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Immediate Effects of Vocal Warm-Up on the Acoustic and Aerodynamic Parameters of Speech-Language Pathology Students

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ABSTRACT

Objective: Although vocal warm-up is vital for singers and other professional voice users, no consensus has been reached regarding its underlying physiological effects, especially for the non-singing community. Accommodating speech and language pathology (SLP) students, this research aimed to investigate the effects of vocal warm-up on the acoustic and aerodynamic parameters of voice.
Material and Methods: A quasi-experimental, pre-test–post-test research design was used. A total of 28 SLP students performed a 20-minute session of vocal warm-up based on breathing, stretching, phonation, and resonance exercises. Data analysis consisted of instrumental analysis in which the Multidimensional Voice Programme (MDVP) and Phonatory Aerodynamic System (PAS) were used to measure acoustic and aerodynamic parameters before and after vocal warm-up.
Results: A significant decrease in jitter and shimmer values was detected after the vocal warm-up period. Additionally, significantly higher values were found in the subglottal pressure estimate.
Conclusion: Following vocal warm-up, acoustic and aerodynamic parameters improved to normal values. The findings indicate that vocal warm-ups improve the objective voice quality.
Keywords: Acoustic analysis, aerodynamic analysis, phonatory aerodynamic system, voice quality, warm-up

INTRODUCTION

A professional voice user is anyone who relies on their voice for their livelihood. This population includes not only singers and actors, but also teachers, salespeople, telemarketers, and anyone who needs to maintain optimum vocal quality as part of their profession (1). Considering the higher prevalence of voice disorders among professionals with heavy vocal demand, the development of preventive strategies, such as voice training, is of critical importance (2). Research findings revealed that speech language pathology (SLP) candidates as future professional voice users exhibit more voice-related problems (12%) than the general population (3–9%) (3). The manner of SLP voice use differs from routine conversation level, as SLPs must demonstrate voice therapy techniques and provide vocal coaching (4).

The analogy of vocal athletes is commonly used to refer to professional voice users who rely on their voices for earning their livelihood; such as singers, teachers, and performers (5). Professional voice users are required to warm up their voices before vocally demanding activities in much the same manner that athletes prepare their muscles for sports performance (6, 7). Studies have shown that warming up the voice affects the physiology of the vocal mechanism (8-17), in addition to helping mental preparation for the upcoming activity (18). Positive changes in both objective measurements and subjective/perceptual evaluations (8-17, 19-24) were documented following vocal warm-up. Although it is widely acknowledged that a vocal warm-up is essential for optimal voice function, relatively little progress has been made in describing the underlying physiological effects and their impact on the acoustic and aerodynamic parameters of the voice.

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Acoustic analysis, as an objective and non-invasive measurement tool, assesses vocal fold function and tracks changes over time (25). Research has demonstrated that vocal warm up has positive effects on acoustic parameters, including improvement in fundamental frequency (F0) and formant values, decrease in perturbation values, improvement in noise-to-harmonic ratio, increase in singer's formant amplitude and spectral energy (8-14, 16), establishment of singer's formant cluster, and increase in vocal range profile (12-17). On the other hand, no significant changes in the abovementioned acoustic parameters following vocal warm-up have been reported in the literature (8, 9, 11). A study recruiting untrained singers found no significant changes in acoustic measurements following straw phonation as a vocal warm-up, whereas decreased shimmer along with increased fundamental frequency were reported following traditional vocal warm-ups (8). In another study with speech language pathology students, the vocal warm-up yielded no improvements in perturbation values, whereas an overall increase in objective vocal quality represented by the Dysphonia Severity Index was noted (11).

Although used less frequently in relevant literature, aerodynamic analysis provides valuable data on laryngeal valve mechanisms, airflow during sound production, and subglottal air pressure, which are related to underlying voice physiology (26). Studies investigating the effects of vocal warm-up on aerodynamic parameters have yielded inconclusive results, especially regarding the phonation threshold pressure, which is defined as the minimum subglottal pressure required to initiate phonation vocal fold oscillation (27). After vocal warm-up, the phonation threshold pressure increased or decreased in some studies, whereas in others, inter-subject variability, gender variability, or no change was observed (7, 8, 19, 21, 28-31). Portillo et al. compared the effects of vocal exercises using the semi-occluded vocal tract (SOVT) and open vocal tract (OVT) as a vocal warm-up for contemporary commercial music singers (19). Decreased sound pressure level, increased airflow, and decreased aerodynamic efficiency were found for the latter; and the findings were interpreted by the authors as indicative of vocal fatigue. In another study by Saldias et al., both water resistance therapy (a type of SOVTE) and OVT warm-up decreased the subglottic pressure and inspiratory airflow duration, whereas the sound pressure level decreased only in the OVT group (32). Although increased self-perceptions of vocal quality were reported for both conditions, SOVTEs were shown to be more effective in preparing vocal mechanisms for an upcoming vocal load, leading to a more economic voice. While determining the optimal vocal warm-up protocols, their potential effects on the physiology of vocal mechanisms should also be considered, in addition to the psychological component.

The findings of the aforementioned studies indicate that the literature on the effects of vocal warm-up is somewhat inconclusive. This inconsistency arises because the methodologies are quite varied. The use of a variety of warm-up exercises, the duration of the warm-up, and the measurement of voice quality using different techniques make it difficult to reach a consensus regarding the ideal warm-up protocol.

Titze suggests that the five best exercises for vocal warm-up are a) lip trill, tongue trill, humming, and tube phonation on glides, scales, or arpeggios, b) two-octave pitch glides on high vowels, c) forward tongue roll and extension, vowel sequences /a/-/i/, 4) messa di voce, 5) staccato on arpeggios (33). Furthermore, he clarifies the specific purpose each exercise serves. In parallel with Titze's proposals, vocal warm-up regimens commonly selected for research purposes include SOVTE, which consists of lip trills, tongue trills, humming, and nasal consonants, bilabial fricative, straw phonation, LaxVox, hand-over mouth, and finger kazoo technique (14). SOVTE have been hypothesised to reduce the phonation threshold pressure and perceived phonatory effort; improve acoustic qualities of voice, and lead to morphometric differences of the vocal tract that help establish healthy voice production (34).

Vocal warm-up preferences also vary across the singing and non-singing community; and the current literature mostly focuses on the singing community (13-17, 35-39). In such a study, Gish et al. investigated the characteristics of vocal warm-up regimens for 170 vocalists (40). 54% of the participants stated that they always warmed up their voice before singing. The most frequently used singing exercises were ascending/descending five-note scales, octave scales, legato arpeggios, and glissandi. Regarding the non-singing warm-up exercises; stretching muscles, breathing, and postural alignment exercises were the most preferred. As vocal warm-up is recommended to be performed by other professional groups with high vocal loads, warm-up protocols for non-singing communities should also be investigated. Vocal warm-up has a positive effect on the quality of speaking and singing voices, and warming up the voice can be beneficial for non-singing communities by preventing vocal fatigue and improving vocal economy.[8] In addition, vocal warming is proven to be effective when used for voice rehabilitation in people with voice disorders, so warm-up can also be practised as a therapeutic method or a preventive measure for occupational dysphonia (12, 41). Therefore, this study was conducted with SLP candidates because they will be required to use their voice intensively in the future due to the nature of their future employment facing an increased risk of developing voice disorder. For this purpose, this study aimed to determine whether SOVTE, as a warm-up, differentially affects the acoustic and aerodynamic parameters of voice in future SLPs. We hypothesised that vocal warm-up will have an immediate and significant improvement in vocal acoustic and aerodynamic properties.

MATERIALS and METHODS

Participants

Employing the convenience sampling method, this study employed a quasi-experimental pre-/post-interventional research design. A total of 28 undergraduate and graduate SLP students (10 female and 18 male) within the age range of 20-35 years were recruited after obtaining informed consent to participate in writing. Participants with a history of hearing defect, surgery of the vocal apparatus, vocal pathology, head and neck trauma, neurological disorder, respiratory tract infections, or smoking were excluded from the study. None of the participants received any vocal training or previous voice therapy. There were no singers among the participants. The ethics committee of Anadolu University approved the study.

Voice assessment and equipment

The data collection process was carried out in the voice analysis laboratory of Anadolu University Research Centre for Speech and Language Disorders. A multi-dimensional voice analysis (acoustic and aerodynamic measurements) was performed before and immediately after each vocal warm-up session. The first author collected data and completed the vocal warm-ups with the participants.

The Multi-Dimensional Voice Programme (MDVP) Model 3700 (Kay Elemetrics Corp., Lincoln Park, NJ) was used to compute the acoustical data. Voice recording was performed using a unidirectional dynamic microphone (Shure SM48 Dynamic Cardioid Microphone) in a sound-attenuated room. A constant mouth-to-microphone distance of 10 cm at a 45° angle was maintained during each recording. Voices were recorded at a sampling rate of 44.1 kHz. Participants were instructed to perform sustained /a/ vowel phonation three times with comfortable pitch and loudness for three seconds. The middle second of the vowel prolongation was segmented for analysis. The acoustic parameters measured were fundamental frequency (F0, Hz), frequency perturbation (Jitter, %), amplitude perturbation (Shimmer, %), and noise-to-harmonic ratio (NHR, dB).

Aerodynamic measurements of the voice were performed using the Phonatory Aerodynamic System (PAS) Model 6600 (Medical Kay Pentax). The selected protocol within the scope of this study is the Voicing Efficiency Protocol (VOEF), which calculates a number of parameters describing glottal behaviour. Before each recording session, the researcher calibrated the measuring equipment appropriately. The participants were asked to press the mask firmly against their face to prevent air leakage, as shown in Figure 1. An intraoral tube was inserted 2 cm into their mouths to acquire oral pressure. They were instructed to repeat the syllable [pa:] seven consecutive times in a single breath at a comfortable pitch and loudness. Three trials were performed. Before the recording, the experimenter trained the participants on how to produce the syllables at an appropriate rate (1.5 to 2 syllables per second). The first and last syllables in the string were not included, and the middle five syllables in between were analysed. The subglottal pressure was estimated from peak air pressure during the production of the voiceless plosive [p], while average airflow and sound pressure level measurements were obtained during the vowel segment [a] (42). Variables analysed in this phonatory task were mean sound pressure level (SPL, dB), average airflow rate (Lit/Sec), and subglottal pressure estimate (P_{sub}, cmH2O).

Figure 1: The correct way to hold the PAS external module during data capture (picture taken from PAS instructional manual)

Vocal warm-up exercises

The vocal warm-up protocol consisted of gentle stretching exercises, breathing exercises/posture alignment, and phonation/resonance exercises. Warm-up exercises were designed based on previous research regarding vocal warm-up and adapted for the non-singing community (7, 11, 43). The entire warm-up period lasted 20 minutes. The researcher provided corrective feedback to ensure that the exercises were performed in accordance with their purposes. The participants were advised to perform the exercises without tension in the head and neck area.

A warm-up activity began with gentle stretching exercises of the muscles of the head, neck, arm, shoulders, and mandible region. Then, they transitioned to diaphragmatic breathing exercises, improving their respiratory function without excessive shoulder and neck movements. Each exercise was performed using due attention to proper body alignment. For the last part of the vocal warm-up, participants engaged in phonation and resonance exercises, increasing the flexibility of their vocal folds and facilitating voice production. Phonation and resonance exercises were performed as follows:

1) Lip and tongue trill at a habitual speaking pitch and loudness, and ascending and descending glissandos through a comfortable vocal range 2) Humming at a habitual speaking pitch and loudness, and ascending and descending glissandos through a comfortable vocal range 3) Ascending and descending scales on syllables with nasal consonant and vowel sequences 4) Gliding yawning on open-mouthed vowels.

Statistical analysis

All statistical analyses were performed using SPSS (IBM SPSS Corp., Armonk, NY, USA) 22.0. The Shapiro-Wilk test was used to evaluate the distribution of the selected acoustic and aerodynamic parameters. In the case of a normal distribution, the paired t-test was performed to compare pre- and post-warm-up conditions. To compare non-normally distributed data, the Wilcoxon signed-rank test was used. The level of significance was set at $p<0.05$ in all tests.

RESULTS

This study aimed to investigate the immediate effects of vocal warm-up on acoustic and aerodynamic parameters in future SLPs. The paired sample t-test and Wilcoxon signed-rank test revealed significant effects of vocal warm-up exercises on objective voice quality. The results are detailed below:

Acoustic parameters

Acoustic analysis of the six recordings could not be performed for technical reasons; therefore, the corresponding subjects were excluded from the MDVP analysis. Table 1 presents the mean and standard deviation of the acoustic parameters pre- and post-vocal warm-up. A significant difference was observed in the jitter and shimmer values with p-value <0.05 of the Wilcoxon signed-rank test. No statistically significant effect was found for fundamental frequency or noise-to-harmonic ratio (p>0.05).

Aerodynamic parameters

The aerodynamic parameters measured under pre- and post-warm-up conditions are presented in Table 2. A statistically significant difference was found in the subglottal pressure estimate (p<0.05). However, there were no statistically significant differences between pre- and post-warm-up for the sound pressure level and average airflow rate variables (p>0.05).

Table 1: Mean values and standard deviations of acoustic measurements before and after vocal Warm-up

	Pre		Post		
	Mean	**SD**	**Mean**	**SD**	**P value**
F0 (Hz)	180.09	60.03	180.28	60.76	0.894
Jit (%)	0.964	0.72	0.583	0.432	0.000*
Shim (%)	3.099	0.857	2.402	0.637	0.000*
NHR (dB)	0.124	0.013	0.124	0.014	0.865

SD: Standart Deviation; F0: Fundamental Frequency; Jit: Jitter; Shim: Shimmer; NHR: Noise to Harmonic Ratio, *: Significance level <0.05.

Table 2: Mean values and standard deviations of aerodynamic measurements before and after vocal Warm-up

	Pre		Post		
	Mean	**SD**	**Mean**	**SD**	**P value**
SPL (dB)	92.78	3.80	93.65	4.14	0.207
Airflow (Lit/Sec)	0.165	0.83	0.159	0.074	0.799
Psub (cmH2O)	5.66	1.24	7.00	2.00	0.000*

SD: Standart Deviation; SPL: Sound Pressure Level; P_{sub}: Subglottal Pressure Estimate
* Significance level <0.05.

DISCUSSION

In the present investigation, the authors attempted to determine the immediate effects of vocal warm-up on acoustic and aerodynamic parameters in speech and language pathology students. Significant changes across parameters were determined (decrease in jitter and shimmer values, increase in subglottal pressure estimate) under the postwarm-up condition, indicating that vocal warm-up alters the physiology of the vocal mechanism.

According to Bishop, warming up muscles improves sport performance, resulting in physiological changes, such as increased blood flow to muscles, decreased muscle viscosity, increased oxygen delivery, acceleration of metabolic reactions, and increased speed of nervous impulses. In addition, warm-ups have been proposed to decrease the risk of sports injury (44). As voice production is a complex biomechanical phenomenon, mostly controlled by laryngeal muscle activation, warm-up is thought to improve the vocal mechanism in a similar way as that of other muscles of the human body. Furthermore, a vocal warm-up may help reduce potential risk factors of voice disorders in professional voice users, such as speech language pathologists. Despite their heavy voice use and elevated vocal risk given their occupational demands, voice issues among SLPs and SLP students have received little attention from researchers (45).

Acoustic analysis showed positive effects of vocal warm-up in two parameters. Jitter, which is related to frequency perturbation, is defined as the amount of cycle-to-cycle variability of frequency. The other perturbation measure, shimmer, assesses cycle-to-cycle variations in the period amplitude. These parameters are frequently used as baseline measures to capture changes between pre- and post-intervention measures in voice research. High jitter and shimmer values are associated with dysphonia, which is an indication of the vibrational irregularity of vocal folds (6, 25, 46). The results of this study revealed a significant decrease in jitter and shimmer after a 20-minute vocal warm-up. This suggests that vocal fold vibration can be controlled more effectively via vocal warm-ups (47). Improvements in the jitter and shimmer parameters following vocal warm-up were in line with previous research (12-14). A recent study designed to assess the impact of vocal warm-up exercises consisting of tongue trills, lip trills, and humming at a steady tone and then with pitch variations revealed similar positive results for jitter and shimmer values in singing students (14). Amir, Amir, and Michaeli's work also confirmed that performing a vocal warm-up based on vocal exercises at different pitches, as well as breathing, posture, and relaxation exercises, which is also a similar protocol to that of our study, significantly decreased jitter and shimmer values and improved vocal stability in 20 singers (13).

Regarding aerodynamic analysis, an increased subglottic pressure was observed in the post-warm-up condition. The subglottal air pressure is estimated from the intraoral air pressure produced during lip occlusion for a series of /pVpV/ syllables. The same task performed at the minimum loudness level was used to estimate the phonation threshold pressure, another frequently used aerodynamic variable (6, 25). The aforementioned literature on the aerodynamic effects of vocal warm-up is still scarce and has conflicting findings, especially concerning the two parameters (7, 19, 21, 28-32). Contrary to our findings, a study comparing the effects of OVTE and SOVTE found a significant decrease in subglottal air pressure post-warm-up under both conditions. It was suggested that this decrease might be related to vocal fatigue as Titze stated that reduced subglottal pressure could be a consequence of respiratory muscle fatigue, promoting the early phase of vocal fatigue (48).

The warm-up protocol used in this study was heavily based on SOVTE (lip trills, tongue trill, humming and nasal consonants). In an integrative review by Apfelbach and Guzman, studies investigating the effects of SOVTE on subglottal pressure have not produced consistent results. SOVTE has been reported to increase or decrease subglottic pressure or result in no change. The authors explained this discrepancy because of different baseline measures. In other words, SOVTE normalise subglottal pressure level by either increasing or decreasing, depending on the pre-intervention amount of pressure (34). Although increased subglottal pressure generally indicates hyperfunctional voice use, which is undesirable for optimum vocal quality, the findings can be interpreted from this perspective (6). The mean subglottal pressure increased from 5.66 cm H2O to 7.00 cm H2O following vocal warm-up in our research. According to the normative data for phonatory aerodynamic measures obtained with PAS among healthy Turkish speakers, the norm value for subglottal pressure parameter within the corresponding age group was 7.67 cm H2O in voicing efficacy protocol (49). Thus, the increase in subglottal pressure levels in our study generated an improvement towards normal values in a healthy Turkish-speaking population. It is worth noting that normative data for air pressure measurements in a Turkish-speaking population are higher than the data of an adult normative study on PAS by Zraick et al. This difference has been interpreted as a result of the participants' native language (49, 50).

Schaeffer conducted pre- and post-stimulation research to measure aerodynamic parameters on PAS in 20 participants with vocal complaints (26). Stimulation training targeted coordination of respiration and phonation in addition to control of abdominal muscles during phonation. After the stimulation training, 17 out of 20 participants approximated their subglottal pressure level to the normal range, which was in line with our study findings.

In summary, data from the current study revealed positive effects of vocal warm-up on the acoustic and aerodynamic parameters of the voice. Specifically, the jitter and shimmer perturbation measures significantly decreased, indicating better acoustic quality. In addition, the subglottal pressure estimate improved to the normal range.

It may be interesting to conduct further research in real-life settings where it is possible to observe the vocal demands of professional voice users during an ordinary day. Future research on vocal warm-up should include a larger number of participants and different warm-up protocols with varying durations. A fully experimental research can also be conducted by including a control group, which is lacking in this study.

The current study has some methodological limitations related to research design and sample size. Using a quasi-experimental approach, the study lacks equivalent control group and randomisation. The sample size is relatively small. Further studies should attempt to recruit more participants and control threats to internal validity in order to generalise the findings to a broader population.

CONCLUSION

Vocal warm-up is critically important for obtaining the optimum vocal quality in both speaking and singing voices. Although professional voice users are advised to perform a vocal warm-up before intensive voice use, the physiological mechanism of warm-up remains unclear. This study highlights the positive influence of a vocal warm-up on objective voice quality. The instrumental analysis of voice using MDVP and PAS demonstrated a significant decrease in perturbation parameters and improvement in the subglottal pressure estimate. Professional voice users, such as speech-language pathologists, should implement vocal warm-up strategies in their routines to improve the quality of their voice and attenuate the adverse effects of vocal load.

Data Availability Statement: Raw data were generated at the voice analysis laboratory of Anadolu University Research for Speech and Language Disorders. Derived data supporting the findings of this study are available from the corresponding author M. A. on request.

Ethics Committee Approval: This study was approved by the Ethics Committee of the Anadolu University (Date: 15.12.2015, No: 27441).

Informed Consent: Informed consent was obtained in writing from all the participants.

Peer Review: Externally peer-reviewed.

Author Contributions: Conception/Design of Study- M.A., E.T.Ö.; Data Acquisition- M.A.; Data Analysis/Interpretation- M.A., E.T.Ö.; Drafting Manuscript- M.A.; Critical Revision of Manuscript- M.A., E.T.Ö.; Final Approval and Accountability- M.A., E.T.Ö.

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