity (min Int) in the voice range profile (VRP) (Echternach et al., 2020). Hence, in this present study, PTP was measured indirectly based on min Int in VRP.

Some studies found insignificant or inconclusive results: Duke et al. (2015) compared the voice spectrum effects of traditional singing exercises with SOVTE (SP) in 13 male trained singers. They found no statistically significant effects on the participants’ perceived phonatory effort (PPE) or spectral characteristics between six minutes of SOVTE and nine minutes of TVW (Duke et al., 2015). Vintturi et al. (2001) and Motel et al. (2003) discovered a significant increase in PTP after vocal warm-up exercises, while other studies reported significant variability among the participants or no effect. Milbrath and Solomon (2003) asserted that PTP is neither a specific nor sensitive metric to identify changes in vocal function following vocal training. Upon assessing 30 CCM professional singers, Portillo et al. (2018) found insignificant variations in aerodynamic measurements (PTP & electrographic [EGG]) in participants who conducted TVW and those who completed SOVTE. Kang et al. (2019) involved seven men and 19 women who were vocally healthy untrained singers and reported insignificant differences in PTP for traditional singing exercises.

Notably, the literature depicts mostly professional or trained singers, except Kang et al. (2019), who tested vocally healthy untrained singers. No study has solely assessed untrained female singers. Table 1 lists studies that examined the acoustic impact on TVW and SOVTEs.

The literature review unravels a research gap on the inconclusive evidence concerning the objective physiological effects of vocal exercises. Hence, it is crucial to determine if vocal warm-ups can enhance both vocal quality and vocal efficiency of untrained female singers - the key focus of this present study.

Second, no study has examined the potential differences between physiological and TVW involving untrained female singers using standard diagnostic measures and non-invasive approaches, such as maximum phonation time (MPT), dysphonia severity index (DSI), VRP, and acoustic analysis measurements. Therefore, to bridge this research gap, the standard diagnostic measures mentioned above were deployed to compare the short-term effects of SP and TVW on the vocal quality of vocally normal untrained singers in Malaysia, apart from assessing if each exercise type affected the vocal economy or skill acquisition.

The following research question guided this investigation:

Among the 80 vocally normal female untrained singers, are there differences in the effect on objective vocal outcome measures of MPT, VRP, acoustic parameters (F0 [Hz], jitter [%], shimmer [%], & HNR) and DSI between the experimental group (SOVTE) and the control group (TVW) before and after three weeks of vocal warm-up training?

It was hypothesised that both physiological and TVW exercises could improve the vocal quality and the efficiency of vocally normal untrained female singers. The SOVTEs may have a significant and quantifiable effect on the vocal economy due to increased inertive reactance (Kang et al., 2019; Meerschman et al., 2017; Portillo et al., 2018), while traditional singing exercises may exert a significant and quantifiable impact on the acoustic variables that can result in better soundwave quality, thus improving technical singing skills (Kang et al., 2019; Portillo et al., 2018).

METHODOLOGY

This study employed the quantitative experimental research approach using the

Table 1
Summary of studies that investigated the effects of semi-occluded vocal tract exercise (SOVTE) and traditional vocal warm-up (TVW)

Researchers	Participants	Conditions / Training	Assessment	Results
Guzman, Angulo, et al. (2013)	N = 38 20 women, 18 men Mean age: 34 Vocally healthy, trained singers (Based on self-report and GRBAS scale)	1. Vocal function exercises (VFE) (n = 20) Duration of exercise: 15 minutes 2. Traditional vocal warm-up (n = 18) Duration of exercise: 15 minutes	1. Long-term average spectrum (LTAS) parameters: alpha ratio, L1:L0 ratio and singing power ratio (SPR) in both groups' speaking voice analysis and singing voice analysis.	VFE group: - SPR significantly increased in singing voice analysis - SPR and alpha ratio significantly increased in speaking voice analysis Control group: -The alpha ratio significantly increased The VFE group improved better than the traditional singing exercise group regarding spectral slope declination in speaking voice analysis.
Duke et al. (2015)	N = 13 13 men Age range: 19 – 42 (M= 22.615, SD = 5.785) Trained singers Singing experience: a few years – 35 years	1. no warm-up (n = 13) 2. classical warm-up (n = 13) Duration: 6 minutes of actual singing 3. semi-occluded vocal tract warm-up with a straw (n = 13) Duration: 6 minutes	1. Singing power ratio (SPR) 2. Perceived phonatory effort (PPE)	1. No significant changes in SPR across warm-up conditions 2. SPR was significantly different for vowels /i/ and /e/. Vowel /i/ had the most significant SPR 3. No significant difference in PPE across warm-up conditions
Portillo et al. (2018)	N = 30 18 female, 12 male Mean age for the experimental group: 32 years (age range: 24–29) Mean age for the control group: 34 years (age range: 27–38) CCM singers	1. Semi-occluded vocal tract exercise (SOVTE)—Straw phonation (n = 15) Duration: 15 minutes 2. Traditional singing exercises using vowel /a/ (n = 15) Duration: 15 minutes	Objective measures: 1. Aerodynamic 2. Electroglottographic 3. Acoustic Subjective measures: 4. Self-assessment	1. No significant differences in objective or subjective measurements between the two methods of vocal warm-ups 2. Better self-perceived quality in both groups 3. Traditional vocal warm-up group: - Significant reduction in sound pressure level - Significant increase in glottal airflow - Significant reduction in aerodynamic efficiency
Kang et al. (2019)	N = 26 7 men, 19 women Vocally healthy untrained singers	1. Physiological vocal warm-up—straw phonation exercises (n = 26) Duration: 20-min exercises that consisted of four 5-minute sessions 2. Traditional singing exercise (n = 26) Duration: 20-min exercises consist of four 5-minute sessions	1. Acoustic 2. Aerodynamic	1. Maximum decline in phonation threshold pressure (PTP) at 10-min straw phonation warm-up 2. In the traditional vocal warm-up group, there were significant variances in shimmer and F0 from m0 to m15 and m20 3. No significant changes in acoustic variables after straw phonation

2 × 2 mixed-factorial analysis (ANOVA). It paired t-test to determine the significant differences in effect between the two study groups over the stipulated time.

Study Participants

A total of 80 adult untrained female singers were recruited based on purposive sampling. They were randomly assigned into an experimental group (practising SP exercise across three weeks, n=40) and a control group (practising TVW exercise across three weeks, n=40). The experimental group's mean age was 41 years (SD = 12.84, range = 18-60 years), while the average age of the control group was 38 years (SD = 14.98, range = 18-64 years). The inclusion criteria applied for this study are as follows: (1) female, age between 18 and 64 (M = 39.5, SD = 13.96), (2) self-identification as an untrained singer who neither attended any singing lesson nor received any formal vocal training, particularly never had any SOVTE before participating in this experiment, (3) non-smoking, (4) no history of major voice issues based on the participants' self-report, and (5) no history of hearing impairment based on participants' self-report. The participants were required to maintain their usual daily voice use for 24 hours prior to participation to minimise systemic and vocal fold physiological uncertainty. They were also advised to follow the regular minimum water intake to prevent dehydration. Men were excluded from this study as the mean of (F0) measure, related to the anatomical characteristics of vocal folds, is unequal between adult males and females (Schwartz et al., 2009). In order to hinder the confounding effects of prior vocal training behaviour found in trained singers, only participants without any vocal training were considered. All the participants provided written informed consent prior to study participation. All participants were required to fill in the participant questionnaire. The research ethics application was filed and approved by The University of Malaya Research Ethics Committee (UMREC; Reference Number: UM.TNC2/UMREC_1145).

Experimental Protocol

For three weeks, all the participants performed SP exercises or TVW exercises at a frequency of two 10-minute sessions per day.

The vocal warm-up exercises performed by the experimental group included phonatory exercises similar to those deployed by Kang et al. (2019). Each participant was guided by the National Center for Voice and Speech video "Ingo Titze's Tip for Tired Voices: Grab a Straw!" (NCVS456, 2010): (1) to use a natural speaking pitch and loudness to phonate a sustained vowel /u/-like sound into a straw (2) to ascend and descend glissandos into a straw using a comfortable vocal range (including falsetto), and (3) pitch and loudness accents into a straw using a respiratory support system, primarily the diaphragm. The rapid pitch and loudness fluctuations were performed at an upward F0, and (4) vocalised the song's melody "Happy Birthday" using the straw. The commercial plastic drinking straw (length: 18.5cm & inner diameter: 5mm) was used for all the phonatory exercises. In addition, the participants were instructed to feel buzzy sensations in their mouths and head. The total time for the entire exercise sequence was 10 minutes per session.

The TVW exercises using vowel /a/ were used for the control group. The method adhered to Guzman, Angulo, et al. (2013). Each participant was given the task of singing a simple melody using musical intervals of a third. Musical pitch ranges were adjusted based on the voice type of the participants. For instance, for the middle female voice, the first note was C, followed by E, G, E, and repeating the first note of C for the final note. The task was repeated across a comfortable vocal range, shifting musical tonality by ascending and descending semitones. The participants were given an audio recording of the melody for home practice tasks. The total time for the entire exercise sequence was 10 minutes per session.

The participants completed an initial start-up of a 30-minute recording-and-training session. Voice recordings for both groups were executed during this session. The experimenter guided the first training session. The contents of the exercises were described in detail prior to the experiment. The participants were encouraged to practice at home at a frequency of two 10-minute sessions per day for three weeks. They were required to record their daily practice in the exercise log provided. In order to control the correct performance of the exercises, the participants were asked to attend a 20-minute training session per week. The weekly training sessions were guided by two research assistants who were not informed about the study hypotheses to hinder training bias.

Data Collection

Praat and Vocalgrama were used to record speech signals. The voice recordings were made in a closed room in a quiet environment (<50dB measured by a sound pressure level meter). The participants were recorded twice at their habitual intensity level (before & after vocal warm-up exercises). The microphone was calibrated with a sound pressure level meter before data collection. The sound intensity measurements in Praat were compared with the output of the sound pressure level meter, whereby the readings were recorded. The program Praat Phonanium's script Calibration v.01.01. praat was employed to calculate the calibration formula, in which the calibration factor was derived. All the measured intensities were corrected using the calibration factor. The pre and post-training data were collected before and after the training using PRO MPA II pre-amplifier, UR22 mkII audio interface, and Neumann TLM102 condenser microphone with a sensitivity level of 11 mV/Pa at 1 kHz into 1 Kilohm and a frequency range of 20 Hz to 20 kHz. During the pre and post-vocal training recordings, the participants were required to produce the same loudness level. The microphone was placed 30cm away from the mouth. Each participant was asked to produce a sustained phonation at a comfortable pitch and loudness in a standing position. Data were recorded and sampled at a rate of 44.1 kHz with 16 bits/sample quantization in WAV format. The audio files were assessed for signal-to-noise ratio (SNR), which exceeded 30dB - acceptable for acoustic analyses (Deliyski et al., 2005).

Voice Evaluation

A standardized voice evaluation comprising objective vocal measures and determinations (MPT, DSI, VRP, & acoustic analysis) was performed to assess the participants' voices. The evaluation was executed before and after the three-week vocal warm-up training.

Maximum Performance Task–Maximum Phonation Time (MPT). The MPT is an objective measure of glottal competence (Lundy et al., 2004). The closer the vocal folds are, the less air is wasted, and the longer the sound is sustained. Vocally healthy adult females can sustain vowel sounds for 15–25 seconds (Costello & Sandhu, 2015; Mathieson et al., 2001). The participants were instructed to sustain the vowel /a/ as long as possible following deep inspiration, and the duration of the phonation was measured (MPT, in second). After the experimenter modelled the MPT, the participants were requested to produce the longest possible sample in a standing position at their natural pitch and loudness. Praat was applied to determine the length of a sustained vowel. The best of three attempts was selected for further evaluation.

Voice Range Profile (VRP). The VRP is an evaluation method used to measure vocal capacity and efficiency (Gökdoğan et al., 2016). The VRP was determined using Vocalgrama software (CTS Informática) and a Neumann TLM102 condenser microphone placed 30 cm from the mouth. This evaluation determined the intensity (I-low & I-high), the lowest and the highest fundamental frequencies (F-low & F-high), and the area and F0 extension. Voice samples of minimum and maximum frequencies and minimum and maximum intensity (min & max Int) were recorded for each participant. The experimenter modelled each sound production. In addition, the participants were required to utter the vowel /a/ for at least two seconds in a standing position at their natural pitch and loudness.

Acoustic Analysis. The Praat software, a speech analysis software developed by Paul Boersma and David Weenik from the University of Amsterdam, was used to calculate the HNR, jitter, F0 (Hz), and shimmer. First, the participants were instructed to sustain vowel /a/ for at least five seconds at their natural pitch and loudness in a comfortable standing position. Then, the mid-vowel segment of three seconds was selected for further analysis.

Dysphonia Severity Index (DSI). The DSI refers to an objective multi-parametric voice quality index that measures and describes the overall voice quality (Wuyts et al., 2000). The DSI is sensitive to small changes in voice quality. It is extrapolated from a few voice parameters, such as highest frequency, jitter, lowest intensity, and MPT. The index ranges between -5 and +5. For example, a DSI of 1.6 distinguishes normal voices from dysphonic voices. A lower index denotes the poorer vocal quality, while a higher index displays improved vocal quality (Raes et al., 2002). Program Praat was applied to measure DSI.

Statistical Analysis

All statistical analyses were performed using Statistical Product and Service Solutions (SPSS) Version 25. Descriptive statistics for the variables included calculating mean values with a 95% confidence interval. In addition, the Shapiro-Wilk test was carried out to determine if the variables exhibited normal distribution at a significance level of $p < .05$. All the variables were normally distributed.

A 2 × 2 mixed-factorial ANOVA was performed on all task variables. Pre and post-training served as a within-group factor, and vocal warm-up functioned as a between-group factor. Separate ANOVA was calculated for each outcome measure. For within-group comparisons, each condition variable was analysed using a two-tailed paired t-test. The significance level for both ANOVA and t-test was set at 0.05. Regardless of the significance of the main effects or variance interactions analyses, a t-test was performed to assess the significance of mean differences in each condition. The Bonferroni correction approach was deployed, and the significance level (α) was adjusted to 0.025.

RESULTS

This section presents the experimental outcomes. Mean and standard deviation values (in parentheses) of the acoustic parameters are tabulated in Table 2. Table 3 illustrates the mixed-factorial ANOVA and paired t-tests results derived from SP and TVW groups, which involved 80 participants. As for the VRP's fundamental frequency maximum (F0-max) and min Int, shimmer, HNR, and DSI, significant time-by-group interactions were discovered, indicating significant variations in changes over time between the experimental and control groups. However, insignificant time-by-group interaction was noted for other variables, demonstrating insignificant variances between the two groups over time.

Significant time effects were observed for parameters MPT; min Int, max Int, and area of the VRP and jitter, shimmer, HNR, and DSI, which indicated that regardless of group assignment, the sample changed significantly over time. In addition, a significant group effect was discovered for F0 that signified a significant difference among groups independent of time.

In the SP group, within-group effects of time revealed a significant decrease in min Int (p <.001) but increment in max Int (p <.001) and area (p <.001) of VRP. In the TVW group, significant increase was noted for F0-max (p = .004), max Int (p = <.001), and area (p = <.001) of the VRP; F0 (p = .04), HNR (p = <.001), and DSI (p = <.001), whereas a significant drop was observed for jitter (p = <.001) and shimmer (p = <.001).

Table 2
Mean and standard deviation values (in parentheses) of the acoustic parameters

Parameters	Group	Pre-training, Mean (SD)	Post-training, Mean (SD)
MPT (s)	SP	15.28 (4.56)	16.17 (3.92)
	TVW	16.71 (4.86)	17.85 (4.63)
Voice Range Profile			
F0-min (Hz)	SP	203.73 (20.80)	196.93 (21.10)
	TVW	203.21 (24.70)	205.32 (24.69)
F0-max (Hz)	SP	590.41 (0.77)	590.09 (0.82)
	TVW	590.01 (0.98)	590.63 (0.76)
PR (Hz)	SP	386.68 (20.59)	393.16 (21.29)
	TVW	386.80 (24.60)	385.31 (24.79)
PR (St)	SP	18.51 (1.75)	19.10 (1.87)
	TVW	18.58 (2.10)	18.41 (2.09)
Min Int (dB)	SP	59.27 (0.04)	59.24 (0.02)
	TVW	59.26 (0.03)	59.26 (0.04)
Max Int (dB)	SP	90.94 (7.15)	99.96 (7.86)
	TVW	91.14 (8.71)	102.09 (5.38)
Area (%)	SP	7.04 (1.23)	8.14 (1.09)
	TVW	7.07 (1.24)	8.36 (0.82)
Acoustic Analysis			
F0 (Hz)	SP	223.91 (14.66)	224.29 (15.16)
	TVW	228.09 (24.93)	239.31 (27.22)
Jitter (%)	SP	0.30 (0.11)	0.26 (0.09)
	TVW	0.32 (0.13)	0.23 (0.09)
Shimmer (%)	SP	6.32 (3.23)	5.25 (1.91)
	TVW	8.17 (4.20)	4.58 (2.44)
HNR (dB)	SP	18.76 (6.90)	20.60 (5.39)
	TVW	16.21 (6.71)	21.47 (7.10)
Dysphonia Severity Index (DSI)			
DSI	SP	4.65 (1.62)	5.20 (2.11)
	TVW	4.51(1.35)	6.15 (1.06)

Note. MPT = maximum phonation time; F0 = fundamental frequency; HNR = harmonics-to-noise ratio; PR = pitch range; Int = intensity; DSI = dysphonia severity index; SP = straw phonation; TVW = traditional vocal warm-up

DISCUSSION

This study compared the short-term effects of SP with TVW on the vocal quality of vocally normal untrained female singers, apart from assessing if each exercise type favourably affected the vocal economy or skill acquisition measured using VRP, multi-parametric index, acoustic and aerodynamic parameters. In particular, the quantitative experimental research approach was employed in this study using the 2 × 2 mixed-factorial ANOVA and paired t-test

Table 3
Mixed-factorial ANOVA and Paired t-Test results on straw phonation (SP) and traditional vocal warm-up (TVW) groups for 80 participants

	ANOVA (1, 78)									Paired *t*-test (39)			
	Time			Group			Interaction			Straw Phonation		Traditional Vocal Warm-up	
	F	*p*	*η2p*	*F*	*p*	*η2p*	*F*	*p*	*η2p*	*t*	*p*	*t*	*p*
MPT (s)	6.79	.01**	.08	2.81	.10	.04	0.10	.75	.001	-1.76	.09	-1.92	.06
Voice Range Profile													
F0-min (Hz)	0.46	.50	.01	1.09	.30	.01	1.65	.20	.02	1.40	.17	-0.43	.67
F0-max (Hz)	1.16	.29	.02	0.34	.56	.004	11.41	.001**	.13	1.67	.10	-3.08	.004**
PR (Hz)	0.52	.47	.007	1.04	.31	.013	1.33	.25	.02	-1.34	.19	0.30	.76
PR (St)	0.54	.46	.007	0.87	.36	.01	1.69	.20	.02	-1.41	.17	0.41	.69
Min Int (dB)	10.86	.001**	.12	0.08	.93	.000	9.54	.003**	.11	4.82	<.001**	0.14	.89
Max Int (dB)	139.77	<.001**	.64	0.68	.41	.009	1.31	.26	.02	-7.82	<.001**	-8.87	<.001**
Area (%)	69.86	<.001**	.47	0.42	.52	.005	0.42	.52	.005	-5.54	<.001**	-6.27	<.001**
Acoustic Analysis													
F0 (Hz)	3.85	.05	.05	6.66	.012**	.08	3.36	.07	.04	-0.14	.89	-2.12	.04*
Jitter (%)	19.44	<.001**	.20	0.07	.79	.001	3.79	.06	.05	1.86	.07	4.25	<.001**
Shimmer (%)	25.02	<.001**	.24	1.37	.24	.02	7.38	.01**	.09	1.91	.06	4.81	<.001**
HNR (dB)	26.50	<.001**	.25	0.42	.52	.005	6.11	.02**	.07	-1.81	.08	-5.68	<.001**
Dysphonia Severity Index (DSI)													
DSI	37.78	<.001**	.33	1.72	.19	.02	9.55	.003**	.11	-1.73	.09	-9.80	<.001**

Note. MPT = maximum phonation time; F0 = fundamental frequency; HNR = harmonics-to-noise ratio; PR = pitch range; Int = intensity; DSI = dysphonia severity index. Degrees of freedom for tests are provided in parentheses - (1, 78) and (39). *F* = variation between sample mean values. *η2p* = partial eta squared. * indicates a significant effect. *p* was set at .05. $p < .05$, ** indicates a significant Bonferroni correction, *p* was set at .025. $p < .025$.

to determine the significant variations in effect between the two study groups over the stipulated time. The main findings revealed that several parameters, such as F0-max, max Int, and area of VRP; F0; jitter; shimmer; HNR; and DSI, displayed significant changes after three weeks of warming up exercise in the TVW group. Meanwhile, the SP group showcased significant changes only for max Int and area of VRP. However, both groups did not portray significant changes in min Int, which indirectly measures PTP, indicating that vocal economy was not improved. Overall, it was revealed in this study that the participants in the TVW group benefitted from vocal warm-ups by improving their vocal quality, technical singing skills, and vocal efficiency. On the other hand, the SP group benefitted from vocal warm-ups only by improving their vocal efficiency.

It was hypothesised earlier that both physiological and TVW exercises could improve the vocal quality and efficiency of vocally normal untrained female singers. The SOVTEs can have a significant and quantifiable effect on the vocal economy due to increased inertive reactance (Kang et al., 2019; Meerschman et al., 2017; Portillo et al., 2018), while traditional singing exercises can have a significant and quantifiable impact on acoustic variables that result in better soundwave quality, thus improving technical singing skills (Kang et al., 2019; Portillo et al., 2018).

The hypothesis that SOVTEs might have a significant and quantifiable effect on the vocal economy due to increased impedance in the vocal tract, specifically the inertive reactance, which can lead to an improved vocal economy (Bele, 2005; Story et al., 2000; Titze & Story, 1997) is not supported by the min Int finding recorded in this present study. Referring to Tables 2 and 3, SP resulted in a statistically significant difference in min Int ($p < .001$) before ($M = 59.27$dB, $SD = 0.04$) and after ($M = 59.24$dB, $SD = 0.02$) the vocal warm-up. According to Backus (1977), a general reference is that the just noticeable difference (JND) in soft sound at 30-40 dB for the human ear is about 1 decibel. It may drop to 1/3 to 1/2 of a decibel for loud sound. Since the min Int was lowered by merely 0.03 dB, the change is negligible to be considered clinically meaningful for practical performance despite its statistical significance. A caveat is that the statistical significance outcome can be ascribed to the larger sample size that tends to transform small differences into statistically significant variance (Faber & Fonseca, 2014). Therefore, statistical tests should never constitute the sole input to inferences or decisions about associations or effects (Greenland et al., 2016). Meerschman et al. (2017) asserted that a significant reduction in min Int could be explained by a lower PTP associated with SOVTE. A low PTP denotes that relatively little respiratory effort (less subglottal pressure) is required to drive vocal fold vibration, whereby the vocal economy is achieved due to higher inertive reactance in the vocal tract (Guzman et al., 2017; Guzman, Laukkanen, et al., 2013; Guzman, Rubin, et al., 2013; Kapsner-Smith et al., 2015; Titze, 1988). Since the results of min Int appear to be clinically insignificant in this present study, the assumption that SP can increase vocal economy is not supported. The study findings are consistent with the results reported by Portillo et al. (2018), which depicted no evident variations in PTP when comparing both types of vocal warm-up. The findings refute the postulation made by Kang et al. (2019) that SP reduced PTP. It calls for more studies to validate these findings.

No statistically significant difference was observed for min Int in TVW. It is attributable to the fact that the shape of the open vocal tract (OVT) when producing the vowel [a:] is linked with increased airflow passing through the vocal folds at the glottis and lower intraglottal pressure, which reflects a higher amplitude of vocal fold vibration during phonation that can potentially heighten the risk of generating larger impact stress (Titze, 2002, 2006; Tyrmi & Laukkanen, 2017). In addition, studies have revealed that vocal warm-up exercises with OVT configuration can promote efficient vocal production but not necessarily a high vocal economy (Saldías et al., 2020).

Within-group analyses portrayed in Table 3 showed no significant difference for MPT in both groups. A possible explanation is that three weeks of practice might be too short to experience a change by the untrained singers. The results displayed no differences related to F0-min, PR (Hz) and PR (St) of VRP in both experimental and control groups. However, a statistically significant difference was observed in max Int for both SP and TVW groups. Tilsen (2016) stated that F0 and acoustic intensity are correlated. Increment in subglottal pressure increases the transglottal pressure gradient, thus increasing both amplitude and vocal fold vibration rate (F0), resulting in higher resonances and intensity harmonics (Tilsen, 2016). Therefore, insignificant F0-min, PR (Hz), and PR (St) variations in both groups are ascribed to the changes in intensity.

The within-group analyses revealed significant max Int and area improvements in SP and TVW groups. The significantly increased max Int and area values following SP support the hypothesis of improved vocal efficiency as greater vocal output can be achieved with less vocal fold impact tension and physical effort (Croake et al., 2017; Gaskill & Quinney, 2012; Maxfield et al., 2015; Mills et al., 2017; Titze, 2006). As measured by the VRP, the maximum amplitude of differentiated transglottal airflow was expressed in the dynamic range and the max Int of voice (Gramming et al., 1988). The vocal training effect is attributed to the increased max Int and area values following TVW. Untrained singers may have developed stronger laryngeal muscles after three weeks of vocal training, thus enabling them to support higher subglottal pressures and achieve higher sound pressure level values (Ballenger & Snow, 2003; Barone, 2015).

In the TVW group, the within-group effects of time revealed significant improvements in F0-max, F0, jitter, shimmer, HNR, and DSI. The vocal cords' mass, elongation, length, and tension determined the natural pitch (F0). Conventional singing exercises increase muscle contractility and blood circulation, resulting in more elongated and elastic vocal folds (Bishop, 2003). These physiological changes account for the significant increase in F0, thus discovering F0-max after conventional singing exercises. According to Kang et al. (2019), the optimal duration for traditional singing exercise is 20 minutes. Considering that only 10 minutes per session of TVW was applied in this present study, one can safely state that vocal fatigue was avoided. These findings align with prior studies that reported a rise in F0 following a singing voice impedance test (Mendes et al., 2003; Onofre et al., 2017).

Jitter is a frequency change measurement within a sample of phonation that varies with strain, stiffness, and vocal fold mass, while shimmer is affected by subglottal pressure and glottal resistance (Robieux et al., 2015). Improved respiratory control offers more stable voice frequencies and amplitudes, which result in less jitter and shimmer (Kang et al., 2019). Respiratory control signifies the ability of a vocalist to control subglottal pressure (Salomoni et al., 2016). Subglottal pressure and the pull of a relatively small cricothyroid muscle control the F0 of vocal fold vibration. The cricothyroid muscle must exert significantly greater force to reach a high target pitch if the subglottal pressure is too low with inadequate breath support, which may cause it to fatigue faster and affect voice stability (Parncutt & McPherson, 2002). A significant reduction in jitter and shimmer for the TVW group was observed in this study. A probable explanation is that the untrained singers might have improved their respiratory control following three weeks of TVW (Kang et al., 2019).

Harmonics-to-noise ratio (HNR) measures acoustic harmonics and noise in a voice sample (Brockmann-Bauser & Drinnan, 2011). This study's HNR seemed to increase significantly, indicating improved voice control. The sound characteristics of the sample are enhanced when voice perturbation parameters are improved, which may explain the increased HNR in the TVW group (Eskenazi et al., 1990).

After the SP exercises, most acoustic parameters (e.g., F0-max of VRP, F0, jitter, shimmer, & HNR) did not reveal as many significant variations as they did after TVW. This finding is ascribed to SP exercises that restrict lip and jaw motions; the velum, the tongue, and the orbicular muscle of the mouth are more constrained in SP than in singing (Austin, 1997). As a result, SP is less effective as an exercise to improve singing voice and ability. Furthermore, due to the limited location at various registers, pitches, and amplitude levels, and the limited range of voice production, SP adheres to a relatively monotonous pattern. Traditional singing exercises, on the contrary, are more suitable for a singer's practical, physiological, and mental preparation that affect acoustic outcomes (Kang et al., 2019).

The TVW group experienced significant improvement in DSI due to the within-group effects of time. In the TVW group, the DSI increased by 1.64 points from

4.51 pre-training to 6.15 post-training. Upon analysing the DSI parameters, it was discovered that all of them displayed a positive trend (MPT = +1.15 s; jitter = -0.09%; min Int = -.0005dB; F0-max = +.42 Hz). This result explains the increment in DSI after TVW.

The limitations of this study are that the Acoustic Voice Quality Index (AVQI) and subjective vocal measures were omitted in this study. In addition, all the study participants were untrained female singers who had never had any formal singing experience. The exclusion of male participants in this study is deliberate in controlling for differences between the anatomical characteristics of the vocal cords of both genders. Hence, the impact of both types of vocal warm-up exercises on male participants may be explored in future studies. On the other hand, different levels of trained and untrained voices can yield different outcomes. Therefore, future studies should investigate the impact of conventional singing exercises and SP methods on acoustic and aerodynamic variables in participants at varied training levels. As portrayed in this study with untrained singers, vocal warm-up is a non-invasive, low risk, and cost-effective method to enhance both vocal quality and performance in the general population. The study findings revealed that conventional singing exercises effectively improved singing technique and vocal efficiency in untrained singers. However, whilst SP exercises effectively improved vocal efficiency, on an overall basis, they appeared to be less effective as an exercise to enhance natural singing. As a result, the public should be encouraged to practice TVW, which results in the more effective use and healthier voice for singing.

CONCLUSION

Several parameters, such as F0-max, max Int and area of VRP; F0; jitter; shimmer; HNR; and DSI, displayed significant changes after three weeks of warming up exercise in the TVW group. Meanwhile, the SP group exhibited significant changes only in max Int and area of VRP. Furthermore, both groups did not showcase significant changes in min Int that indirectly measures PTP, thus failing to improve the vocal economy. Overall, this study revealed that the participants in the TVW group benefitted from vocal warm-ups due to improved vocal quality, technical singing skills, and vocal efficiency. On the other hand, the SP group benefitted from vocal warm-ups only with improved vocal efficiency. Hence, it would be more preferential for untrained singers to use the TVW to improve their technical singing skills.

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