Evaluating the Influence of Warmup on Singing Voice Quality Using Acoustic Measures

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Summary: Vocal warmup is generally accepted as vital for singing performance. However, only a limited number of studies have evaluated this effect quantitatively. In this study, we evaluated the effect of vocal warmup on voice production, among young female singers, using a set of acoustic parameters. Warmup reduced frequency-perturbation ($p < 0.001$) and amplitude-perturbation values ($p < 0.05$). In addition, warmup increased singer's formant amplitude ($p < 0.05$) and improved noise-to-harmonic ratio ($p < 0.05$). Tone-matching accuracy, however, was not affected by warmup. The effect of vocal warmup on frequency-perturbation parameters was more evident among mezzo-soprano singers than it was among soprano singers. It was also more evident in the low pitch-range than in the higher pitch-ranges ($p < 0.05$). The results of this study provide valid support for the advantageous effect of vocal warmup on voice quality and present acoustic analysis as a valuable and sensitive tool for quantifying this effect.

Key Words: Warmup—Acoustic analysis—Singing voice—Voice quality.

INTRODUCTION

Vocal warmup is viewed by trained singers and performers as mandatory. However, there remain a number of singers who regard warmup as optional or even deleterious to their performance. Different routines are available for vocal warmup,[1,2] and although the actual exercises in such routines may vary, most vocal warmup routines include (1) body posture alignment and relaxation exercises, (2) breathing exercises, and (3) voice productions and placement at different pitches, registers, and amplitude levels.[3,4] The literature on vocal warmup and its effect on voice production is mostly based on the subjective experience of singers, voice teachers, and professionals. Elliot et al,[5] for example, reported that all singers who participated in their study felt that after warmup, their voice quality was better, singing required less effort, and that their voice was controlled more easily. These reports are consistent with other subjective reports of improved vocal flexibility, range, and quality after warmup.[3,4]

Although it is widely accepted that warmup improves vocal production and facilitates easier phonation, very little is known about the mechanism underlying the effect of warmup in general[6,7] and specifically in voice.[5] Over the past few years, with the increasing availability of objective tools for voice evaluation, a limited number of studies have

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examined vocal warmup more quantitatively. Most of these studies examined the physiological effect of warmup on vocal-fold activity. Elliot et al[5] examined whether vocal warmup reduces phonatory effort, as reflected by phonation threshold pressure (PTP). They reported that, in many cases, PTP was indeed affected by vocal warmup. Their results, however, were inconclusive because the magnitude and direction of this effect were not consistent across all participants. Therefore, based on the assumption that warmup decreases vocal-fold viscosity, they concluded that PTP is not affected significantly by vocal warmup. It was thus suggested that warmup affects other physical characteristics of the vocal folds, such as reducing vocal-fold thickness, modifying surface wave velocity, and modifying prephonatory glottal width, which could all affect voice production. In a comparable study, Milbrath and Solomon[8] reached a similar conclusion and remarked that although "there is little argument that warming up the vocal mechanism is beneficial to vocal performance…the results of this study did not support the common assumption that vocal warmup exercises are beneficial to vocal function as measured by PTP" (p. 433). Motel et al[9] examined the effect of vocal warmup in ten soprano singers at different pitch levels. They, too, reported considerable intersubject and intrasubject variability in PTP values prior and after vocal warmup. Nevertheless, warmup was found to increase PTP only for high-pitch phonations (80% of vocal range), but not for lower pitches (10% and 20% of vocal range). They attributed these results to the effect of the warmup on vocal-folds viscosity. This result led them to hypothesize that vocal warmup causes loss of water from the vocal-fold mucosa, but at the same time, it increases water absorption in the muscle.

In addition to the studies that evaluated the effect of vocal warmup on voice production through PTP measurements, others have examined this effect by evaluating ergonomic factors[10] and aerodynamic factors.[11] The common conclusion drawn from these studies was that although it is clear that vocal warmup contributes to voice production, it is still difficult to identify a specific factor that can be measured, quantified, and ultimately explain this effect.

Computerized acoustic analysis has been previously demonstrated as a valid and reliable tool for measuring subtle changes in voice quality and stability.[12] This tool has the potential benefit of reliably revealing, measuring, and quantifying small differences that are, otherwise, difficult to identify. The standard acoustic measures of vocal quality include jitter, shimmer, and noise-to-harmonic ratio.[13] There are, however, contradicting data regarding the question of whether these acoustic measures can fully assess vocal aesthetics. Statistically significant changes in acoustic values were not always shown to reflect clinically meaningful changes in vocal capabilities. Lundy et al,[14] for example, reported that the singing voice is characterized by lower shimmer and noise-to-harmonic ratio values in comparison with speaking voice. In a different study,[15] however, no significant differences were found between singers and untrained speakers using these voice quality parameters. Thus, it is not clear from the literature whether these acoustic parameters would contribute to illustrate the specific effect of vocal warmup on voice quality.

Two additional acoustic features that can be expected to relate to the quality of the singing voice, and that were included in the present study, are singer's formant and relative-accuracy of production. Singer's formant (SF) is defined as an increased intensity in the spectral energy between the third and fourth formants.[16,17] It enables the singer's voice to be heard over the accompanying music or over large distances, in addition to contributing to its subjective richness and clarity. Omori et al[18] suggested quantifying the SF by calculating the ratio of the greater harmonic peak in the 2–4-kHz range to the greater harmonic peak in the 0–2-kHz range. They termed this measure Singing Power Ratio (SPR) and demonstrated that it differentiates singers from nonsingers and that it correlates with perceptual scores of "ringing" quality of voice.

Finally, the accuracy of tone production (ie, singing in tune) is one of the major features that characterize singers' vocal ability. Musicians with no voice training are known to be more accurate than nonmusicians, in their ability to vocally track or reproduce tones.[19] This was demonstrated by measuring *rel*Accuracy%, which was calculated as the absolute difference between the observed fundamental frequency and the reference frequency in percent. In different studies, trained singers were shown to be greatly more accurate in pitch-matching tasks than were nonsingers.[20,21] It was also reported that pitch-matching accuracy was regarded as a prerequisite for evaluating the professional voice.[21]

Because SF and production-accuracy are two distinctive features that were shown to be specific to singers, we decided to include these parameters in the present study, in addition to the conventional voice quality parameters. Thus, the purpose of this investigation was to evaluate the effect of vocal warmup on voice quality of trained singers using acoustic measurements of voice quality (frequency- and amplitude-perturbation and noise indices), in addition to measuring singer's formant and accuracy of production before and after vocal warmup.

METHOD

Subjects

Twenty young female singers participated in this study, after obtaining the approval from our institutional review board and consent from all participants. All participants had professional classical voice training for a mean period of 5.4 years (SD = 2.9). Sixteen singers were conservatory students, and the other four were students or graduates of the Israeli music academy. Overall mean age was 18.62 years (SD = 3.2), mean weight was 61.5 kg. (SD = 13.4), and mean height was 164.9 cm (SD = 6.1). All singers were healthy, with no remarkable medical history.

Recording procedure and instrumentation

Subjects were recorded twice: before and after vocal warmup. Prior to the recordings, the subjects were instructed not to sing or warmup their voice to ensure the validity of the measurements. Each singer was recorded individually in a quiet room while sustaining the vowels /a/ and /i/ in three different pitches: 20%, 50%, and 80% of their reported vocal range. These target tones were calculated to the nearest semitone and were regarded as low, mid, and high pitch, respectively. Each reference tone was presented by a piano in a random order, and the singer was asked to sustain the produced vowels (target tones) as accurately as possible for 5 seconds. The signal was recorded through a microphone (ACO Pacific, Inc., Belmont, CA) situated approximately 15 cm from the subject's mouth, using a Sony-TCD D7 digital recorder (Sony, Tokyo, Japan). Sampling rate for the recording was set for 48 kHz (16 bits per sample).

After the first recording ("before warmup" condition), subjects were instructed to warmup their voice in an optimal manner, using their personal warmup routine, until they were satisfied with their voice production. Most singers were assisted by a singing teacher during the warmup routine, whereas the others performed the warmup independently. Naturally, each singer employed a different warmup routine, including different exercises; yet, most warmup routines included similar elements: (1) body posture alignment and relaxation exercises, (2) breathing exercises, and (3) voice productions and placement at different pitches, registers, and amplitude levels using a variety of syllables sung in different pitches. The rationale of allowing each singer to use a different warmup stems from the view that, ideally, warmup is idiosyncratic to the particular singer's needs and it also varies with the demands and expectations of the performance. Thus, creating an arbitrary set of tones for all participants may not have been adequate. Mean duration of the warmup routine performed by the singers in this study was 11 minutes (range: 7 to 23). In an attempt to minimize the effect of the time of day on the singers' vocal quality, all recording sessions were performed in the afternoon.

Acoustic analysis

Each recording of sustained vowel was fed to a Kay Elemetrics *Multi-Dimensional Voice Program* (*MDVP*) model 5105, version 2 (Kay Elemetrics, Lincoln Park, New Jersey) via the same tape recorder on which data were acquired. Sampling rate for data capture procedure was set at 44.1 kHz. Acoustic analysis was performed on 1-second segments, taken from the steady state of the vowel. For the purpose of these analyses, a cursor was placed 400 ms after the onset of the vowel, and another cursor was placed 1 second after the first cursor. The acoustic parameters that were measured for each vowel consisted of three frequency-perturbation parameters: jitter, relative average perturbation (RAP), and pitch perturbation quotient (PPQ); two amplitude-perturbation parameters: shimmer and amplitude perturbation quotient

(APQ); and two noise-indices: noise-to-harmonic ratio (NHR) and voice turbulence index (VTI). These parameters were obtained from the *MDVP*. Singer's formant was measured by SPR (the ratio of the greater harmonic peak in the 2–4-kHz range to the greater harmonic peak in the 0–2-kHz range) as defined by Omori et al.[18] This calculation was performed using a *MATLAB* program written for the purpose of this study. The accuracy of each vowel production in comparison with the reference tone was measured by *rel*Accuracy%, as defined by Amir et al.[19]

RESULTS

For each vowel (/a/ and /i/) and pitch level (20%, 50%, and 80%), a group mean was obtained for all acoustic parameters (jitter, RAP, PPQ, shimmer, APQ, NHR, VTI, SPR, and *rel*Accuracy%) before and after vocal warmup. These data are presented in Table 1.

A series of separate analyses of variance (ANOVA) with repeated measures were conducted independently, one for each acoustic parameter. In these analyses, Warmup ("before" and "after"), Vowel (/a/ and /i/), and Pitch level (20%, 50%, and 80%) were treated as the repeated factors, whereas Voice-Category (Soprano and Mezzo-soprano) was regarded as the between-subject factor.

Warmup effect

Most acoustic parameters were affected by vocal warmup. Specifically, the three frequency-perturbation parameters as well as the two amplitude-perturbation parameters decreased significantly after warmup {jitter [$F(1, 18) = 19.42$, $p < 0.001$], RAP [$F(1, 18) = 18.48$, $p < 0.001$], PPQ [$F(1, 18) = 20.05$, $p < 0.001$], Shimmer [$F(1, 18) = 12.11$, $p = 0.003$] and APQ [$F(1, 18) = 6.11$, $p = 0.024$]}. These differences between voice quality before and after warmup are illustrated in Figure 1.

The overall mean value of the noise-index parameter NHR decreased after warmup from 0.101 to 0.096. This reduction was statistically significant [$F(1, 18) = 5.45$, $p = 0.031$]. On the other hand, the other noise-index parameters, VTI, did not change significantly after warmup ($p > 0.05$).

Overall mean SPR values increased after warmup from −29.25 to −27.82. This increase in the singer's formant amplitude was statistically significant [$F(1, 18) = 6.36$, $p = 0.021$]. Finally, no significant main effect for warmup was observed for the *rel*Accuracy% parameter ($p > 0.05$).

Pitch level effect

A general trend for a decrease in values was observed for the two amplitude-perturbation parameters, as pitch level increased. This trend was statistically significant for both shimmer [$F(2, 38) = 56.87$, $p < 0.001$] and APQ [$F(2, 38) = 27.60$, $p < 0.001$]. Contrast analyses confirmed a significant decrease between all pairs of pitch levels, for the shimmer parameter ($p < 0.05$), but only between low pitch level (20%) and the other two levels ($p < 0.05$) for the APQ parameter.

The two noise-indices (NHR and VTI) demonstrated a statistically significant trend for a decrease as pitch level increased {[$F(2, 38) = 135.81$, $p < 0.001$] and [$F(2, 38) = 22.76$, $p < 0.001$], respectively). Contrast analyses revealed significant differences between all pitch levels ($p < 0.05$). In addition, significant differences were observed between pitch levels for the SPR parameter [$F(2, 38) = 4.58$, $p = 0.017$]. Contrast analysis revealed significant differences between the high pitch level (80%) and the other two levels ($p < 0.05$). No statistically significant differences were observed among the three pitch levels for *rel*Accuracy%, nor for the frequency-perturbation parameters (jitter, RAP, PPQ) ($p > 0.05$).

Significant pitch level X warmup interactions were observed for the three frequency-perturbation parameters: jitter, RAP and PPQ {[$F(2, 38) = 3.75$, $p = 0.033$], [$F(2, 38) = 3.66$, $p = 0.035$] and [$F(2, 38) = 4.07$, $p = 0.025$], respectively}. These interactions are illustrated, in Figure 2, for the jitter parameter. Similar results were obtained for the RAP and PPQ parameters. As can be seen, warmup effect was more pronounced in the lower pitch level (20%) than in the other levels.

Voice category effect

No statistically significant main effect was found for voice category ($p > 0.05$) using any of the acoustic parameters tested. However, a significant warmup X voice-category interaction was found for the three frequency-perturbation parameters: jitter, RAP, and

TABLE 1. *Mean Values and Standard Deviations (in Parentheses) of Jitter, RAP, PPQ, Shimmer, APQ, NHR, VTI, SPR, and relAccuracy% for the Vowels /a/ and /i/ in the Three Pitch-Conditions, Before and After Vocal Warmup*

		Vowel /a/			Vowel /i/		
Variable	Warmup	20%	50%	80%	20%	50%	80%
Jitter	Before	1.11	.90	1.03	1.56	1.07	1.03
(%)		(.68)	(.41)	(.42)	(1.00)	(.57)	(.51)
	After	.85	.75	.84	.80	.91	1.05
		(.43)	(.38)	(.47)	(.56)	(.50)	(.49)
RAP	Before	.67	.55	.60	.93	.65	.63
(%)		(.41)	(.25)	(.25)	(.61)	(.35)	(.31)
	After	.51	.45	.51	.48	.56	.64
		(.27)	(.22)	(.29)	(.35)	(.31)	(.29)
PPQ	Before	.67	.54	.60	.94	.63	.60
(%)		(.40)	(.25)	(.30)	(.61)	(.33)	(.28)
	After	.51	.45	.51	.46	.54	.63
		(.26)	(.20)	(.28)	(.30)	(.29)	(.28)
Shimmer	Before	3.23	2.22	2.14	3.46	1.81	1.23
(%)		(1.07)	(.86)	(1.51)	(1.70)	(.70)	(.47)
	After	2.77	1.93	1.48	2.87	1.46	1.25
		(.84)	(.85)	(1.14)	(1.22)	(.75)	(.72)
APQ	Before	2.86	1.86	2.32	2.55	1.46	1.07
(%)		(1.16)	(.84)	(2.19)	(1.02)	(.72)	(.54)
	After	2.63	1.70	1.50	2.18	1.31	1.04
		(1.19)	(1.12)	(1.70)	(.89)	(.99)	(.68)
NHR	Before	.13	.10	.08	.13	.09	.08
		(.02)	(.01)	(.01)	(.03)	(.02)	(.02)
	After	.12	.09	.07	.13	.09	.08
		(.01)	(.01)	(.01)	(.02)	(.02)	(.02)
VTI	Before	.04	.03	.02	.04	.03	.03
		(.01)	(.01)	(.01)	(.01)	(.01)	(.01)
	After	.04	.03	.03	.04	.03	.02
		(.01)	(.01)	(.01)	(.02)	(.01)	(.01)
SPR	Before	−29.42	−28.53	−33.26	−28.91	−26.78	−29.02
(dB)		(7.37)	(7.68)	(7.24)	(8.64)	(7.98)	(8.86)
	After	−28.85	−27.77	−31.31	−26.36	−25.46	−26.94
		(6.93)	(7.09)	(8.33)	(8.42)	(7.63)	(6.03)
*rel*Accuracy%	Before	.65	.97	2.11	1.00	.92	1.21
		(.66)	(.74)	(4.11)	(.88)	(.51)	.76
	After	.65	.74	1.15	1.53	1.13	1.10
		(.75)	(.72)	(1.15)	(2.78)	(.60)	(.66)

PPQ {[$F(1, 18) = 5.34$, $p = 0.033$], [$F(1, 18) = 5.32$, $p = 0.032$], and [$F(1, 18) = 5.15$, $p = 0.036$], respectively}. These interactions are illustrated in Figure 3, for the jitter parameter. As can be seen, although the singers in both voice-categories had similar frequency-perturbation values prior to warmup (1.12% and 1.08% for the mezzo-soprano and soprano group, respectively), the mezzo-soprano singers improved these values, after warmup, more than the soprano singers did (0.68% and 0.94%, respectively). Similar results were observed for the other frequency-perturbation parameters (RAP and PPQ).

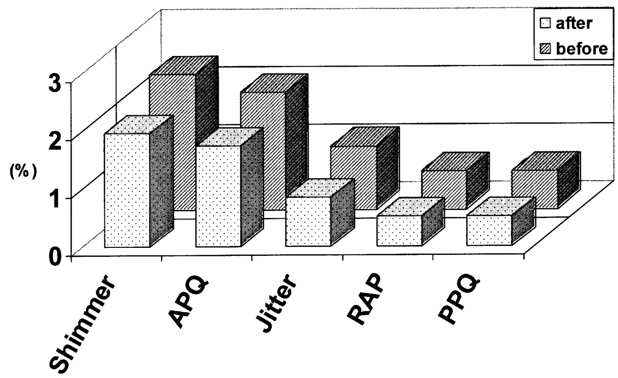

FIGURE 1. Group mean values of the frequency- and amplitude-perturbation parameters before and after vocal warmup.

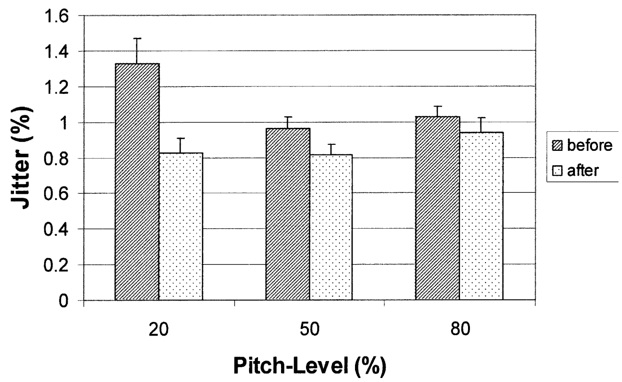

FIGURE 2. Group means values (± 1 standard error bars) for the jitter parameter at each of the three pitch levels, before and after warmup.

DISCUSSION

Several attempts to demonstrate the effect of warmup on voice were conducted previously. Although all researchers who addressed this issue agree that warmup is advantageous for the vocal mechanism, many studies have encountered difficulties in identifying a specific measurable parameter that would illustrate this effect reliably. The present study provides evidence for the effect of vocal warmup on voice quality using an acoustic analysis paradigm. The improvement in voice quality due to warmup was evident in the different domains of the voice signal; all frequency- and amplitude-perturbation parameters as well as the NHR and SPR parameters improved significantly after warmup. Our findings present acoustic analysis as a valuable tool for evaluating and quantifying the effect of vocal warmup on voice production. In addition, these results support the importance of incorporating different exercises into the warmup routine, which target not only the laryngeal muscles, but also breathing, posture, and relaxation exercises. The fact that the amplitude-perturbation measures were improved after warmup asserts that the control of the breathing mechanism, which has a major role in amplitude variation, is also improved by warmup, in addition to vocal fold control.

Frequency-perturbation is influenced mainly by changes in vocal fold mass, stiffness, and strain, whereas amplitude-perturbation is influenced mainly by the interaction between subglottal air-pressure and glottal resistance.[22] The two perturbation (frequency and amplitude) measures are related, and hence, it is not surprising that both aspects of voice improved after warmup. The effect of warmup on vocal stability can be attributed to various factors. Bishop[6] suggested different mechanisms by which warmup could affect muscle activity, and although these mechanisms were described in relation to different musculature organs, they can be readily applied to the voice production mechanism.[5] Muscle activity generates considerable heat; thus, the majority of the suggested general effects of warmup have been attributed to temperature-related mechanisms. Such mechanisms include decrease in viscosity resistance, increase in oxygen delivery to muscles, speeding of rate-limiting oxidative reactions, increase in anaerobic metabolism, increase in thermoregulatory strain, and increase in nerve conduction rate. In addition, other mechanisms, which are non-temperature related, have also been suggested as contributing to the effect of warmup on muscle activity. These include increase in blood flow to the muscles, elevation of baseline oxygen consumption, postactivation potentiation, and various psychological effects. It is beyond the scope of the present study to determine which of these suggested physiological effects is more significant in the specific case of vocal warmup. Yet, because the present paradigm provides a clear illustration of the effect of warmup on voice, it is suggested that future studies, examining the different possibilities mentioned

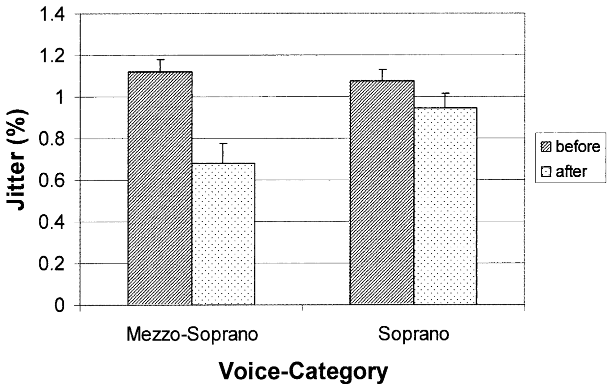

FIGURE 3. Group means values (±1 standard error bars) for the jitter parameter at each voice-category, before and after warmup.

above, incorporate acoustic analyses for identifying subtle changes between the different experimental conditions.

One interesting finding was that the two noise-indices that were included in the analysis (NHR and VTI) yielded different results. Specifically, NHR values improved significantly after warmup, whereas VTI values did not. The NHR parameter measures noise in the signal globally. As such, it is influenced by subharmonic components, voice breaks, and turbulent noise as well as by frequency- and amplitude-perturbation. These features are affected by irregularities in the vibration-pattern of the vocal folds.[23] On the other hand, the VTI parameter is designed to identify high-frequency components, which are commonly related to "breathiness." VTI is described as affected mostly by turbulences that result from incomplete or loose adduction of the vocal folds.[23] Because the effect of warmup was evident using the NHR but not the VTI parameter, it is suggested that warmup influences mainly vocal-fold regulation-of-vibration, and less so the magnitude or efficiency of adduction. This can be viewed as an acoustic support to the basic idea that underlies warmup: improving muscle activity and coordination. Apparently, warmup affects the body of the vocal folds more than it affects other superficial layers, which affect efficiency of adduction of the glottis. Nonetheless, due to the novelty of this finding, in the context of vocal warmup, this interpretation of the results requires further support by future studies.

The SPR parameter, which measures singer's formant (SF) amplitude, was also affected by warmup. SF is a specific voice-quality component that characterizes professional voices. It results from shaping the resonatory tract such that a unique formant is formed, with a center frequency between 2.3 and 3.8 kHz.[18] As all vocal warmup routines include voice production and placement exercises,[3,4] it is not surprising that singers achieved a more pronounced SF after warmup. Moreover, the addition of the SF to the voices of the singers, after warmup, can also help in explaining the difference in the results between the NHR and VTI parameters. It is possible that the added harmonic energy around 3 kHz (SF) improved the NHR values, which compare harmonic energy in the 70–4500-Hz range to inharmonic (noise) components in the 1500–4500-Hz range. On the other hand, the VTI parameter, which measures inharmonic energy in the 2800–5800-Hz range, is expected to be less affected by the contribution of the SF to the 3-kHz range. It is possible, then, that the difference between the results obtained by the NHR and VTI parameters can be partially attributed to the changes in the resonance of the vocal tract after warmup, and not only to the improvement in the regulation-of-vibration.

In addition to the significant main-effect that was found for vocal warmup, an interaction between warmup and voice-category was found for all frequency-perturbation parameters (jitter, RAP, PPQ). Specifically, the mezzo-soprano singers appeared to benefit more from warmup than the soprano singers did. As described above, both groups improved frequency-perturbation values after warmup, and yet the magnitude of the improvement in the mezzo-soprano group was approximately three times greater than that observed in the soprano group (see Figure 3). One possible explanation for this difference is that mezzo-soprano singers have longer and heavier vocal folds than soprano singers.[24,25] As warmup affects mainly muscle mass,[6,7] it is possible that the effects of warmup (both temperature- and non-temperature-related effects) are more pronounced in the mezzo-soprano group. Validating this possibility using previous studies is difficult, because none of these studies, which examined vocal warmup, have compared its effectiveness among different voice-categories.[5,8–11,26] Possibly, though, the reason that many of these studies failed to identify a consistent warmup effect, is that they did not distinguish among the different voice-categories. Future research should address this issue and further explore the effect of vocal warmup in different voice-categories using both men and women. In addition, the present study, similar to previous ones, used single before and after measurements. Added support for the effect of warmup on voice quality in specific voice categories could be obtained, therefore, in future studies by using multiple prewarmup and postwarmup measures.

Finally, in addition to the fact that warmup effect was influenced by voice-category, it was also found to be affected by pitch level, for all frequency-perturbation parameters. Our results indicated that, in the 20% pitch level, warmup effect on frequency-perturbation values was approximately three times larger than it was in the 50% and 80% pitch levels (see Figure 3). Interestingly, although frequency-perturbation values after warmup were similar across all pitch levels, this measure was significantly larger in the 20% pitch level in the "before warmup" condition. The reason for this finding is not clear yet. It is possible that because during the lower pitch-production, vibrating mass is larger and vocal folds less strained, they can be more affected by irregularities. Hence, vocal warmup affects this pitch-range more significantly than it does in other pitch-ranges. This explanation is reminiscent of Motel et al's[9] findings. They reported that phonatory effort in the 80% pitch levels was significantly higher than in the 10% and 20% pitch levels. Their finding of lower phonatory effort in the lower pitch-range supports the possibility that the looser vocal folds are more susceptible to vibratory irregularities. They also suggested that, under specific conditions, vocal warmup could increase PTP by increasing the viscosity of the vocal folds and, as a result, improve vocal stability. Clearly, a more definite answer to this question would require a study that combines physiological and acoustic measurements and preferably supplementing stroboscopic evaluation.

In summary, the results presented here demonstrate, through an acoustic analysis paradigm, that vocal warmup has a significant and measurable influence on vocal quality of young female singers. Further research, as suggested above, could show the extent of this influence on a wider range of voices and ages, and it may shed light on the physiological mechanism involved in this process.

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