Vocal Fatigue in Prospective Vocal Professionals

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Summary: Objectives. The goals of the study were to (a) examine vocal fatigue in speech-language pathology students through subjective and objective measures following a novel 30-minute vocal loading task (VLT) and (b) evaluate the effects of psychosocial factors on vocal fatigue.

Methods. Seventeen speech-language pathology students completed a 30-minute VLT using the LingWAVES software program. In addition to maintaining target intensity goals during reading a text, participants were also required to modify their pitch and voice quality. Vocal fatigue was measured subjectively using Vocal Fatigue Index and Borg vocal effort scale and objectively using variations of relative sound pressure level, fundamental frequency, pitch strength, smoothed cepstral peak prominence (CPPS), and acoustic voice quality index before, during, and after VLT. Participants provided information on their sleep quantity, stress, and depression through nonstandardized and standardized surveys.

Results. Results revealed that perceived effort and fatigue increased significantly after the 30-minute VLT. Acoustic measures of relative sound pressure level and fundamental frequency and increased systematically during and after the completion of task. All students were moderately stressed and measures related to pitch were highly related with perceived stress.

Conclusions. The results of this study provide support for altering multiple vocal parameters to induce measurable changes in vocal fatigue following a short-duration VLT.

Key Words: Vocal fatigue–Speech-Language Pathology (SLP) students–Vocal loading–Acoustics–Psychosocial factors.

INTRODUCTION

It is estimated that between one-fourth and one-third of the working population in the United States[1,2] and across the world[3] rely heavily on their voice to perform their job duties. These "professional voice users" (eg, singers, theatre artists, teachers, lawyers, fitness instructors, telephone/call center operators, priests, and speech-language pathologists [SLPs]) are often required to meet heavy vocal demands such as using their voice for prolonged periods of time and/or using their voice that is not habitual in their everyday life. Prior research also highlighted nonoccupational voice use (between 4 and 10 pm and weekends) in teachers and reported intensity levels to be only slightly lower compared to occupational settings (−2.5 dB) and that such nonoccupational voice use could affect the already overloaded voice.[4] Furthermore, professional voice users are often faced with environmental constraints such as poor room acoustics, humidity levels, and high ambient noise. Indeed, all these lifestyle factors make them highly susceptible for developing voice disorders and dysphonia compared to the general population. For example, the prevalence of reporting a current voice problem was higher in teachers (11.0%) than in nonteachers (6.2%).[5] Dysphonia in professional voice users can have significant negative impact on job performance, can lead to loss of wages due to absenteeism or even loss of employment, and can subsequently result in poor quality of life.[6,7]

Research on preprofessional voice use

Preprofessional voice users, that is, students who are training to be in vocally demanding professions also experience vocal demands similar to professional voice users (eg, multiple class presentations/singing/theatre activities), often participate in community and social events that require talking, and may also have additional jobs that involve continuous or prolonged voice use, yet there are limited number of research studies in this population.[8] These epidemiologic studies were largely focused on student teachers[9–11] or singers.[12,13] Their results showed that 20%–30% of the trainees suffer from voice symptoms (eg, vocal fatigue) and disorders due to vocal misuse (eg, prolonged periods of voice use) and vocal abuse (eg, persistent throat clearing). Similar to teachers and singers, SLPs are one group of professionals who extensively use their voice daily for providing therapy and counseling among other tasks and require optimal voice quality to guide and model good targets for better treatment outcomes. Despite this significance, there is minimal focus on this population both at professional and preprofessional levels.[14–17] Gottliebson et al (2007)[15] reported voice problems among 12% of a total of 104 SLP students, and this percentage was similar to previous reports on teachers (11%) and was more common than the general population (3%–9%). Cross-sectional study involving 197 Dutch female SLPs from all four years of education (three undergraduate and one graduate) revealed that 93% of student SLPs reported presence of pain after speaking (71% sore throat) and many had problems with voice quality.[17] The purpose of the current study was to examine vocal fatigue in the understudied SLP students through an experimental vocal loading paradigm.

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Remainder of the introduction provides background information leading to experimental research questions.

Overview of vocal fatigue and vocal loading tasks

Vocal fatigue has been commonly reported as one of the symptoms in several voice disorders. Although a precise and a universally accepted definition of vocal fatigue is currently lacking, it has been described as the negative vocal adaptation that occurs as a consequence of prolonged voice use.[18] Clinicians have often described it as a feeling of vocal tiredness and weak voice after prolonged voice use.[19] Furthermore, vocal fatigue has been generally identified through multiple symptoms including perception of increased vocal effort and discomfort, reduced pitch range and flexibility, reduced vocal projection or power, reduced control of voice quality, increase in symptoms across the speaking day, and improvement in symptoms after a period of rest.[7] Given the nature of extreme vocal demands of professional voice users, it is not surprising that they are significantly more likely to have symptoms of vocal fatigue, for example.[13,20,21] Indeed, Roy et al (2004) reported that teachers were significantly more likely than nonteachers to have experienced symptoms of hoarseness, discomfort, and increased effort while using their voice, tiring or experiencing a change in voice quality after short use, and difficulty projecting their voice. Vocal fatigue has been extensively studied in naturalistic[22–25] or in laboratory[26–30] settings. Specifically, in the laboratory, vocal fatigue has been induced through different types of stressors and/or vocal loading tasks (VLTs). For example, external stressors such as room acoustics and background noise[31–33] and internal stressors such as duration and type of the speaking task have been varied.[23,26–28,34,35] Among these studies elevated intensity and prolonged duration of the speaking task have been most commonly used in VLTs to induce vocal fatigue.

Effects of sleep, depression, and stress on vocal health and function

The World Health Organization sees health as a multidimensional state of being that encompasses physical, mental, and social conditions.[36] By extension, vocal health can also be considered multifactorial that may be influenced by vocal loading (eg, prolonged or intensive voice use), physical factors (eg, poor body posture, respiratory allergies, and poor sleep behaviors), environmental factors (eg, dust and humidity), psychological/emotional factors (eg, anxiety, stress, and depression), and personality (eg, neuroticism, extraversion, and psychoticism). Indeed, prior research has indicated that voice symptoms/disorders can be exacerbated by psychological factors such as stress and personality, for example.[37] Regarding sleep, in young adults, sleep deficiency in terms of quantity and quality, resulted in poor self- and listener-perceptions, reduced fundamental frequency (f_0), and higher scores on voice handicap index. Listeners perceived voices to sound more tired and poor in voice quality.[38,39] Moreover, sleep quality was also better related to overall health (including feelings of tension, depression, and anger) and satisfaction with life.[40] Regarding depression, Marmor et al (2016)[41] examined the association between depression and voice problems based on 2012 National Health Interview Survey data. Young adults between the ages of 18 and 30 reported to have more voice problems in the past year compared to other age groups included in the study. Furthermore, the presence of depressive symptoms was associated with nearly 2-fold increase in the likelihood of reporting a voice problem. Regarding stress, research has been conducted on teachers,[42] young adults,[43] and college students[44] including those from SLP program.[44] Adults with hypertension were 42% more likely to report voice disorders and adults with a history of mood disorders reported more voice disorders than overall population (9.9% for anxiety/panic disorder and 9.2% for depression). Study by Ferreira et al (2012)[44] showed that vocal fatigue was significantly related to with intense voice use, stress, and digestive problems in a prospective survey study of 517 students. Perceived stress evaluated through Perceived Stress Scale, PSS[45] and electrophysiology (measures of heart rate and heart rate variability) revealed higher stress levels prior to mindfulness training. It is likely that stress for SLP students stems from both academic and clinical demands.

Research questions

Students training to be future vocal professionals frequently exhibit symptoms of vocal fatigue and could potentially be at a high risk for developing voice disorders. To our knowledge, only a limited number of studies have examined vocal fatigue in SLP students and these studies were mostly based on questionnaires/surveys. Therefore, the primary goal of the current study was to examine vocal fatigue in SLP students through an experimental vocal loading paradigm. Prior studies on vocal loading have largely focused on speaking at a high intensity level for durations of approximately 2 hours.[46] The current study tested a novel VLT paradigm that required students to alter/modify a combination of three vocal parameters; intensity, f_0, and voice quality for a relatively shorter duration (30 minutes). Such a task may potentially be useful in clinical settings where time constraints do not allow clinicians to obtain a true picture of the habitual voice use specifically in professional/preprofessional voice users. Majority of the research on vocal fatigue have examined the tasks and outcome measures in general population and professional voice users but have failed to examine the effects of physical/psychological factors such as sleep, depression, stress, and generalized fatigue adequately. Given the significance of the effects of underlying physical/psychological factors on vocal symptoms/fatigue especially in professional/preprofessional voice users, the secondary goal of this study was to investigate/determine this missing relationship.

METHODS

Participants

A total of 28 students (undergraduate and graduate) majoring in SLP and music completed an initial Qualtrics questionnaire.

All students were expected to meet the following inclusionary criteria: native speakers of American English, between 18 and 35 years of age, and absence of comorbid health conditions affecting respiration and voice. Exclusionary criteria included students with history of smoking, chronic alcohol use, recent upper respiratory infections, asthma or other respiratory disorders, or self-reported reflux disease. Of these, 23 students fit all the criteria and 17 (16 SLPs and one music) completed the vocal loading task in the laboratory. All participants were female and ranged between 22 and 24 years of age. All study procedures were approved by the Institutional Review Board at the University of South Florida. All participants consented to participation and were compensated for their participation.

Speech stimuli and tasks

All participants completed 3 trials of sustained /a/ phonation for 5−6 seconds and read "The Rainbow Passage"[47] pre- and post-VLT. The VLT was accomplished by adapting the Vocal Loading Test module/protocol from LingWAVES software program (Version 3.0; Wevosys, 2014). All participants read text from Charlotte's Web by White and Williams[48] for the duration of VLT. The VLT module in LingWAVES required participants to alternate vocal intensity every 5 minutes between two predetermined levels ("low load" and "high load") for a total duration of 30 minutes. Thus, there were six 5-minute intervals, 3 with low-load and 3 with high-load conditions. Throughout the task, the software indicated if the participants fell below the desired dB sound pressure level (SPL) goals using a large arrow on the computer screen. Recordings were made at 50 cm mic-to-mouth distance in a sound booth. In this study, two novel modifications were made to the VLT. *First*, the intensity level for high-load condition was customized to each participant's baseline SPL and was set at ***High load dB SPL*** = ***Low load dB SPL*** + (***Low load dB SPL x*** 0.15). The current study chose the addition of 15% increase as "ideal" based on pilot testing by 2 of the authors with levels varied between 10% and 20%. At 10%, there was consensus (subjective impression) that the high-load condition did not stress the vocal mechanism adequately to induce fatigue. At 20%, there was consensus that the high-load condition may potentially risk a vocal injury given that participants were required to sustain it for a relatively long duration. In addition, the 20% increase may also be too high depending on a participant's baseline/low-load dB level. For example, a low-load level of 72 dB will result in a high-load level of 83 dB as per the equation above. Indeed, prior studies on vocal fatigue have reported maximum levels between 75 and 85 dB.[46] The intensity level for the low-load condition was the baseline reading SPL for each participant. *Second*, in addition to varying their intensity, participants were instructed to vary their f_0 and voice quality by mimicking the voices of famous cartoon characters of "Minnie Mouse" and "Mufasa" during the low-load and high-load conditions, respectively. All participants knew that they were participating in an experiment on vocal fatigue, however, VLT procedure and specific outcomes/observations were not specifically emphasized.

Evaluation of vocal fatigue and effort

Vocal fatigue was evaluated objectively using acoustic measures of SPL, f_0, pitch strength (PS), smoothed cepstral peak prominence (CPPS), and the Acoustic Voice Quality Index (AVQI) from the *pre- and post*-vowel and speech tasks. The average among all SPL values was computed per participant, and this mean was subtracted from each SPL value performed by that participant. This within-subject centering was performed in order to evaluate the variation in the participant's vocal behavior in the different conditions from the "mean" vocal behavior and to reduce the variance among participants. After transformation, the measure was termed ΔSPL. For each recording (pre- and post-VLT; vowel and speech) and acoustic measure, average/mean and standard deviations were calculated. Measures of f_0, SPL, and PS were computed in MATLAB (Version 2017a; MathWorks, Natick, MA) and measures of CPPS, and AVQI were computed in PRAAT software (Version 6.0.13).[49] PS refers to saliency of pitch sensation and was selected due to its proven relationship with voice quality dimensions (eg, breathiness).[50,51] Computational estimates of PS were extracted from a sawtooth waveform-inspired pitch estimator with auditory front-end (Aud-SWIPE').[52] A detailed description of the computation can be reviewed in Camacho.[52] CPPS provided the magnitude of the cepstral peak relative to the amplitude of phonation.[53] The AVQI is a multivariable model based on acoustic measures that permitted the objective assessment of overall dysphonia severity using sustained vowel and continuous speech.[54] To derive the AVQI, a weighted combination of six acoustic measures were modeled in a linear regression formula. Measures were representative of time (shimmer local, shimmer local dB, and harmonics-to-noise ratio), frequency (general slope of the spectrum and tilt of the regression line through the spectrum) and quefrency domain (CPPS).[55] Vocal fatigue was evaluated subjectively using the Vocal Fatigue Index (VFI)[56] pre- and post-VLT. Participants also completed the adapted Borg CR10 physical exertion scale[57] after VLT. Performance *during* the VLT was measured using the same set of acoustic measures, except for AVQI.

Evaluation of sleep, depression, and stress

Amount of sleep (average number of hours/night) was evaluated through a question on the Qualtrics survey. Depression was evaluated through 21 questions on the Beck Depression Inventory[58] and perceived stress was evaluated through 10 questions on the PSS.

Statistical analyses

Linear mixed models (LMEs) fit by restricted maximum likelihood (REML) were built using lme4[59] and lmerTest[60] packages. The model output included estimates of fixed effects coefficients, standard error associated with the estimate, degrees of freedom, df, the test statistic, t and the P value. Estimates and standard deviations of fixed effects represent the values of the regression coefficients associated with each factor of interest included in the model and their standard deviation. The Satterthwaite method[61] was used to approximate degrees of freedom and calculate *P* values. All statistical analyses were completed using R software (Version 3.1.2).[62] Such LMEs have also been used in prior vocal fatigue[31] and vocal effort[63] studies.

A series of LMEs were fitted by REML for each of the acoustic measures as the response variables, with task as the fixed factor (pre- and post-VLT) and their interaction, and the participant as the random effects term. The reference levels were vowel for the task and pre-condition for the VLT. In addition, VFI was evaluated as an additional fixed factor along with task (pre- and post-VLT) and paired *t* tests were also performed to evaluate the change in VFI performance and pain scores pre- and post-VLT. Furthermore, LME model was fitted by REML for each of the response variables with task as a fixed factor (pre- and post- VLT) and stress index (overall PSS score) from participants as a random effect.

RESULTS

Comparison of acoustic measures pre- and post-VLT

Table 1 represents a summary table with multiple LME models fit by REML for each of the response variables (ΔSPL, f_0, f_0 standard deviation, PS, CPPS, and AVQI). Figures 1−6 represent mean and the standard error of each of the response variables measured pre- and post-VLT for vowel and connected speech stimuli. The values on all the figures represent raw data and these could be slightly different than the values of the model output in which we considered participants as random factor.

1. *Delta sound pressure level (ΔSPL, dB):* The estimate of standard deviations for random effect participant was 0 (because of the within-subject centering), while the residual standard deviation was 3.11. ΔSPL was 10.56 dB higher in vowel compared to connected speech. For both vowel and connected speech, ΔSPL increased by 4.22 dB post-VLT. The SPL standard deviation did not change significantly between the stimuli and pre- and post-VLT.
2. *Fundamental frequency (f_0, Hz):* The estimate of standard deviations for random effect participant was 12.13, while the residual standard deviation was 14.58. f_0 was 27.44 Hz higher in connected speech compared to vowel. For both vowel and connected speech, f_0 increased to 8.62 Hz post-VLT.

TABLE 1.
A Summary Table Depicting Multiple LME Models Fit by REML for All Response Variables With Task as the Fixed Factor (pre/post VLT) and Their Interaction, and the Participant as the Random Effects Term. The Reference Levels were Vowel for the Task and Pre-condition for the VLT

Fixed Factors	Estimate	Std. Error	df	*t*	*P*
1. ΔSPL (dB)					
(Intercept)	0.58	0.45	132	1.29	0.200
Task speech	−10.56	0.96	132	−11.73	<0.001***
Pre/post VLT POST	4.22	0.62	132	6.74	<0.001***
Task speech: Pre/post VLT POST	−0.94	1.25	132	−0.75	0.454
2. f_0 (Hz)					
(Intercept)	200.0	3.6	26.8	55.0	<0.001***
Task speech	27.4	4.2	114.5	6.5	0.004**
Pre/post VLT POST	8.6	3.0	115.7	2.9	<0.001***
Task speech: Pre/post VLT POST	−4.0	5.9	114.5	−0.7	0.500
3. f_0 standard deviation (Hz)					
(Intercept)	105.8	1.9	31	56.4	<0.001***
Pre/post VLT POST	−10.4	2.3	17	−4.6	<0.001***
4. PS (-)					
(Intercept)	0.46	0.01	28	42.47	<0.001***
Task speech	−0.03	0.01	115	−2.45	0.015*
Pre/post VLT POST	0.05	0.01	116	5.41	<0.001***
Task speech: Pre/Post VLT POST	−0.03	0.01	115	−1.74	0.083
5. CPPS (dB)					
(Intercept)	16.59	0.45	31	36.85	<0.001***
Pre/post VLT POST	1.10	0.52	17	2.12	0.049*
6. AVQI (-)					
(Intercept)	3.66	0.15	23	23.87	<0.001***
Pre/post VLT POST	−0.50	0.11	16	−4.39	<0.001***

Abbreviations: AVQI, Acoustic Voice Quality Index; CPPS, smoothed cepstral peak prominence; dB, decibel; f_0, fundamental frequency; Hz, Hertz; PS, pitch strength; SPL, sound pressure level.
Significance codes: ″***″<0.001 ″**″<0.01 ″*″<0.05 ″.″<0.1

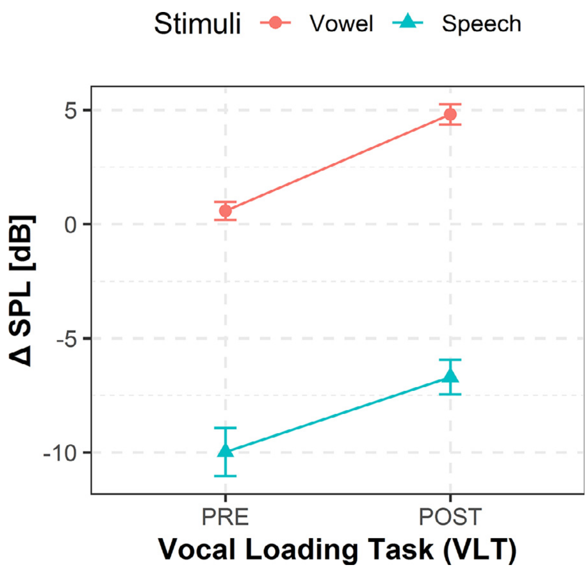

FIGURE 1. Mean and the standard error (SE) of the relative sound pressure level (ΔSPL) measured pre- and post-vocal loading task (VLT) for vowel and connected speech stimuli.

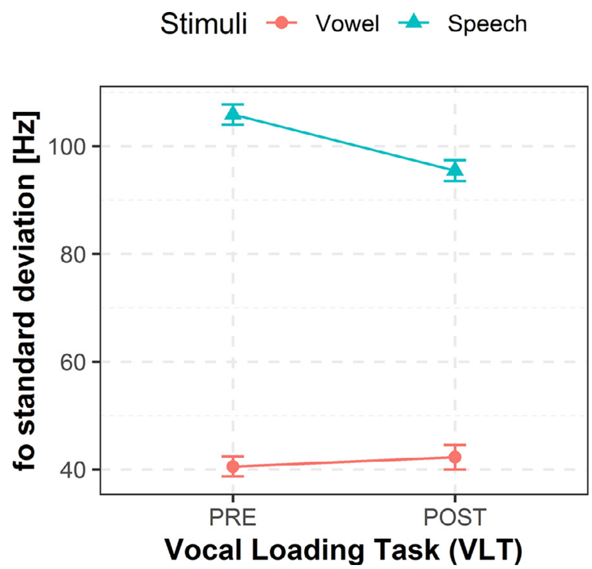

FIGURE 3. Mean and the standard error (SE) of fundamental frequency standard deviation (f_0 SD) pre- and post-vocal loading task (VLT) for vowel and connected speech stimuli.

3. *f_0 Standard deviation*: Unlike f_0, f_0 standard deviation decreased significantly to 10.35 Hz post-VLT in connected speech.
4. *Pitch strength (PS):* The estimate of standard deviations for random effect participant was 0.04 and the residual standard deviation was also 0.04. PS was lower by a small magnitude (0.03) in connected speech compared to vowel. For both vowel and connected speech, PS increased by a magnitude of 0.05 post-VLT.
5. *Smoothed cepstral peak prominence (CPPS, dB):* There was a significant increase in CPPS (1.10 dB) post-VLT only for the connected speech.
6. *Acoustic Voice Quality Index (AVQI):* The AVQI was calculated combining vowel and connected speech stimuli. The estimate of standard deviations for random effect participant was 0.53, while the residual standard deviation was 0.32. AVQI decreased by a magnitude of 0.50 post-VLT.

Vocal Fatigue Index

Results of the LME analysis revealed that the associations between the aforementioned acoustic measures of voice and the VFI scores were not statistically significant ($P > 0.05$).

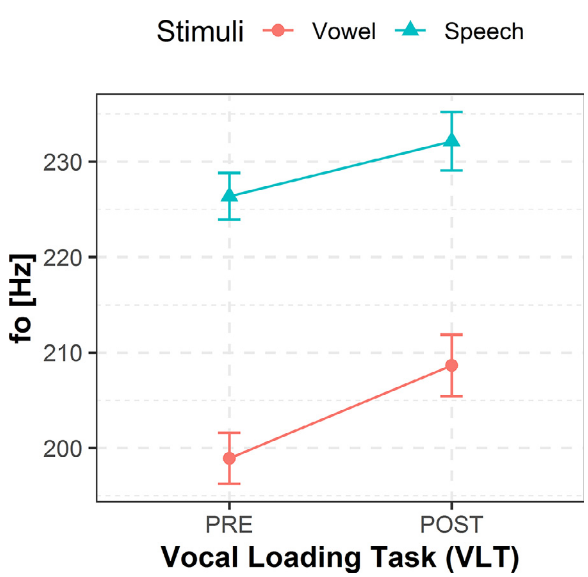

FIGURE 2. Mean and the standard error (SE) of fundamental frequency (f_0) pre- and post-vocal loading task (VLT) for vowel and connected speech stimuli.

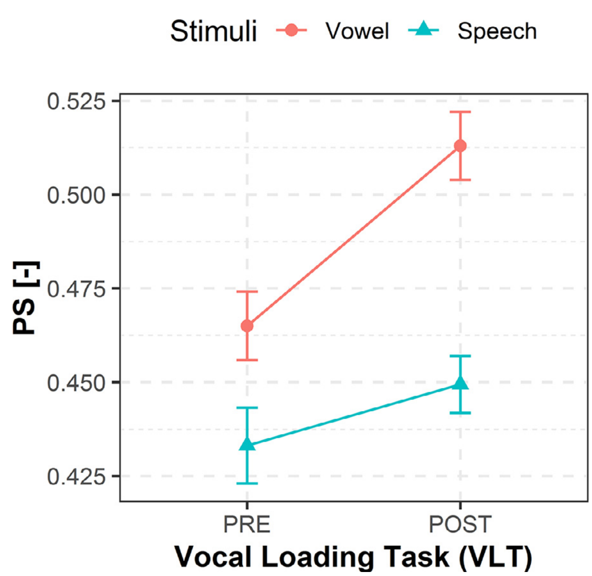

FIGURE 4. Mean and the standard error (SE) of the pitch strength (PS) measured pre- and post-vocal loading task (VLT) for vowel and connected speech stimuli.

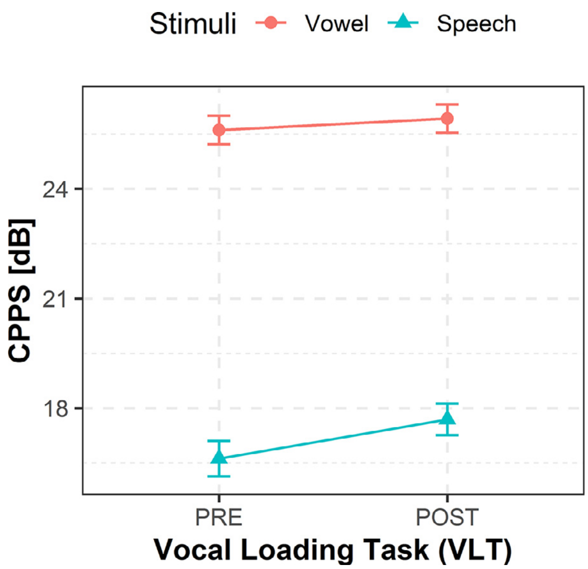

FIGURE 5. Mean and the standard error (SE) of the smoothed cepstral peak prominence (CPPS) measured pre- and post-vocal loading task (VLT) for vowel and connected speech stimuli.

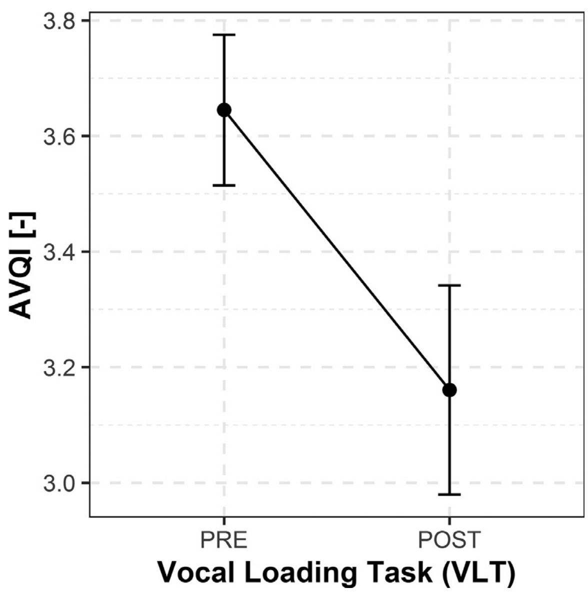

FIGURE 6. Mean and the standard error (SE) of the acoustic voice quality index (AVQI) measured pre- and post-vocal loading task (VLT).

Although a significant relationship was not observed, mean ± standard error VFI scores on the three categories namely general tiredness of voice (performance), physical discomfort associated with voicing (pain), and improvement of symptoms with rest (recovery) were inspected pre- and post-VLT. For pre-VLT, mean scores (averaged across 17 participants) on performance, pain, and recovery, were 8.22 ± 2.32, 2.28 ± 0.92, and 5.63 ± 1.15, respectively. For post-VLT, mean scores (averaged across 17 participants) on performance, pain, and recovery, were 14.73 ± 2.96, 5.18 ± 1.23, and 6.63 ± 1.32, respectively. After checking the normal distribution of the data, a set of paired-samples *t* tests was conducted to compare VFI performance and pain scores in pre- and post-VLT conditions. There was a significant increase in performance ($t[16] = -3.980$, $P = 0.001$) and pain ($t[16] = -3.785$, $P = 0.002$) scores post-VLT. While, an increase in mean score in first and second category indicates greater fatigue (poor vocal performance and elevated pain), an increased mean score in third category indicates lower severity (greater improvement after rest). Given that the focus of the current study was to evaluate vocal fatigue after VLT, scores have been reported per category and statistical analyses were conducted on first two categories. Similar reporting of sub-category VFI scores can also be found in Banks et al (2017).[64]

Performance during VLT

An additional set of linear mixed effect models were fitted by REML for the response variables ΔSPL and f_0 with time, vocal load (low vs high) as the fixed factors and their interaction, and the participant as the random effects term. The reference level for the vocal load factor was low.

Delta sound pressure level (ΔSPL, dB)

The model output is reported in Table 2. The estimate of standard deviations for random effect participant was 0.61, while the residual standard deviation was 11.89. In both vocal load conditions, ΔSPL increased with time, however the slope of the increase was higher in the low-load condition. As per the task requirement/instructions SPL was 3.24 dB higher in the high-load compared to the low-vocal load task condition. Figure 7 shows the ΔSPL values averaged across all the participants over the total duration of

TABLE 2.
LME Model Fit by REML for the Response Variable ΔSPL During the Vocal Loading Task (VLT)

Fixed factors	Estimate	Std. Error	df	*t*	*P*
(Intercept)	−1.16	0.16	13	−7.16	<0.001***
Time	0.0019	0.00	273403	29.10	<0.001***
VLT high	3.24	0.20	273402	33.99	<0.001***
Time: VLT high	−0.0005	0.00	273402	−5.19	<0.001***

Significance codes: ″***″<0.001 ″**″<0.01 ″*″<0.05 ″.″<0.1

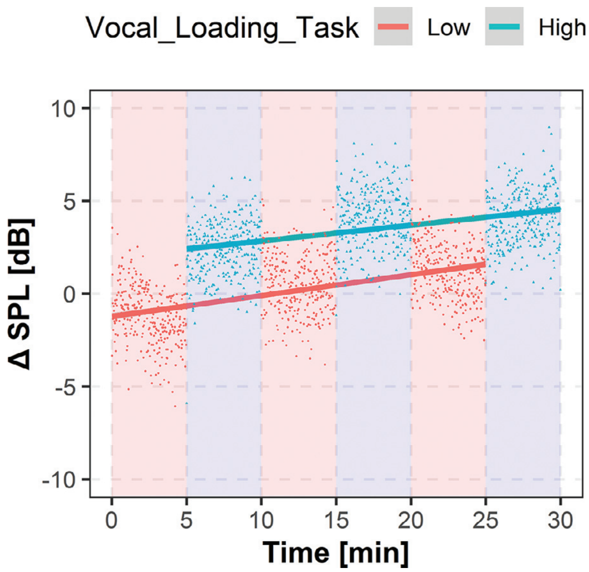

FIGURE 7. Mean relative the sound pressure level (ΔSPL) for low and high-load conditions over the total duration of the vocal loading task (VLT).

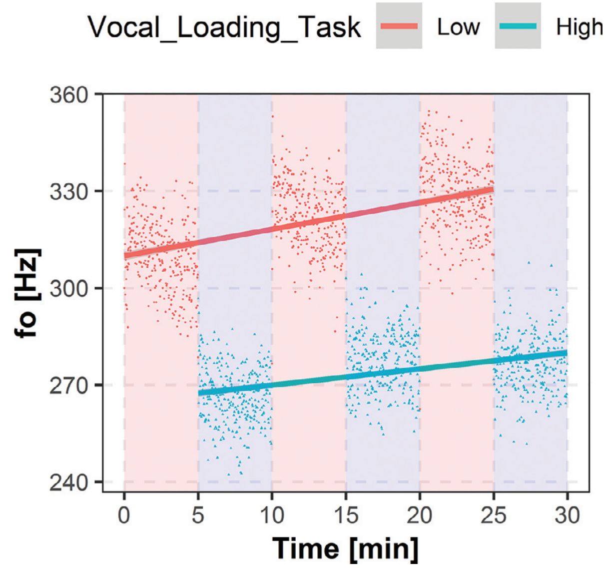

FIGURE 8. Mean fundamental frequency (f_0) for low and high-load conditions over the total duration of the vocal loading task (VLT).

the VLT (30 minutes), and two linear models for two conditions: high and low vocal load.

Fundamental frequency (f_0)

The model output is reported in Table 3. The estimate of standard deviations for random effect participant was 30.86, while the residual standard deviation was <0.001. In both vocal load conditions, f_0 increased with time, however the slope of the increase was higher in the low-load condition. As per the task requirement/instructions, f_0 was 50 Hz higher in the low-load compared to the high vocal load condition. Figure 8 shows f_0 values averaged across all the participants over the total duration of the VLT (30 minutes), and two linear models for two conditions: high and low vocal load.

Pitch strength (PS) and smoothed cepstral peak prominence (CPPS)

Figure 9 shows PS (left) and CPPS (right) values averaged across all the participants for low and high-load conditions. The box plots depict 25th percentile, median, 75th percentile, and the whiskers of the box plots depict minimum and maximum values. There were negligible differences in PS and CPPS over time in the VLT. Therefore, values were averaged across the load conditions and only the descriptive statistics on the load conditions are provided in Figure 9.

Effects of sleep, depression, and stress on vocal fatigue

All but one participant reported to sleep between 6 and 10 hours. Overall depression score ranged from 0 to 7 with a mean of 1.77 for 13/17 participants. This score ranged from 19 to 27 for the remaining four participants with a mean of 21.5. Given that there was a limited distribution of the sleep and depression scores, further analysis was not plausible. Overall PS scores ranged between 16 and 25 (mean of 20) indicating moderate stress among participants. LME model outputs revealed statistically significant associations between stress index and measures related to pitch, independently by the type of stimuli (vowel or speech) and by the VLT. As shown in Figure 10, participants with higher stress index showed higher f_0 ($P = 0.030$) and smaller f_0 standard deviation ($P = 0.005$) and higher values of PS ($P = 0.017$).

TABLE 3.
LME Model Fit by REML for the Response Variable f_0 During the Vocal Loading Task (VLT)

Fixed factors	Estimate	Std. Error	df	*t*	*P*
(Intercept)	309	6.67	17	46.48	<0.001***
Time	0.014	0.00	284029	28.08	<0.001***
VLT high	-44.99	0.72	284029	−62.23	<0.001***
Time: VLT high	-0.005	0.00	284029	−7.66	<0.001***

Significance codes: ''***''<0.001 ''**''<0.01 ''*''<0.05 ''.''<0.1

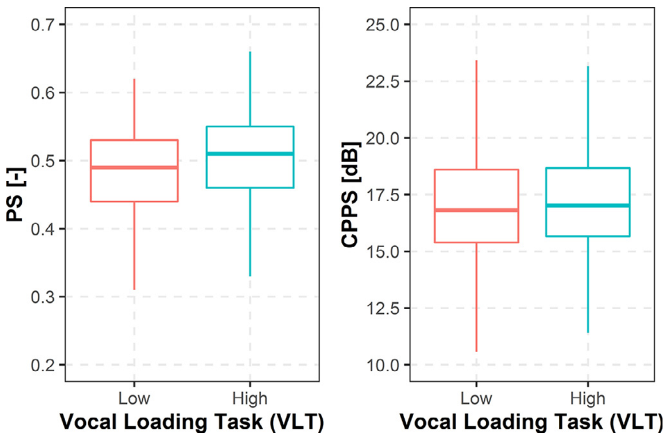

FIGURE 9. Pitch strength (PS) and smoothed cepstral peak prominence (CPPS) averaged across all participants and across low and high-load conditions on the vocal loading task (VLT). Boxplots are based on median, 25th and 75th quartiles, and minimum and maximum values.

DISCUSSION

The primary goal of the current study evaluated vocal fatigue in SLP students through a vocal loading experimental paradigm that required them to vary a combination of parameters (f_0, SPL, and voice quality). Vocal fatigue was quantified using self-perceived/subjective and objective measures conducted before, during, and after the VLT. Our results demonstrate measurable changes in most of the acoustic measures during and post-VLT task. Subjective VFI scores on performance and pain categories significantly increased post-VLT indicating that VLT did elicit sensations of vocal fatigue. Furthermore, 15 participants reported severe ($N = 7$; values of 5 or 6) and very severe ($N = 8$; values of 7 or 8) perceived vocal effort on the Borg scale post-VLT. A secondary goal of the study was to determine the effects of sleep, depression, and stress on measures of vocal fatigue. Participants with higher stress level showed an increase in f_0 and a decrease in f_0 variability.

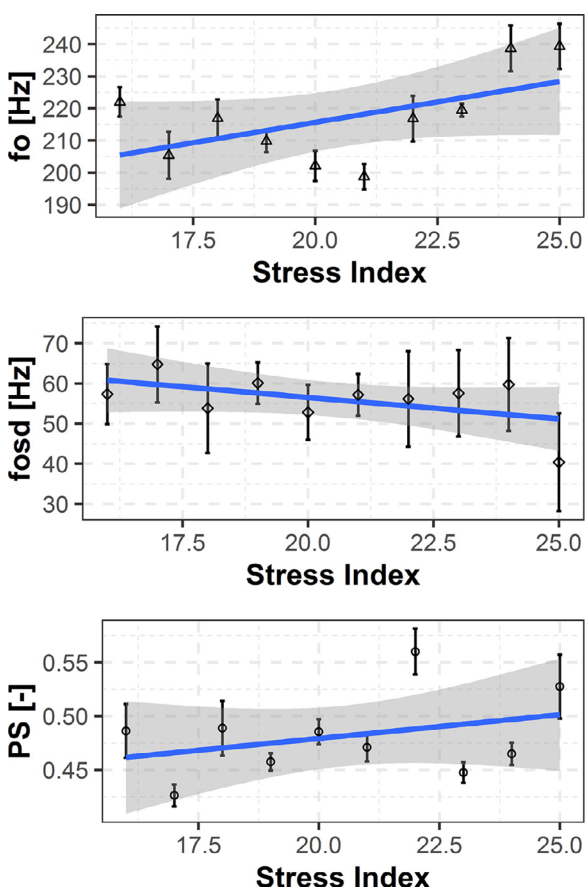

FIGURE 10. Fundamental frequency (f_0), f_0 standard deviation (f_0 SD), and pitch strength (PS) as a function of stress index.

Novel/modified VLT

Vocally demanding tasks, (ie, VLTs) that highly impact the vocal mechanism and induce vocal fatigue, vary considerably in their experimental methods (eg, stressor/task types, durations, and outcome measures). This study leveraged the LingWAVES software program routinely used for acoustic analysis of the dysphonic voice in clinics and adapted the LingWAVES vocal loading protocol to achieve the first goal. In addition to increasing SPL, all participants also altered pitch and voice quality for 30 minutes. Specifically, in the "low-load" condition, participants were required to speak at baseline intensity, high pitch, and a squeaky voice and in the "high-load" condition, participants were required to speak at a higher intensity, low pitch, and a deeper voice. The need for modification of additional factors in this study was motivated from previous studies in professional voice users that reported no measurable changes when only elevated intensity was used in shorter duration VLTs.[65] Furthermore, to our knowledge, only one previous study has reported the use of altered voice quality (pressed voice) in their VLT.[66] Similarly, although elevated intensity has been one of the common stressor in VLTs, studies have used a common intensity threshold for all participants. This study accounted for interindividual differences in dose thresholds by setting them to increase by 15% of baseline reading SPL in the "high-load" condition.

Acoustic measures pre- and post-VLT

ΔSPL and f_0 increased post-VLT in both types of speech stimuli (ie, vowel and connected speech) in the current study. These results are consistent with prior literature on SPL[28,35,67] and f_0[30,35,67-72] despite the differences in study population and task duration. The results of the current study support the notion that changes in acoustic parameters can be measured in 30 minutes unlike the cited studies that report durations ranging from 45 minutes to 2 hours. It is likely that the nature of the VLT requiring modifications in both intensity and f_0 may have led to these noticeable results. Such increases in f_0 post-VLT have been attributed to greater laryngeal muscle activity and tension, indicative of speakers compensating for the task.[72,73] Furthermore, vocal fatigue resulting from high vocal loads are known to change vocal fold properties (eg, viscosity and stiffness) requiring increased phonation threshold pressure and increased SPL leading to increased rate of vocal fold vibration and thereby increased f_0.[74,75] Current results are also similar to Bottalico[76] where 20 young adults read a text in normal and loud styles in different conditions and environments (eg, with normal vocal effort and without the presence of the reflective panels and with loud vocal effort and without the presence of the reflective panels). Across all tasks, f_0 was higher in the loud style (~16 Hz compared to ~8 Hz in the current study). The differences in absolute magnitude could be explained by the varied environmental conditions/rooms in Bottalico.[76] Only one study reported SPL and f_0 measures in six SLP students who were on a full-time internship.[14] This study obtained recordings (through multidimensional voice program as well as ambulatory phonation monitor) from students during initial, medial, and end of the academic semester and did not report any significant statistical changes in the acoustic measures. The decrease in f_0 standard deviation in connected speech could reflect the maintenance of increased fatigue post-VLT in the current study.

Measures of voice quality (PS, CPPS, and AVQI) revealed small but significant changes post-VLT in the current study. CPPS increased post-VLT only in connected speech. Limited studies have examined the effects of vocal loading on cepstral measures such as CPP.[28,29,66] In a study by Fujiki et al (2017) [66] eight males and eight females (mean age of 22 years) completed a 30 minutes vocal loading task in the presence of background noise and at different humidity levels. In addition, participants were asked to read at low/high pitch as well as normal/pressed voice quality. Authors reported no loading effects on CPP for the reading task and that CPP may be more sensitive to dysphonic voice quality rather than subtle changes in healthy nondysphonic voices. In another study by Sundarrajan et al (2017),[29] 14 young adults read aloud for 40 minutes in the presence of background noise and CPP increased slightly after the loading task. The study population (young adults without significant dysphonia) and results (minimal changes in CPP) from Fujiki et al and Sundararajan et al are similar to the current study. Given the small magnitude of change, the clinical significance of CPP remains to be investigated. To our knowledge, AVQI has been investigated in only one study in professional voice users.[77] After a 1.5 hour theatre performance, AVQI did not change significantly but was reported to be 3.48 pre-performance indicating mild dysphonia in 26 theatre actors. Similarly, in the current study, SLP students demonstrated mild dysphonia prior to VLT. Borderline dysphonic voice quality of 68% (evaluated through dysphonic severity index) has also been reported by Van Lierde et al (2010).[17] Although there seems to be decrease in AVQI post-VLT, the magnitude of change is small despite statistical significance. Similar to PS and CPP, it is likely that voice quality modifications completed through the VLT were not adequate to mirror the characteristics of a dysphonic voice and therefore may need further examination with other acoustic measures that are sensitive to capture the subtle changes or require modification of the VLT methods.

Performance during VLT

Very few studies have quantified a continuous measure of performance on VLT.[69,78,79] During the 30-minute VLT, ΔSPL and f_0 increased linearly with time, similar trends were observed across ΔSPL and f_0 measures, and the slope was greater in low-load condition (Figures 7 and 8). It is likely that there was a ceiling effect for the high-load condition. Similar rising trends were reported by Laukkanen et al (2004).[69] Prior research has indicated that there is a significant intra- and intersubject variability in vocal resilience and subsequently the vocal dose thresholds.[30,80,81]. Furthermore, prior research has reported the most common duration of VLT to be 2 hours and that shorter duration tasks must use an additional factor to elicit measurable changes.[46] In the current study, three vocal parameters were modified and although measures of voice quality did not change during or post-VLT, measurable changes were observed in two commonly reported acoustic measures within a short duration during VLT.

Effects of sleep, depression, and stress on vocal fatigue

There is a growing evidence on the “mind-body” philosophy that demonstrates the physiological changes caused due to psychological/emotional factors. For example, when emotions are heightened, there is increased muscular tension within the larynx, resulting in reduced vocal fold flexibility and an increased effort to produce and sustain voice.[82,83] Indeed, a recent study based on cross-sectional analysis of National Health Interview Survey data revealed that the presence of depressive symptoms were associated with a nearly two-fold increase in the likelihood of reporting a voice problem.[41] Specifically, this risk was higher in young adults aged 18−30 years.[41] College students in general are known to sleep less, be more stressed, anxious, and depressed.[40] Therefore, physical factors (ie, sleep) and psychosocial factors (ie, depression and stress) and their effects on vocal fatigue were examined in the current study. Depression was borderline to moderate in 4 participants and the others did not exhibit any depression. These 4 participants were graduate students and it is likely that added workload/demands of both academic coursework, clinic, and/or other unique circumstances may have partly contributed to increased stress and consequently depression scores. Stress was significantly correlated to measures of f_0 identical to previous studies.[84] f_0 was higher and f_0 standard deviation was lower in participants with greater stress index. The increase in f_0 could be explained by increased activity of the extralaryngeal muscles and the decrease in f_0 standard deviation could reflect the interaction between stress and lessened emotion or vocal fatigue. Such psychosocial factors have long been associated with hyperfunctional voice disorders commonly developed by professional voice users.[37,83] Prior research has also reported increased stress in females compared to males.[83,85] All participants in the current study were females. Indeed, according to the 2016−2017

Communication Sciences and Disorders Education Survey—National Aggregate Data Report by ASHA, males were highly underrepresented in undergraduate and graduate level programs compared to their female counterparts (~4.5%; *ASHA*).

CONCLUSIONS

Current study used a 30-minute vocal loading task that required participants to modify vocal parameters in addition to the conventional intensity level. Current study included SLP students at both undergraduate and graduate levels, however, their vocal demands are likely to be different. Our results demonstrate that the novel/modified VLT task was sufficient to induce vocal fatigue in all participants through both subjective and objective measures. In particular, discernable changes in ΔSPL and f_0 were observed during and post-VLT. Further, a significant association between perceived stress and f_0 measures was also observed. Future research will consider better voice quality modifications and metrics (eg, eliciting greater breathiness, roughness, or strain through better instructions/modeling to allow greater changes on current voice quality metrics such as CPP or other metrics such as spectral energy ratios; tilt) as well as use multidimensional assessment methods (eg, physiological and autonomic measures). A logical extension of the current study will include comparison of SLP students with student teachers, student singers, and students who are nonprofessional voice users to examine if SLP students were more likely to experience vocal fatigue after VLT. This group comparison study will also incorporate a detailed examination of vocal health and voice use patterns.

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