Acoustic Effects of the Singing Voice Quality of Untrained Female Singers in Malaysia

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ABSTRACT

Vocal warm-ups are widespread and comprehensive in the singing community. Although it is well recognised and practised by professionals, warm-ups are sometimes bypassed and neglected by singers and voice teachers. The objective of this study is to assess the impact of vocal warm-up on vocal quality through acoustic parameters of jitter (%), shimmer (%), and harmonics-to-noise (HNR [dB]) in two-pitch conditions, A_3 (chest register) and C_5 (head register), before and after vocal warm-up. Forty untrained female singers were recorded twice while uttering the vowels /a/, /o/, and /i/ in two different pitches: Low—A_3 (220.0 Hz) and High—C_5 (523.2 Hz) for at least five seconds. A standardised warm-up protocol with a duration of 20-minute was carried out in this study. The subjects were recorded immediately before and after a 20-minute vocal warm-up session. Significant improvements were found in the mean values of measured acoustic parameters. A decrease was observed compared with the mean jitter and shimmer values before and after a vocal warm-up, while the HNR increased. All the acoustic variables, jitter, shimmer, and HNR were found to have significantly larger improvements in the lower pitch, A_3 (chest register), compared to the higher pitch, C_5 (head register). The findings of this study provided empirical evidence for the beneficial effect of vocal warm-up on the voice quality of untrained female singers. The positive effects of the findings indicated that the vocal warm-up should be encouraged and not bypassed.

Keywords: *jitter, shimmer, harmonics-to-noise ratio (HNR), vocal warm-up, voice quality*

INTRODUCTION

Vocal warm-up is considered necessary for optimal voice. Warm-ups are used to address specific vocal issues and repertoire problems, and to address the fundamental elements of good vocal technique. Singers reported more comfort when singing following vocal warm-up, but limited research is found regarding the impact of warm-up in voice production (Amir, Amir, and Michaeli 2005; Elliot, Sundberg, and Gramming 1995; McHenry, Johnson, and Foshea 2009).

Vocal warm-ups have also been shown to help reduce the thickness of the vocal folds, change the velocity of the surface waves, and modify the width of the glottis before phonation. These changes affect many characteristics of the vocal mechanism, which then affect voice production (Amir, Amir, and Michaeli 2005). In principle, vocal warm-up could improve vocal tract performances (Laukkanen et al. 2012), improve the muscle fatigue resistance of the vocal folds (Milbrath and Solomon 2003; Motel, Fisher, and Leydon 2003), physically warm-up the vocal folds (McHenry, Johnson, and Foshea 2009), or improve vocal efficiency (Laukkanen et al. 2012; Reckers, Donahue, and LeBorgne 2021). There was no evidence of vocal warm-up causing physiologic changes to vocal folds (Elliot, Sundberg, and Gramming 1995; Milbrath and Solomon 2003; Motel, Fisher, and Leydon 2003), but vocal tract and subsequent vocal acoustic changes were found in research studies (Laukkanen et al. 2012). Physical warm-up exercises can range from passive warm-ups, such as massage, to general warm-ups, such as jogging, to specific warm-ups involving actual activity movements (McArdle, Katch, and Katch 1996). The duration and content of vocal warm-up routines among singers and professionals varied too (Gish et al. 2012), though most are "variations of a few key topics." Singing teachers are facing challenges in determining how to warm-up. The warm-up time varies considerably between vocalists (Gish et al. 2012). For instance, a 20-minute vocal warm-up was suggested by Miller (2004). Nonetheless, in some studies, the length of warm-up protocols ranged from 7 to 30 minutes (Gish et al. 2012, e5). Most vocal warm-up exercises lasted from 5 to 10 minutes, as reported by a study by Gish et al. (2012). According to Milbrath and Solomon (2003), an ideal vocal warm-up time ranging from 10 to 30 minutes can enhance the voice performance of most singers. Miller, however, warns that singing for more than 30 minutes will affect the voice production quality (2004, 243).

Singers, voice instructors, speech therapists, and scientists dedicate considerable time and energy to developing and validating vocal warm-up exercises to enhance the voice quality of a performer. In voice pedagogy, the term "voice quality" refers to the distinctive characteristics which characterise the singing voice. In an evaluative context, the same word is often used to denote to what degree a specific vocal production meets professional quality expectations. Acoustic measures are instrumental in describing voice qualities (Teixeira and Fernandes 2014; Frühholz and Belin 2019).

Three standard acoustic measures used to measure vocal quality are jitter, shimmer, and harmonics-to-noise ratio (HNR) (Brockmann-Bauser, Bohlender, and Mehta 2018; Teixeira and Fernandes 2014; Frühholz and Belin 2019). Acoustic perturbation measures, which reflect the short-term variability in the fundamental frequency and amplitude, are frequently included in acoustic evaluations of voice. It is the purpose of these perturbation measures to attempt to determine the aperiodicity in voicing resulting from laryngeal pathology (Scherer et al. 1988). In general, it is assumed that the greater the amount of acoustic perturbation, the more dysphonic the voice (Brockmann-Bauser, Bohlender, and Mehta 2018). In the classification of normal and dysphonic speakers, the acoustic parameters, jitter, and shimmer, have been shown to be effective in evaluating sustained vowel production, vocal characteristics related to roughness and hoarseness, respectively. These perturbation measures were used to track and record frequency variability and instability in the signal. The measure of fundamental frequency cycle-to-cycle variation, which is known as the vocal perturbation, is referred to as jitter (Asiaee et al. 2020; Teixeira, Oliveira, and Lopes 2013). The following authors studied jitter measures. Brown, Morris, and Michel (1990) studied sustained vowel /a/ in young and elderly female subjects; Sabol, Lee, and Stemple (1995) collected values for sustained vowels /a/, /i/, and /u/; and Brown, Rothman, and Sapienza (2000) studied values for sung and spoken vowel /i/.

Shimmer, also known as amplitude perturbation, quantifies the cycle-to-cycle variability in waveform amplitude (Coan and Allen 2007). The following authors studied shimmer measures: Brown, Rothman, and Sapienza (2000) studied the sustained vowel /i/ from speaking and singing tasks between male and female singers and non-singer groups, and Amir, Amir, and Michaeli (2005) investigated sustained vowels /a/ and /i/ in classical voices. The perturbation measures provide valuable voice and vocal health information. Jitter (roughness) has been reported mainly due to insufficient control of vocal fold vibrations. Patients with vocal fold pathologies reported a higher percentage of jitter. With reduced vocal fold lesions and glottal resistance, shimmer improves. The presence of noise at emission and breathiness is associated with shimmer. The hoarseness and breathiness of voice normally execute vocal quality changes due to the deterioration of voice and laryngeal diseases (Coan and Allen 2007; Teixeira, Oliveira, and Lopes 2013).

The noise-related measure, which is the HNR, calculates all periodic to aperiodic energy in the speech signal. HNR is an objective and quantitative evaluation of the degree of roughness (Teixeira, Oliveira, and Lopes 2013). The following authors studied noise-related measures. Brown, Rothman, and Sapienza (2000) studied the sustained vowel /i/ from speaking and singing tasks between male and female singers and non-singer groups, and Amir, Amir, and Michaeli (2005) investigated sustained vowels in classical voices. Normal voices have a low additive noise in voice and are characterised by a high HNR (Asiaee et al. 2020). Greater harmonic energy or greater signal in the voice represents more effective vocal fold vibration and hence better voice quality. Thus, increased noise energy within the signal suggests abnormal vocal function. HNR is a function of the additive noise, which is responsible for the aperiodic component in the voice signal, and a higher measure of HNR, which is associated with decreased noise energy, represents better vocal quality (Asiaee et al. 2020; Müller 2007; Teixeira, Oliveira, and Lopes 2013). Reduced perturbation measurements are associated with reduced variability in the signal and, therefore, better vocal quality.

Vocal warm-ups are widespread and comprehensive in the singing community (Amir, Amir, and Michaeli 2005). However, a major drawback of earlier research is that the vocal warm-up procedures were used differently by various studies. Some research permitted subjects to use a customised warm-up regimen (Amir, Amir, and Michaeli 2005), while others utilised structured warm-up procedures (Elliot, Sundberg, and Gramming 1995; Motel, Fisher, and Leydon 2003). In previous studies, the duration of warm-up procedures differed significantly between 7 minutes and 30 minutes (Amir, Amir, and Michaeli 2005; Elliot, Sundberg, and Gramming 1995; Motel, Fisher, and Leydon 2003). This lack of consistency may lead to conflicting results between studies. In this study, we standardised the warm-up protocol with a duration of 20-minute. Traditionally, vocal musicians and vocal pedagogy often distinguish chest and head voices. Therefore, an acoustic evaluation of the chest voice and head voice is necessary to determine whether the vocal warm-up has different acoustic effects on the modal register and falsetto register. The objective of the present study is to analyse the impact of vocal warm-ups on the voice quality of untrained female singers in Malaysia using acoustic measures in two-pitch conditions, A_3 (chest register) and C_5 (head register), before and after vocal warm-up. Although it is well recognised and practised by professionals, warm-ups are sometimes bypassed and neglected by singers and voice teachers. This study aims to evaluate whether vocal warm-up affects the voice produced in the chest register and head register using the three acoustic parameters, determining whether there is scientific evidence to support vocal warm-up practice and whether it should be encouraged or avoided. Hypothetically, one can assume that the percentage of jitter and shimmer decreased while the HNR increased after a vocal warm-up. The following research questions were addressed:

1. Does vocal warm-up (before and after) significantly alter the acoustic parameters—jitter, shimmer, and HNR in two-pitch conditions, A_3 and C_5 of the untrained singing voice?
2. Are there differences between the two-pitch conditions, A_3 and C_5 and vowel /a/, /o/, and /i/ for jitter, shimmer, and HNR?

METHODOLOGY

The quantitative experimental research approach was used in this study, with the paired samples *t*-test comparing differences in acoustic parameters before and after vocal warm-up and the repeated measures Analysis of Variance (ANOVA) comparing the main and interaction effects of pitch condition and vowel.

Subjects

Forty females between the ages of 21 and 35 years old who enjoyed singing as a hobby but never had any previous vocal training were included in this study. The reason for choosing untrained singers in this study was to avoid the potential confound effects of previous voice training. All participants were in good health and had no voice or hearing problems history. On the days of the experiment, the participants were instructed to maintain their normal dietary and sleep patterns, and they were told not to sing before the experiment. All the participants were asked to fill in the participant questionnaire. The research ethics application was approved by the University of Malaya Research Ethics Committee (reference number: UM.TNC2/UMREC–812).

Recording Procedure and Instrumentation

According to Miller (2004), a comfortable amount of warm-up time for beginners is between 10 minutes and 20 minutes before feeling fatigued. Miller (2004) stated that an advanced singer might take 30 minutes to touch all technical areas. Therefore, a 20-minute vocal warm-up was chosen for the untrained female singers in this study. Subjects were recorded immediately before and after a 20-minute vocal warm-up. Participants were told not to sing or warm-up their voices before recording. Each subject was instructed to sustain the vowels /a/, /o/, and /i/ in two different pitches: Low—A_3 (220.0 Hz) and High—C_5 (523.2 Hz). The low pitch was produced in the chest register and the high note in the head register. Each participant was recorded individually in a quiet room (< 50 dB measured by a sound level meter). The subject was guided by each reference tone provided in the piano recording and was instructed to produce the sustained vowels (target tones) for five seconds. The recording was performed twice based on the criteria above. The mean of these two values was used for the purpose of statistical analysis. The audio recording was recorded through a Neumann TLM102 microphone situated approximately 30 cm from the participant's mouth, using a digital recording program, Studio One 4 Professional, with a frequency response of 44,100 Hz at 16-bits per sample and high-quality speakers. The signal was pre-amplified with an Art Pro MPA-II amplifier.

The subjects were instructed to warm-up their voices following a specific protocol, created by the author after the first recording ("pre-warm-up" condition). The warm-up consists of phonation and positioning using a collection of syllables sung at different levels, registers, and amplitude in different pitches. It also consists of breathing exercises, scales and triads, range extension exercises, and body posture and relaxation tasks.

The vocal warm-up procedure in this study was implemented based on activities established by a few research: vocal warm-up and fatigue (Milbrath and Solomon 2003); and vocal warm-up and cool down, a systematic review (Ribeiro et al. 2016). The exercises consisted of general and specific vocal warm-ups (Table 1). Warm-ups started with general practices that included stretching and respiratory activities, where participants must follow the presented instructions before phonation. Breathing exercises consisted of low focused abdominal breathing as well as further stretching of the arms over the head and down to expand and stretch the ribcage. This training aimed to improve the musical activity's preparation and mental concentration, and provide guidance for air flows and air output controls. These were all important conditions for singing and creating a richer tone.

Specific exercise such as humming was then performed to mobilise and relax the mucosa to improve glottal closure (Ribeiro et al. 2016). For vocal projection, a full second of bilabial nasal sound emission /m/ exercise was performed before switching into /a/ (Falcão et al. 2014). To have a greater vocal extension and enhance sound modulation, ascending, and descending exercises were carried out (Gish et al. 2012). The subjects were instructed to sing arpeggios scales of single-syllable words while focusing on breath and posture support as they extend up and down their phonation range.

The experimenter was present during the warm-up to assist and coach subjects, and ensure optimal understanding of the exercise. All subjects were instructed to perform the same tasks before and after the warm-up. Overall, the experiment recorded 240 tokens (40 untrained singers × 3 vowels × 2 times) of singing vowels.

Table 1 Vocal warm-up protocol.

Procedures	**Total time (min)**
Stretching exercises	3
Respiratory exercises	3
Diaphragmatic breathing, releasing air with emission in /s/: 3 ×	
Resonance exercises	4
Hum a comfortable note for five seconds. Feel the vibration in front of the nose or upper lip	
Softly sing /m: a:/ on each of three pitches that descend a fifth of a scale (e.g., G_4–E_4–C_4). Hold the /m/ for a full second before switching to the /a/. Repeat the entire syllable /m: a:/ at the two remaining pitches in the same breath.	
Phonation exercises	10
Ascending, descending, and arpeggios scales on vowels /a/, /o/, and /i/	

Acoustic Analysis

Each recorded data was analysed using Praat—a software program that provides a quantitative acoustic analysis of voice quality. For these analyses, only the central three seconds of the vowels /a/, /o/, and /i/ were taken into account. The acoustic parameters measured for each vowel were jitter, shimmer, and HNR.

Statistical Analysis

Statistical analysis was performed with the Statistical Product and Service Solutions (SPSS) version 25. Basic descriptive statistics were used to analyse the collected data, namely the mean and standard deviation of the quantitative variables for each measurement period. The normality distribution hypothesis for the jitter, shimmer, and HNR variables were tested with the Shapiro-Wilk test. All the variables were normally distributed. The independent variable was vocal warm-up instructions, and the dependent variables were the acoustic parameters of jitter, shimmer, and HNR. To compare the differences before and after the vocal warm-up for the acoustic analysis, a paired samples t-test was performed independently for each of the three acoustic parameters. The significance level was set at 5% ($p < 0.05$). Repeated measures ANOVA was performed to compare the main and interaction effects of pitch condition and vowel. Pairwise comparisons with Bonferroni corrections ($\alpha < 0.016$) were performed when a significant within-subjects difference was found.

FINDINGS AND DISCUSSIONS

Results

Warm-up effect

Table 2 demonstrates the mean and standard deviation (SD) of the acoustic parameters (jitter, shimmer, and HNR) for each vowel /a/, /o/, and /i/ in the two-pitch conditions, A_3 and C_5, before and after vocal warm-up. A decrease (improved) in values is found in frequency perturbation-jitter and amplitude perturbation-shimmer for each vowel /a/, /o/, and /i/ in both pitch conditions after vocal warm-up. Conversely, an increase in values is observed in the HNR for each vowel /a/, /o/, and /i/ in both pitch conditions after the vocal warm-up.

Table 2 Mean and SD (in parentheses) of the acoustic parameters (jitter, shimmer, and HNR) for each vowel /a/, /o/, and /i/ in the two-pitch conditions, A_3 (chest register) and C_5 (head register), before and after vocal warm-up.

Parameters	Warm-up	Vowel /a/	Vowel /o/	Vowel /i/	Vowel /a/	Vowel /o/	Vowel /i/
		A_3			C_5		
		Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Jitter (%)	Before	0.37 (0.08)	0.36 (0.10)	0.37 (0.09)	0.27 (0.07)	0.25 (0.08)	0.26 (0.07)
	After	0.25 (0.07)	0.25 (0.09)	0.25 (0.06)	0.19 (0.06)	0.17 (0.06)	0.21 (0.06)
Shimmer (%)	Before	5.61 (1.98)	6.30 (2.47)	8.97 (4.18)	2.66 (0.88)	2.30 (0.76)	2.19 (0.69)
	After	2.96 (0.90)	3.79 (1.40)	5.30 (2.36)	2.16 (0.84)	1.70 (0.53)	1.68 (0.49)
HNR (dB)	Before	16.36 (3.15)	18.68 (3.35)	17.57 (3.27)	23.69 (3.10)	25.93 (2.94)	25.02 (3.97)
	After	21.55 (2.96)	22.78 (3.09)	20.47 (3.14)	26.83 (3.23)	28.98 (3.67)	26.64 (4.00)

Table 3 shows the paired samples *t*-test for the acoustic parameters (jitter, shimmer, and HNR) for each vowel /a/, /o/, and /i/ in the two-pitch conditions A_3 and C_5, pre- and post-vocal warm-up. The post-warm-up mean of jitter, shimmer, and HNR are all statistically significantly lower than the pre-warm-up mean of jitter, shimmer, and HNR since all the *p*-values are less than 0.05.

Table 3 Paired samples *t*-test (two-tailed). Results of the jitter, shimmer, and HNR parameter classified by vowels.

Subject	A_3						C_5					
	Jitter (%)		Shimmer (%)		HNR (dB)		Jitter (%)		Shimmer (%)		HNR (dB)	
	t-value	*p*-value	*t*-value	*p*-value	*t*-value	*p*-value	*t*-value	*p*-value	*t*-value	*p*-value	*t*-value	*p*-value
a	10.820	< 0.001	9.040	< 0.001	−11.330	< 0.001	3.600	0.001	3.980	< 0.001	−7.090	< 0.001
o	6.290	< 0.001	8.810	< 0.001	−9.480	< 0.001	5.970	< 0.001	4.750	< 0.001	−6.100	< 0.001
i	7.970	< 0.001	6.700	< 0.001	−6.240	< 0.001	5.271	< 0.001	7.090	< 0.001	−2.855	0.007

The variations between the three parameters for pre- and post- vocal warm-up are shown in Table 4. The results illustrate that the jitter and shimmer are reduced by 0.13% and 1.78%, respectively, as well as the HNR, increased by 3.16 dB. In general, we noticed that the jitter and shimmer have decreased, and HNR has increased following the vocal warm-up.

Table 4 Mean values and SD (in parentheses) of jitter, shimmer, and HNR parameters before and after vocal warm-up.

Subject	Jitter (%)	Shimmer (%)	HNR (dB)
Before	0.37 (0.11)	4.66 (1.37)	21.72 (2.19)
After	0.24 (0.07)	2.88 (0.77)	24.88 (2.58)

The overall post-warm-up mean value for the jitter parameter is less ($p < 0.001$) than the pre-warm-up mean value for all the vowels in the two-pitch conditions—low (A_3) and high (C_5). The value decreases from 0.37% to 0.24%. A paired samples *t*-test was performed to compare the jitter parameter vowels /a/, /o/, and /i/ pre-warm-up and post-warm-up of both low (A_3) and high pitch (C_5) conditions. The data are presented in Table 5. A significance difference is found in the pre-warm-up, mean (SD) = 0.37 (0.08) and post warm-up, mean (SD) = 0.25 (0.07) conditions; t (239) = 9.60, $p < 0.001$. The null hypothesis of equal jitter pre- and post-warm-up mean is rejected, since $p < 0.05$. Thus, the post-warm-up jitter mean is statistically significantly lower than the pre-warm-up jitter mean.

Table 5 Paired *t*-test results of the acoustic parameters before and after vocal warm-up.

	Jitter (%)		**Shimmer (%)**		**HNR (dB)**	
	***t*-value**	***p*-value**	***t*-value**	***p*-value**	***t*-value**	***p*-value**
Paired *t*-test	9.60	< 0.001	11.48	< 0.001	−12.17	< 0.001

The overall post-warm-up shimmer mean value for the parameter is less than ($p < 0.001$) the pre-warm-up mean value for all three vowels in the two-pitch conditions, low (A_3) and high (C_5). The figure decreases from 4.66% to 2.88%. A paired samples *t*-test was performed to compare shimmer parameter vowels /a/, /o/, and /i/ pre-warm-up and post-warm-up low (A_3) and high pitch (C_5) conditions. The data are presented in Table 5. A significance difference is found in the pre-warm-up, mean (SD) = 4.66 (1.37) and post-warm-up, mean (SD) = 2.88 (0.77) conditions; t (239) = 11.48, $p < 0.001$. The null hypothesis of equal shimmer pre- and post-warm-up mean is rejected, since $p < 0.050$. Thus, the post-warm-up shimmer mean is statistically significantly lower than the pre-warm-up shimmer mean.

The overall mean value for the HNR parameter, which is determined after warm-up, is greater ($p < 0.001$) than the value before warm-up, for all the vowels in the two-pitch conditions, low (A_3) and high (C_5). The value has increased from 21.72 dB to 24.88 dB. A paired sample *t*-test was performed to compare HNR parameter vowels /a/, /o/, and /i/ pre-warm-up and post-warm-up for both low (A_3) and high pitch (C_5) conditions. The data are presented in Table 5. A significance difference was found in the pre-warm-up (mean = 21.72, SD = 2.19) and post-warm-up (mean = 24.88, SD = 2.58) conditions; t (239) = −12.17, $p < 0.001$. The null hypothesis of equal HNR pre- and post-warm-up mean is rejected, since $p < 0.050$. Thus, the post-warm-up HNR mean is statistically significantly higher than the pre-warm-up HNR mean.

Pitch condition and vowel comparison

Table 6 illustrates the repeated measures ANOVA for pitch condition and vowel effect on jitter, shimmer, and HNR. The two within-subjects factors are pitch condition (A_3, C_5) and vowel (/a/, /o/, /i/). The results for jitter reveals a significant main effect of pitch condition $F(1, 39) = 20.01$, $p < 0.001$, $n_p^2 = 0.34$, indicating that vocal warm-up significantly decreases (improves) jitter in the two-pitch condition, A_3 and C_5. The estimated mean difference of jitter in pitch condition—A_3 (EM difference = −0.186, $p < 0.001$) is significantly greater than the mean difference of jitter in pitch condition—C_5 (EM difference = −0.069, $p < 0.001$). The main effect of vowel type on jitter is not significant, $F(2, 78) = 2.014$, $p = 0.140$, $n_p^2 = 0.05$. No significant pitch condition x vowel type interaction is observed for jitter $F(2, 78) = 1.75$, $p < 0.181$, $n_p^2 = 0.043$.

Table 6 Repeated measures ANOVA for pitch condition and vowel effect on jitter, shimmer, and HNR.

	Jitter			**Shimmer**			**HNR**		
	df	***F***	***p*-value**	**df**	***F***	***p*-value**	**df**	***F***	***p*-value**
Pitch condition	1	20.01	< 0.001*	1	70.56	< 0.001*	1	13.632	0.001*
Vowel	2	2.014	0.140	2	5.020	0.019*	2	1.867	0.002*
Vowel * Pitch condition	2	1.746	0.181	2	5.726	0.011*	2	1.409	0.251

Note: *indicates a significant effect. *P* was set at 0.05.

The results for shimmer reveal a significant main effect of pitch condition $F(1, 39) = 70.56$, $p < 0.001$, $n_p^2 = 0.64$, indicating that vocal warm-up significantly decreases (improves) shimmer in the two-pitch condition, A_3 and C_5. The estimated mean difference of shimmer in pitch condition—A_3 (EM difference = −3.02,

$p < 0.001$) is significantly greater than the mean difference of shimmer in pitch condition—C_5 (EM difference = −0.54, $p < 0.001$). The main effect of vowel type on shimmer is significant, $F(2, 78) = 5.02$, $p = 0.019$, $n_p^2 = 0.114$, indicating that vocal warm-up significantly affect shimmer in vowel /o/ and /i/. The estimated mean difference of shimmer for vowel /i/ (EM= −2.20, $p = 0.02$) is significantly greater than the estimated mean difference of shimmer for vowel /o/ (EM= −1.56, $p = 0.02$). Significant vowel type × pitch condition interaction is also observed for shimmer $F(2, 78) = 5.73$, $p < 0.011$, $n_p^2 = 0.128$, suggesting that the mean for shimmer is greater in the A_3 pitch condition for vowel /a/, /o/, and /i/ than in the C_5 pitch condition. As a result, the warm-up effect for shimmer is more prominent in the A_3 pitch condition than in the C_5 pitch condition.

The results for HNR reveal a significant main effect of pitch condition $F(1, 39) = 13.63$, $p = 0.001$, $n_p^2 = 0.26$, indicating that vocal warm-up has significantly increased (improved) HNR in the two-pitch condition, A_3 and C_5. The estimated mean difference of HNR in pitch condition—A3 (EM difference = 4.07, $p = 0.001$) is significantly greater than the estimated mean difference of shimmer in pitch condition—C5 (EM difference = 2.24, $p = 0.001$). The main effect of vowel type on HNR is also significant, $F(2, 78) = 6.98$, $p = 0.002$, $n_p^2 = 0.152$, indicating that vocal warm-up significantly affects HNR in vowel /a/ and /i/. The HNR mean for vowel /a/ (EM = 3.91, $p = 0.001$) is significantly greater than the mean for HNR for vowel /i/ (EM = 2.26, $p = 0.001$). However, no significant pitch condition × vowel type interaction is observed for HNR, $F(2, 78) = 1.41$, $p < 0.251$, $n_p^2 = 0.035$.

DISCUSSION

This research aims to determine the impact of vocal warm-up on the voice quality of 40 untrained female singers in Malaysia. The vocal warm-up procedure is crucial in preparing the singer's voice at its best for any performance and in preventing injury. Different singing schools may employ different vocal warm-up exercises, but in general, most voice-major students generally adopt a warm-up practice. In this study, vocal acoustic parameters were assessed in pre- and post-warm-up sessions, with an intervention of vocal warm-up exercises, and significant improvements were found on all acoustic parameters in two-pitch conditions, A_3 and C_5. Figure 1 illustrates the differences between voice quality of pre- and post-vocal warm-up voice quality.

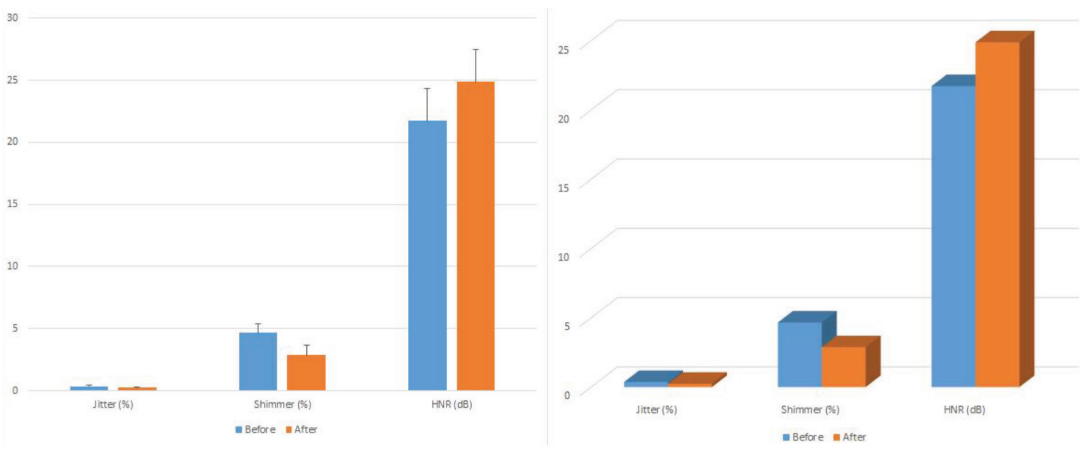

Figure 1 Group mean values of the acoustic parameters before and after vocal warm-up.

The objective of the evaluation results after applying the intervention of vocal warm-up exercises shows that the jitter and shimmer are lower than before the intervention program was applied and the HNR was higher than before applying the intervention programme (Table 4). The lower the jitter and shimmer, the better the voice quality, while the higher the HNR, the better the quality of voice. As a result of statistically verifying the difference of pre- and post-test results, jitter, shimmer, and HNR showed statistically significant difference [jitter ($t(239) = 18.00$, $p < 0.001$); shimmer ($t(239) = 19.38$, $p < 0.001$); HNR ($t(239) = -16.14$, $p < 0.001$)]. This means that the voice quality of the participants has been objectively improved.

Tables 2 and 4 demonstrate a significant decrease in the jitter values after vocal warm-ups. The reduction suggests that the vocal warm-up influences the vocal folds' vibration cycle and decreases perturbations that are present in the normophomic subjects (Asiaee et al. 2020). It also shows that the vocal fold vibration adjustment has improved and enabled easier use of the voice (Teixeira, Oliveira, and Lopes 2013). This means that the vocal warm-up session has improved the participants' vocal performance.

Furthermore, Tables 2 and 4 demonstrate a significant decrease in shimmer values after vocal warm-up. Shimmer is indicative of vocal fold instability. Shimmer changes with the reduction of glottal resistance and mass lesion in the vocal folds (Amir, Amir, and Michaeli 2005). The shimmer also shows short-term variability in amplitude that are often minimally present in normophonic subjects (Asiaee et al. 2020). The decrease in shimmer we observed indicates that the underlying mechanisms of the phonatory effect are affected by the vocal warm-up, as the amplitude changes shown by the shimmer has reduced.

Besides, Tables 2 and 4 demonstrate a significant increase of HNR values after vocal warm-up. A decrease in HNR can indicate either increased additive disturbance noise associated with impaired glottis closure (breathiness) or increased jitter (roughness) (Coan and Allen 2007; Teixeira, Oliveira, and Lopes 2013). The increased HNR in our findings indicates that periodic vocal signals are higher after vocal warm-up than before. This could also be correlated with a corresponding decline in aperiodicity in the signal (Asiaee et al. 2020).

For the main effect of pitch conditions (Table 6), our results indicate that, after vocal warm-up, all the acoustic parameters, acoustic parameters of jitter, shimmer, and HNR are found to have significantly larger improvements in the lower pitch (A_3), which is produced in the chest register compared to the higher pitch (C_5) which is produced in the head register. The reason for this finding remains unclear. One possible explanation is that the vocal folds are less strained, and the vibrating mass is greater during lower pitch production. Therefore, irregularities may be more noticeable. As a result, vocal warm-ups affect the lower pitch condition more significantly than the higher pitch condition. This explanation is similar to the findings of Motel, Fisher, and Leydon (2003). In addition, the authors discovered that phonatory effort was much higher at the 80% pitch level than at the 10% and 20% pitch levels. Their discovery of reduced phonatory effort in the lower pitch range supports the idea that the looser the vocal folds, the more vulnerable they are to vibratory abnormalities. The authors also proposed that, under certain conditions, vocal warm-up could increase phonation threshold pressure by increasing the viscosity of the vocal folds, and as a result, improve vocal stability.

In this investigation, the perturbation parameters were revealed to be unpredictable due to vowel effects. For the main effect of vowels, our findings revealed that no significant differences were found on the jitter variable, whereas, for shimmer results, shimmer has the higher mean for the vowel /i/ and lower for the vowel /o/. One possible explanation is that high vowels generally show larger shimmer (Datta 2018). However, the findings of this study contradict several previous studies on vowel perturbation analysis. For example, a few research have revealed that shimmer values were lowest for the vowel /u/, intermediate for the vowel /i/, and highest for the vowel /a/ (Horii 1980; Ramig and Ringel 1983; Sorensen and Horii 1983) while another study found shimmer to be lowest for /i/, intermediate for /a/ and highest for /u/ (Kiliç et al. 2004). In recent years, it has been argued that the algorithms used to calculate perturbation parameters are only useful for almost periodic voice signals and are unreliable for substantially analysing aperiodic sounds (Jiang et al. 2009). Furthermore, jitter and shimmer have been discovered to be influenced by a variety of recording and analysis settings, such as microphone type and positioning (Titze and Winholtz 1993), analysis systems (Bielamowicz et al. 1996; Karnell, Scherer, and Fischer 1991), and environmental noise (Carson, Ingrisano, and Eggleston 2003; Deliyski, Shaw, and Evans 2005). Given these variable findings of past research, it appears that percent jitter and shimmer are not relevant indicators for accurately expressing acoustic variations across vowels.

For the main effect of vowel type on the HNR, our results showed HNR has the higher mean for the vowel /a/ and lower for the vowel /i/. The results of this study are similar to a study that found the mean HNR value for the vowel /a/ is more compared to the vowels /i/ and /u/ for normal voice female speakers (Alex, Izaath, and Aseem 2020). However, the results of this study were inconsistent with the findings of MacCallum, Zhang, and Jiang (2011). MacCallum, Zhang, and Jiang (2011) found that signal-to-noise ratio (SNR) was highest for the vowel /i/, intermediate for the vowel /u/, and lowest for the vowel /a/ in healthy female subjects. As shown by the lowest SNR values, the low vowel /a/ had less harmonic activity in its signals. High vowels /i/ and /u/, on the other hand, had more harmonic activity and higher vocal fold vibratory frequencies but showed less complexity (MacCallum, Zhang, and Jiang 2011). The ambiguous results showed that vowel effects on the HNR were inconclusive.

The significant reduction in jitter and shimmer and increase in HNR observed after the vocal warm-up confirmed the positive effect and showed the significance of this practice. This means that the untrained singers' larynxes functioned more smoothly and efficiently after performing the vocal warm-up exercises. This could assist the singers in optimising their vocal performance and protecting their vocal folds from injury. The findings in this study indicated that untrained singers could benefit from vocal warm-ups, and they should be encouraged and not bypassed. Therefore, untrained singers should develop a vocal warm-up routine to enhance their vocal qualities and prevent future voice problems. This study's findings could benefit voice teachers in implementing best practices in rehearsals. Researchers may examine the impact of vocal warm-up procedures of varying duration and types in future investigations. Such research could help to establish the best vocal warm-up procedure for singers to improve voice quality and prevent vocal injury. According to the findings of this study, jitter, shimmer, and HNR are not relevant indicators for accurately expressing acoustic variations across vowels. Future research should investigate and validate the acoustic effects of vowel selection found in this study.

The findings of this study seem to reinforce further suggestions of the usefulness of objective measures in achieving a desired vocal quality effectively and efficiently (Teixeira and Fernandes 2014). Acoustic analysis is an effective non-invasive tool for assessing and measuring the impact of voice warm-up on voice output (Brockmann-Bauser, Bohlender, and Mehta 2018; Teixeira and Fernandes 2014; Frühholz and Belin 2019). Audiovisual feedback displays, such as those provided in the Praat software version 6.1.03, might be valuable tools in successfully developing a means of warming up, which is not only not damaging to the voice but beneficial in facilitating an optimal vocal quality (Boersma and van Heuven 2001). Using these objective measures of vocal quality, one could develop a warm-up technique to establish an enhanced tone and increased projection with minimal effort.

CONCLUSION

This study examined the effects of vocal warm-up in improving the voice quality of untrained female singers in two-pitch conditions, A_3 and C_5. The results demonstrated that all the 40 participants' voice qualities had significantly improved in the two-pitch conditions, A_3 and C_5, after a 20-minute vocal warm-up, with decreased jitters and shimmers, and increased HNR. All the acoustic variables, jitter, shimmer, and HNR, were found to have significantly larger improvements in the lower pitch (A_3), which was produced in the chest register, compared to the higher pitch (C_5), which was produced in the head register. The findings indicate that vocal warm-up has positive effects on voice quality and acoustic analysis is an efficient tool for determining and assessing voice production (Brockmann-Bauser, Bohlender, and Mehta 2018; Teixeira and Fernandes 2014; Frühholz and Belin 2019). Such findings also emphasised the value of including multiple exercises in the warm-up procedure, which targeted laryngeal function as well as breathing posture and relaxation. Amplitude perturbation measurements improved following vocal warm-ups, indicating that a vocal warm-up improves the regulation of the respiratory system, which plays an important role in amplitude variation. As for the effect of different vowels on head voice and chest voice, the findings of this study suggested that jitter, shimmer, and HNR are not relevant indicators for accurately expressing acoustic variations across vowels. Therefore, it was impractical to draw a conclusion.

The jitter reduction demonstrated that vocal warm-up affects the vibration cycle of the vocal folds, which minimised disturbances and enhanced voice quality. The decline in shimmer indicated that it also changed the underlying mechanisms of the phonatory effect, reducing the variations in amplitude. The significant decrease in jitter and shimmer indicated an improvement in vocal roughness and vocal breathiness, respectively. The significant increase in HNR indicated an improvement in vocal hoarseness. Overall, this study showed that participants benefitted from vocal warm-ups by significantly improving voice quality, and they should be encouraged and not bypassed.

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