THE IMPACT OF VOCAL FUNCTION EXERCISES ON NORMAL VOICE PRODUCTION

by

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GRADUATE COMMITTEE APPROVAL

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ABSTRACT

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This study attempted to replicate and expand previously published research in order to increase our understanding of how Vocal Function Exercises (VFE) might improve vocal function in normal voices. Measures were made to reflect potential post-treatment changes in acoustic and aerodynamic variables, including a measure of vocal efficiency. The participants of the study included 35 adults with normal voices. Each completed a series of speech tasks (sustained vowels, maximum phonation time, reading of a standardized passage, and repetition of syllable strings) before and after a four-week treatment period. Testing of pre- and post-treatment data revealed no clear improvement in acoustic and aerodynamic measures of the voice. There were also no significant improvements in vocal efficiency following the VFE. These findings suggest the need for further research to better understand the value of VFE in improving vocal function.

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Introduction

Today's society is centered on the idea of self-improvement and "finding the better you." The average person is constantly encouraged to pursue and seek more. There is an abundance of information available to guide one to improved health. For instance, the benefits of exercise are stressed repeatedly. Not only will exercise make our bodies more fit, but it will also make them healthier. With so much guidance available, it is surprising that there has been so little focus on improving the normal speaking voice. Certainly, there are behaviors that we are told to avoid, such as yelling and talking for sustained periods of time. One technique, Vocal Function Exercises (VFE), consists of a series of systematic exercises that were designed to improve the disordered voice. However, there has not been extensive research documenting the benefit of these exercises on the normal, untrained voice. The present study sought to investigate the potential VFE have in improving the acoustic and aerodynamic properties of the average, untrained voice.

Rehabilitation of the voice can be divided into two general categories. The first includes approaches that aim to remove behaviors that perpetuate the voice disorder in order to improve voice production. This may include reducing vocally abusive behaviors or eliminating psychological factors which contribute to the problem. The second category includes approaches that teach specific techniques or exercises that improve voice production. These approaches often include systematic vocal exercise as an important step in rehabilitation. Stemple (2005) hypothesized that many of the approaches designed to improve the disordered voice may also be used to enhance normal voice production. As an advocate of physiologic voice therapy and the creator of Vocal Function Exercises (VFE), he explained that "from both the historical perspective and from the present-day culture of self-improvement, voice improvement is not only for the disordered voice, but also for those who want to enhance their vocal performance and image” (p. 132).

Similarly, adherents of the holistic health perspective believe that optimal health is more than just the absence of disease and sickness. The wellness continuum, a concept of holistic health (O’Donnell, 1986), suggests that there are many degrees of wellness, just as there are many degrees of illness. This can be depicted by the use of a wellness line where the center of the line is neutral because the person lacks apparent disease or illness. Moving from the center to the left shows a progressively worsening state of health while moving to the right of center indicates increasing levels of health and well being.

The holistic health perspective can also be applied to the voice and voice therapy because vocal treatment and training are designed not only to improve the disordered voice but to improve and enhance normal voice production. If the voice were placed on the wellness line, the normal voice would be located in the center. Located to the left of this midpoint would be the disordered voice and located to the right would be the superb voice of the performing artist, who could be considered a vocal athlete. The wellness continuum suggests that voice improvement can be expected not only from the disordered voice but from the normal voice, as well. A study in 1994 by Stemple, Lee, D’Amico, and Pickup demonstrated that VFE were effective in producing significant improvement in 35 adult women with normal voice production. VFE were effective in significantly moving vocal production further to the right on the wellness continuum. Similarly, the present study sought to demonstrate the effectiveness of VFE, and their potential to improve and enhance normal voice production by moving from the center of the wellness line further right towards optimum vocal health and usage.

Physiologic Approach to Voice Disorders

Stemple (1993) encouraged researchers to develop clinical methods that would expand the physiologic approach to voice therapy. He challenged them to devise a management approach that would "…provide direct effective and efficient vocal function exercises similar to the physical therapy utilized for other parts of the body" (p. 298). He encouraged and pursued the development of an approach based on exercise and manipulation that could be used to directly modify the inappropriate physiologic activity. The exercises were designed to "modify and improve laryngeal muscle strength, tone, balance, and stamina, and improve the balance among laryngeal muscle effort, respiratory effort and control, and supraglottic modification of the laryngeal tone" (p. 298).

These exercises would theoretically improve voice production because the laryngeal mechanism is similar to other muscle systems which also show improvement with exercise. Vocal exercises used to rehabilitate the voice are comparable to the exercises employed in physical therapy to rehabilitate the limbs of the body. In physical therapy, active therapy includes the exercises of stretching, strengthening, and postural modification to rehabilitate and prevent re-injury. Thus, physical therapy uses systematic exercise to reduce pain, increase flexibility, increase range of motion, increase function, build strength, and correct posture. Stemple (2005) suggested that on many occasions, voice clients are not fully rehabilitated when full voice usage is resumed because an important step in rehabilitation was neglected. This neglected step was the methodical exercise program that is used to recover the balance between the phonatory, laryngeal, and resonance systems.

Development of Systematic Exercises to Improve Voice Production

In 1959, Briess was the first to introduce the concept of a direct relationship between the condition of the laryngeal musculature and the quality of voice. Briess explained that voice therapy “must restore the normal dynamic equilibrium of the intrinsic and cricothryoid muscles which control the functions of the vocal cords” (p. 61). Effective, normal voice required this balance. Briess proposed four phases in treating the disordered voice and restoring the equilibrium of the musculature to regain healthy voice production. Phase one corrects habits of vocal abuse that should be remediated before therapy begins. The second phase, the muscle retraining phase, teaches the client to maintain this equilibrium by specific, thorough, and precise adjustment of these muscles. The second phase includes a series of laryngeal exercises which restore muscle balance by reducing the tension of hyperfunctioning muscles and reactivating the antagonist muscles. When equilibrium is restored, the symptoms disappear. The third and fourth phases attempt to train the muscles to endure more strain than the normal voice tolerates and teach the patient to recognize symptoms of imbalance between the laryngeal muscles (Briess, 1959).

Barnes (1980) extended Briess’ work when she presented the *Briess Exercises* at the Southwestern Ohio Speech and Hearing Association; these were a modification of the original exercises proposed by Briess in 1959. Stemple then modified and extended the “Briess Exercises” into the VFE. The VFE program strives to balance the subsystems of voice production: airflow, supplied by the respiratory system; laryngeal muscle strength, balance, coordination, and stamina; and coordination among the supraglottic resonators.

The VFE are simple, concrete, and objective. Before learning the exercises, the patient is taught the relationship between the subsystems involved in speech production.

Stemple (2005) recommended that the sequence of exercises be practiced two times through, twice each day – both in the morning and in the evening – for a total of four sessions. Stemple described VFE as a series of four components. The first exercise is a warm-up; the patient sustains /i/ for as long as possible on the musical note (F). Second, the patient glides from their lowest note to their highest note on the word *knoll*. The third exercise requires the patient, on the word *knoll*, to glide from their highest note to their lowest note. Finally, the patient sustains the word *knoll* minus the *kn* on the musical notes (C, D, E, F, & G) for as long as possible.

Studies Examining the Effectiveness of Vocal Function Exercises

Gillivan-Murphy, Drinnin, O'dwyer, Ridha, and Carding (2006) conducted a study of the effectiveness of a voice treatment approach in a group of teachers with voice problems. The study participants included 20 teachers with self-reported voice problems who were randomly assigned to one of two groups: the treatment or no-treatment group. The participants in the treatment group received six weeks of combined treatment using VFE and vocal hygiene education. Upon completion of the treatment, significant improvement was found in the treatment group as measured by the Voice Symptom Severity Scale and Voice Care Knowledge Visual Analogue Scale; however, there was no significant improvement in the treatment group as measured by the Voice-Related Quality of Life instrument. This study suggests that the combined VFE and vocal hygiene approach was effective in improving self-reported voice symptoms and voice care knowledge in a group of teachers.

A recent study compared the effectiveness of either VFE, vocal hygiene, or no treatment in managing the voice disorders of 58 teachers (Roy et al., 2001). The teachers were randomly assigned to one of the three groups and completed the Voice Handicap

Index prior to treatment, which lasted for a period of six weeks. Upon completion of the therapy program, the participants again completed the Voice Handicap Index. Post-treatment reductions on this measure were only significant in the group which received the VFE intervention. The study's authors concluded, therefore, that VFE were effective in improving the disordered voice.

In 2002, 24 men ranging from ages 60-78 participated in a study which examined the effect of VFE on vocal aerodynamics and perceptual quality of voice (Gorman, 2002). The experimental group performed VFE twice a day for 12 weeks, while the control group performed VFE once a week for 12 weeks. Participants in the study completed a series of /pa/ syllable strings and sustained the vowel /a/ for as long as possible. These two tasks were completed at comfortable, low, and high pitch levels. Pitch was monitored and then matched in the pre- and post-treatment data collection sessions. The Rainbow Passage was recorded and perceptually analyzed. The result of the study revealed significant differences between the VFE and control groups for minimum glottal airflow and subglottal pressure (Psub).

Minimum glottal airflow is determined as the amount of airflow passing through the glottis during the closed portion of the glottal cycle (Sapienza, 1996) and is correlated to glottic closure (Gorman, 2002). Participants in the experimental group demonstrated a decrease in minimum glottal airflow. This change suggests that glottic closure became more complete after the 12-week exercise period. Gorman speculated that the subsequent increase in Psub in this population was due to improved glottal closure. With improved closure, it required a greater build up of pressure to drive vocal fold vibration. Perceptual analysis also revealed improved voice quality for those subjects who had been rated as the most dysphonic (Gorman, 2002).

A study conducted by Stemple et al. (1994) found voice improvement in 35 women with normal voices after a period of four weeks using VFE. Similarly, in 1995, Sabol, Lee, and Stemple found significant physiologic improvements with singers using VFE after a four-week period. The acoustic and aerodynamic measures of fundamental frequency, jitter, frequency range, phonation volume, flow rate, and maximum phonation time were collected on sustained vowels (/ɑ/, /i/, /u/) for both of these studies. During data collection, the researchers matched intensity and pitch targets for both pre- and post-treatment recordings. The acoustic and aerodynamic data were collected for tasks that were produced at an intensity level that remained within a 5 dB range. The pitch targets, if appropriate, were selected by the participants pre-treatment and then matched post-treatment.

Participants in the studies demonstrated significant improvements in phonation volume (the volume of air expended during a sustained vowel). In Stemple et al. (1994), phonation volume increased significantly for participants with normal voices during comfortable, low, and high pitches. In Sabol et al. (1995), the singers also demonstrated an increase of phonation volume but only during the low pitch. The authors suggested that the significant increase in phonation volume may be due to improved respiratory muscle strength. The improved strength and control of the respiratory muscles helped the participants to inspire a greater percentage and expire to a lower percentage of their vital capacities. This change in respiration increased the amount of air available to sustain phonation.

Significant changes were also noted in airflow rate, maximum phonation time, and frequency range. There was a similar decrease of airflow rates for participants in both studies during the production of high pitches with no significant changes in airflow rate during the production of comfortable and low pitches. It was hypothesized that the decrease in airflow rate was due to increased strength, balance, and coordination of the laryngeal musculature. As a result, the participants were able to learn to use the minimal amount of airflow needed to drive phonation. Due to the larger phonation volumes and decreased airflow rates of participants in each study, participants' maximum phonation time increased significantly. Lastly, the participants of Stemple et al. (1994) extended the low end of their frequency range by an average of 15 Hz and the high end of their range by an average of 123 Hz. These significant changes in phonation volume, airflow rate, maximum phonation time, and frequency range demonstrated that the VFE were effective in enhancing voice production for normal and elite voice users.

The studies of Gorman (2002), Sabol et al. (1995), and Stemple et al. (1994) required participants to match specific fundamental frequency and intensity targets. This is fairly common practice in that researchers require participants to match fundamental frequency and intensity targets to prevent changes in these two variables from influencing the results. For example, in a report by Lee, Stemple, and Kizer (1999), the authors stated that the "value of any measure of voice production is dependent on its repeatability over time" (p. 277). Their study investigated the consistency of acoustic and aerodynamic measures of voice production over 28 days in 3 different groups of young females. They found that participants who matched both fundamental frequency and intensity when collecting acoustic and aerodynamic data showed repeatable, consistent results on all measures during both tests. Groups only matching intensity or fundamental frequency were inconsistent between tests, thus affecting the reliability of both acoustic and aerodynamic measures. These findings underscore the importance of controlling the conditions under which acoustic and aerodynamic measures are obtained.

However, a question remains about the degree to which findings from frequency- and intensity-matched phonation can be generalized to habitual laryngeal behavior. In 1990 a study by Hanson, Gerratt, and Berke addressed this question by comparing the effects of frequency/intensity-matched phonation samples to spontaneous speech production. The authors sampled spontaneous phonation at comfortable fundamental frequency and intensity levels on the vowel /i/. The spontaneous phonation sample was then compared to phonation produced by the same subject while carefully matching the same frequency and intensity targets. Results indicated significant increases in the open quotient and speed quotient values when frequency- and intensity-matched phonation samples were compared to spontaneous samples. The results indicate that data obtained from participants while matching frequency and intensity targets may not be directly comparable to normal or spontaneous phonation, and may be a greater confounding factor than those attributable to frequency and intensity variation.

Vocal Efficiency

In 1995, Sabol et al. found significant increases in the acoustic and aerodynamic properties in the voices of singers using VFE after a four-week period, which may suggest a possible increase in what they referred to as the *glottal efficiency* of singers. Titze (1992) described efficiency as an energy-conversion process. He illustrated how the human body absorbs energy in one form and releases it in another. One energy source to consider is the aerodynamic power available from the lungs. Vocal efficiency is a measure of how efficiently the larynx is able to use the aerodynamic energy from the lungs and convert it into acoustic energy. Vocal efficiency is the ratio of the acoustic power output to the aerodynamic power input. Aerodynamic power is computed by multiplying Psub by airflow. Titze further explained that as a "phonation machine, the human body is very inefficient. Radiated acoustic power is between .0001 and 1% of the available aerodynamic power in phonation…" (p. 138). The present study sought to determine whether VFE are an effective tool in increasing vocal efficiency in normal voice production.

Conclusions

A review of the literature has found VFE to be effective in improving and enhancing the pathological, the normal, and the elite voice under conditions of frequency and intensity matching. The current study examined how VFE improve normal voice production in adult participants under naturalistic conditions. The study involved 35 individuals with normal voices, as determined by self-report, to replicate and extend the findings of the study conducted by Stemple et al. (1994). Stemple et al. (1994) found significant improvement in phonation volume, flow rate, maximum phonation time, and frequency range in 35 young female adults as demonstrated by acoustic, aerodynamic, and laryngeal videostroboscopic measures. The present study used similar acoustic and aerodynamic measures to those used by Stemple et al. in 1994 to measure change in vocal function. However, this study expanded beyond what Stemple et al. measured by calculating vocal efficiency to document improvements in male and female voices after a four-week VFE treatment period.

Method

Participants

The participants in this study included 17 men and 18 women. They were randomly divided into two groups (experimental group, control group). Participants in the experimental group (n = 18) consisted of 9 men (age range 22-29 years; M = 26.0, SD = 3.2) and 9 women (age range 18-35 years; M = 23.3, SD = 5.2). The control group (n = 17) consisted of 8 men (age range 18-27 years; M = 24.0, SD = 3.2) and 9 women (age range 19-29 years; M = 21.9, SD = 3.0). All participants were volunteers recruited in the Provo, Utah area by word of mouth and classroom announcements. All participants were average voice users with no formal voice training, no history of voice disorders or laryngeal pathology, and no history of smoking. All participants were native English speakers with no history of speech, language, and hearing problems as determined by self-report. Each participant passed a hearing screening at 25 dB HL at 500, 1000, 2000, and 4000 Hz bilaterally. Each participant agreed to participate in the study by reading and signing an IRB-approved consent form.

Instrumentation

Each participant was comfortably seated in an Acoustic Industries 7’ x 7’ single-walled sound booth. The audio signal was recorded from a head-mounted condenser microphone (AKG C-420) at a constant distance of 4 cm from the participant’s lips. The audio signal was filtered by a low-pass Frequencies Devices 9002 filter with a cutoff at 12 kHz and a slope of 48 dB per octave. Speech intensity was measured with a sound level meter (Larson-Davis 712), located 100 cm from the speaker’s lips. A two-channel digital audio tape (DAT) recorder (Panasonic SV-3800) was used to record these two signals. A Glottal Enterprises MA-2 airflow mask with a wide-band flow transducer

(PTW-1) and a pressure transducer (PTL-1) was used to measure the oral airflow and intraoral air pressure. All signals were subsequently digitized with a Windaq 720 (DATAQ Instruments) analog/digital converter at a sample rate of 25 kHz on a lab computer.

Procedure

Treatment phase: Vocal function exercises. The participants were randomly assigned to the treatment group or the control group. All participants were given written and verbal explanation of the procedures. All participants were advised not to engage in vocally abusive behaviors for the duration of the four-week treatment phase.

The control group did not participate in any activities related to the VFE program. The control group participated in an alternate four-week treatment regimen which was designed to exercise the speech mechanism with exception of the larynx. The alternate exercise program was completed twice daily with two repetitions of each exercise. It consisted of four tasks:

1. Deep breathing, exhaling for as long as possible.
2. Sustain voiceless lip trill for as long as possible.
3. Sustain voiceless /s/ for as long as possible.
4. Sustain voiceless /ʃ/ for as long as possible.

The experimental group was instructed how to perform VFE by a graduate clinician as outlined by Stemple (2005). The graduate clinician was trained by a certified and licensed speech-language pathologist with clinical expertise in voice. Each participant was given a CD produced by Stemple that outlined the VFE and instructed the participant how to proceed through the program. The participants were encouraged and instructed to produce all tones softly, with frontal focus. The exercise program, as outlined by Stemple, involves a series of four steps:

1. Sustain /i/ as long as possible on the musical note (F).
2. Glide from the lowest to the highest note in the frequency range, using the word *knoll*.
3. Glide from the highest to the lowest note in the frequency range, using the word *knoll*.
4. Sustain the musical notes (middle C, and the notes above middle C, D, E, F, and G) for as long as possible on the word *knoll* minus the *kn*.

The participants in both the control and experimental groups maintained a written log of daily phonation times. Each participant repeated these exercises two times each day (once in the morning and once in the evening) with two repetitions each time, seven days per week for a four-week period. Each exercise session lasted approximately 15-20 minutes. Each participant met with the graduate clinician once each week. The clinician observed one complete exercise cycle with the participant and discussed any questions the participants had about the exercises program to ensure the exercises were being done properly and consistently.

Pre- and post-treatment data collection. Prior to and at the end of the treatment phase, all the participants' voices were evaluated by several acoustic and aerodynamic measures. Participants were instructed to complete a series of speech tasks. They were instructed to speak at a comfortable level and to repeat the vowels, maximum phonation time, and pitch glissandos three times. Upon completion of these speech tasks, acoustic and aerodynamic analyses were performed on the signals. Participants completed the following speech tasks: sustaining the vowels /ɑ/, /i/, and /u/ for five seconds, phonating as long as possible (maximum phonation time), reading a standardized passage (Rainbow passage), speaking for 30 seconds (informal monologue), gliding higher and lower in pitch (pitch glissandos), and stringing seven /pae/ syllables together with constant effort at three different loudness levels (soft, comfortable, and loud).

Data Analysis

The acoustic data gathered from the sustained vowels were analyzed by the Kay Elemetrics Multi-dimensional Voice Program. The acoustic measures of average fundamental frequency, perturbation (jitter and shimmer), noise-to-harmonic ratio (NHR), voice turbulence index (VTI), soft phonation index (SPI), were averaged across the three trials for the sustained vowel task. The program was also used to measure the longest maximum phonation time out of three trials.

The fundamental frequency from the reading passage, 30-second monologue, and minimum and maximum pitch tasks (glissando) was extracted with the Praat acoustic analysis program. Fundamental frequency variability during speech was converted into semitones using an Excel spreadsheet. Long term average spectral (LTAS) mean, LTAS standard deviation, for the reading passage and 30-second monologue were computed with the TF32 software application.

The binary files from the Windaq software were saved to disk and then imported into custom Matlab applications for aerodynamic analysis. The custom Matlab software was used to measure the mean peak oral pressure during /p/ closure during the repeated /pae/ syllable task which provided an estimate of subglottic pressure. This application was also used to measure the mean air flow at the /ae/ vowel mid-point during the same task. The measures of estimated subglottic pressure and mean airflow were used to determine laryngeal resistance (subglottic pressure / airflow = laryngeal resistance). This application also calculated the mean sound pressure level (dB SPL at 100 cm) for the vowel. Pre- and post-test difference scores were calculated for each of the measures.

Vocal efficiency was measured by dividing the acoustic power by the aerodynamic power. For acoustic power, the data were measured from the sound level meter signal and expressed in watts/cm^2. Aerodynamic power was calculated by multiplying subglottic pressure by airflow. It was also expressed in watts/cm^2. Pre- and post-test difference scores for vocal efficiency were calculated.

Statistical Analysis

Descriptive statistics of means and standard deviations were computed. These scores were subjected to a repeated measures analysis of variance (ANOVA) using SPSS (SPSS-X Inc., Chicago, IL) with an alpha level of .1. The between-subjects factor was the group (VFE versus breathing exercises). The within-subjects factor was the difference in vocal function pre-treatment to post-treatment.

Results

The means and standard deviations for the pre-post aerodynamic measures in the normal condition for the experimental and control group are presented in Table 1. Equivalent data for the soft and loud conditions are presented in Tables 2 and 3, respectively. Table 4 summarizes the descriptive statistics for pre-post acoustic measures on the sustained vowel task for the experimental group, and Table 5 reports the same measures for the control group. Means and standard deviations for the remaining acoustic measures for the experimental and control groups are presented in Tables 6 and 7 respectively. Results of the repeated measures ANOVA for the aerodynamic task are presented in Table 8. Tables 9 and 10 present the results of the repeated measures ANOVA for the acoustic measures on the sustained vowels, reading passage, 30-second monologue, MPT, and frequency range. Only those results that were found to reach statistical significance will be reported here in detail.

Aerodynamic Measures

Soft condtion. Results of the repeated measures ANOVA revealed a significant pre-post main effect for estimated subglottic pressure (Psub), $F(1, 26) = 13.483$, $p = .001$. Psub increased significantly from pre-treatment to post-treatment (see Figure 1). A second significant pre-post main effect was revealed for mid-vowel airflow, $F(1, 22) = 11.546$, $p = .003$. Mid-vowel airflow was found to increase significantly pre-treatment to post-treatment, as shown in Figure 2. Results revealed a third significant pre-post main effect for vocal efficiency, $F(1, 22) = 14.877$, $p = .001$. It revealed a significant decrease in vocal efficiency post-treatment (see Figure 3).

Results of the repeated measures ANOVA revealed a significant pre-post by gender interaction for Psub, laryngeal resistance, SPL, and vocal efficiency. As shown in

Table 1

Descriptive Statistics for the Pre- and Post-Treatment Aerodynamic Measures in the Normal Condition for the VFE and Respiration Group

	Pre-Treatment				Post-Treatment			
	Female		Male		Female		Male	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
VFE								
Press	6.520	1.450	7.655	1.180	6.534	1.485	7.184	1.513
Flow	0.197	0.040	0.249	0.069	0.190	0.041	0.260	0.097
Res	32.956	5.041	32.667	9.096	35.649	10.890	27.509	7.400
SPL	60.681	2.147	62.551	2.807	61.455	1.703	62.354	1.804
VE	20.652	2.042	21.916	2.580	21.665	1.162	21.190	1.947
Respiration								
Pres	7.470	1.097	7.326	2.106	8.064	1.000	7.613	1.876
Flow	0.222	0.064	0.223	0.062	0.230	0.041	0.243	0.112
Res	35.940	7.847	34.423	11.547	35.267	4.828	34.865	14.816
SPL	64.816	2.440	62.881	3.494	65.058	3.930	62.907	4.268
VE	24.768	0.714	22.221	2.827	23.432	1.541	21.258	4.341

Note: Press = estimated subglottic pressure (cm H_20); Flow = mid-vowel airflow (L/sec); Res = laryngeal resistance (cm H_20/L/sec); SPL = sound pressure level (dB); VE = vocal efficiency.

Table 2

Descriptive Statistics for the Pre- and Post-Treatment Aerodynamic Measures in the Soft Condition for the VFE and Respiration Group

	Pre-Treatment				Post-Treatment			
	Female		Male		Female		Male	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
VFE								
Press	4.421	0.264	5.253	1.189	5.172	0.452	5.463	1.357
Flow	0.212	0.046	0.259	0.048	0.238	0.078	0.297	0.087
Res	22.205	6.806	20.279	3.287	24.825	9.557	18.117	4.617
SPL	57.543	1.909	57.590	1.468	57.730	2.285	56.601	1.236
VE	18.793	1.501	17.898	1.751	17.891	2.153	16.156	1.668
Respiration								
Press	5.141	0.892	5.437	1.361	6.224	1.450	5.657	1.217
Flow	0.199	0.048	0.295	0.114	0.238	0.056	0.374	0.078
Res	27.274	8.037	21.483	11.907	27.397	7.936	15.035	3.012
SPL	59.093	2.097	57.896	1.524	60.372	3.366	57.037	2.051
VE	20.227	1.925	17.353	2.788	19.936	3.063	14.533	1.543

Note: Press = estimated subglottic pressure (cm H_20); Flow = mid-vowel airflow (L/sec); Res = laryngeal resistance (cm H_20/L/sec); SPL = sound pressure level (dB); VE = vocal efficiency.

Table 3

Descriptive Statistics for the Pre- and Post-Treatment Aerodynamic Measures in the Loud Condition for the VFE and Respiration Group

	Pre-Treatment				Post-Treatment			
	Female		Male		Female		Male	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
VFE								
Press	10.016	2.774	11.340	1.642	10.664	3.188	10.030	2.457
Flow	0.221	0.054	0.239	0.037	0.235	0.052	0.275	0.091
Res	46.180	9.849	48.529	13.492	44.194	10.303	37.700	14.712
SPL	66.576	2.712	68.902	2.985	66.316	3.115	67.682	2.322
VE	23.915	2.492	26.400	2.788	23.269	2.132	24.800	2.247
Respiration								
Press	10.781	2.077	11.240	4.392	12.028	1.914	11.436	3.587
Flow	0.202	0.051	0.247	0.067	0.228	0.045	0.284	0.108
Res	59.653	17.015	47.116	12.038	53.716	12.198	43.759	12.516
SPL	70.245	3.160	69.436	4.326	71.124	3.716	68.263	4.508
VE	28.635	3.109	26.497	3.857	27.518	2.576	24.690	4.607

Note: Press = estimated subglottic pressure (cm H_20); Flow = mid-vowel airflow (L/sec); Res = laryngeal resistance (cm H_20/L/sec); SPL = sound pressure level (dB); VE = vocal efficiency.

Table 4

Descriptive Statistics for Pre- and Post-Treatment Vowel Acoustic Measures for the VFE Group

	Pre				Post			
	Female		Male		Female		Male	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
/ɑ/ F0 (Hz)	226.940	14.336	126.880	19.108	249.570	32.160	126.440	16.154
/ɑ/ jitter (%)	1.503	0.867	0.956	0.559	1.055	0.749	1.061	0.586
/ɑ/ shim (%)	2.350	0.479	2.704	0.947	1.685	0.374	3.517	1.820
/ɑ/ NHR	0.105	0.027	0.121	0.027	0.108	0.032	0.134	0.016
/ɑ/ VTI	0.032	0.011	0.033	0.008	0.030	0.011	0.033	0.010
/ɑ/ SPI	20.230	9.377	34.716	15.651	24.824	7.244	40.921	22.547
/i/ F0	233.520	16.558	129.180	19.371	259.010	37.697	129.530	16.893
/i/ jitter	1.041	0.692	1.124	0.733	1.662	0.732	1.008	0.723
/i/ shimmer	1.783	0.499	1.631	0.546	1.352	0.618	1.758	0.770
/i/ NHR	0.107	0.025	0.111	0.035	0.124	0.024	0.125	0.033
/i/ VTI	0.037	0.007	0.030	0.006	0.036	0.007	0.031	0.013
/i/ SPI	15.144	6.839	22.895	13.692	25.597	16.058	31.054	23.490
/u/ F0	231.370	15.506	129.910	18.991	257.250	39.180	130.380	16.198
/u/ jitter	1.563	0.595	0.952	0.569	1.735	0.893	0.724	0.219
/u/ shimmer	1.544	0.976	1.497	0.581	3.549	4.231	1.684	0.690
/u/ NHR	0.110	0.028	0.110	0.036	0.158	0.121	0.111	0.040
/u/ VTI	0.025	0.006	0.022	0.012	0.025	0.007	0.023	0.011
/u/ SPI	52.938	20.469	69.125	28.973	78.322	27.245	99.370	52.483

Table 5

Descriptive Statistics for Pre- and Post-Treatment Vowel Acoustic Measures for the Respiration Group

	Pre				Post			
	Female		Male		Female		Male	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
/ɑ/ F0 (Hz)	236.310	26.300	120.920	7.340	246.330	25.978	114.130	11.580
/ɑ/ jitter (%)	0.960	0.226	0.691	0.391	0.891	0.371	0.975	0.623
/ɑ/ shim (%)	2.464	0.915	2.974	1.203	2.117	0.647	2.584	0.862
/ɑ/ NHR	0.104	0.020	0.128	0.018	0.108	0.010	0.129	0.016
/ɑ/ VTI	0.031	0.009	0.033	0.008	0.033	0.007	0.036	0.010
/ɑ/ SPI	22.199	7.635	20.010	18.049	27.427	15.727	28.982	17.041
/i/ F0	246.270	23.748	123.480	9.704	251.290	23.990	117.850	13.339
/i/ jitter	3.923	8.119	0.787	0.602	1.796	0.709	0.830	0.713
/i/ shimmer	1.637	0.722	1.626	0.523	1.454	0.616	1.660	0.410
/i/ NHR	0.120	0.019	0.104	0.034	0.100	0.029	0.104	0.034
/i/ VTI	0.035	0.012	0.037	0.012	0.032	0.018	0.030	0.009
/i/ SPI	20.674	11.022	12.983	12.121	25.590	9.525	17.836	9.166
/u/ F0	243.070	20.447	124.990	9.695	250.740	25.155	120.470	14.264
/u/ jitter	1.479	0.643	0.780	0.709	1.462	0.381	0.826	0.475
/u/ shimmer	1.506	0.922	1.214	0.391	1.794	0.898	1.543	0.540
/u/ NHR	0.119	0.029	0.106	0.031	0.104	0.029	0.108	0.038
/u/ VTI	0.028	0.006	0.022	0.009	0.025	0.011	0.025	0.013
/u/ SPI	54.523	25.767	42.690	21.048	68.728	30.001	71.321	33.385

Table 6

Descriptive Statistics for Selected Acoustic Variables for the VFE Group

	Pre				Post			
	Female		Male		Female		Male	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Mon LT *M*	8.57	1.15	7.52	1.23	8.12	1.40	6.96	0.86
Mon LT *SD*	4.28	0.74	4.74	0.60	4.37	0.65	4.50	0.57
Mon f0 *M*	207.52	11.05	121.82	15.33	208.64	12.16	122.63	15.36
Mon ST SD	2.59	0.47	2.18	0.58	2.93	0.99	2.27	0.74
Rain LT *M*	8.77	1.12	6.62	1.05	8.60	1.40	6.65	1.28
Rain LT*SD*	3.87	0.51	4.35	0.56	3.86	0.58	4.25	0.67
Rain f0 *M*	210.82	14.04	124.56	10.95	209.40	12.98	123.67	12.01
Rain STSD	2.58	0.34	2.24	0.51	2.60	0.46	2.15	0.43
MPT	20.82	6.45	28.75	12.14	22.79	5.75	31.29	11.02
Low Pitch	188.28	23.44	94.89	10.48	172.77	17.03	94.24	11.76
High Pitch	745.73	259.94	485.59	149.67	712.19	274.88	548.88	104.40

Note. Mon = monologue; LT *M* = long term average spectral mean (kHz); LT *SD* = long term average spectral standard deviation (kHz); f0 *M* = fundamental frequency mean (Hz); STSD = semitone standard deviation (semitones); Rain = rainbow passage; MPT = maximum phonation time (sec); Low and High pitch (Hz).

Table 7

Descriptive Statistics for Selected Acoustic Variables for the Respiration Group

	Pre				Post			
	Female		Male		Female		Male	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Mon LT *M*	8.33	2.01	6.38	2.42	8.83	1.66	6.16	1.08
Mon LT *SD*	3.94	1.01	4.71	0.86	4.24	1.25	4.52	0.64
Mon f0 *M*	213.44	17.53	117.24	8.21	210.07	22.51	114.67	14.20
Mon STSD	3.25	0.54	2.15	0.41	3.08	0.93	1.91	0.30
Rain LT *M*	8.78	1.56	6.32	1.63	9.27	0.93	6.10	1.20
Rain LT *SD*	3.40	0.65	4.15	0.75	3.43	0.76	4.30	0.76
Rain f0 *M*	219.10	25.66	124.72	9.25	217.90	23.21	121.66	17.70
Rain STSD	3.18	0.81	2.42	0.58	3.33	0.78	2.29	0.67
MPT	18.64	7.24	26.60	6.04	17.87	6.62	28.81	8.16
Low pitch	184.77	25.47	96.17	17.07	181.48	26.27	94.08	15.55
High pitch	882.55	254.75	468.25	170.72	798.19	271.54	464.18	154.00

Note. Mon = monologue; LT *M* = long term average spectral mean (kHz); LT *SD* = long term average spectral standard deviation (kHz); f0 *M* = fundamental frequency mean (Hz); STSD = semitone standard deviation (semitones); Rain = rainbow passage; MPT = maximum phonation time (sec); Low and High pitch (Hz).

Table 8

Results of Repeated Measures ANOVA for the Aerodynamic Measures

Condition	Pre-post		Pre-post*Treatment Group		Pre-post*Gender	
	F-ratio	*p-value*	*F*-ratio	*p-value*	*F*-ratio	*p-value*
Normal						
Pressure	0.149	0.702	1.494	0.232	0.523	0.476
Flow	0.350	0.561	0.201	0.659	0.342	0.565
Resistance	0.173	0.682	0.119	0.734	1.077	0.312
SPL	0.098	0.756	0.013	0.910	0.194	0.663
Vocal Efficiency	1.291	0.269	2.131	0.160	0.595	0.450
Soft						
Pressure	13.483	0.001	0.310	0.582	5.183	0.031
Flow	11.546	0.003	1.026	0.322	0.928	0.346
Resistance	0.946	0.341	1.265	0.273	3.541	0.073
SPL	0.073	0.788	0.749	0.395	5.509	0.027
Vocal Efficiency	14.877	0.001	0.098	0.757	5.102	0.034
Loud						
Pressure	0.141	0.710	1.027	0.319	2.098	0.158
Flow	7.117	0.013	0.097	0.758	0.595	0.448
Resistance	6.923	0.014	0.176	0.679	0.555	0.463
SPL	0.386	0.539	0.172	0.681	1.113	0.300
Vocal Efficiency	5.110	0.033	0.088	0.769	0.518	0.479

Table 9

Results of Repeated Measures ANOVA for the Vowel Acoustic Measures

Condition	Prepost		Prepost*treatment group		prepost*gender	
	F-ratio	*p-value*	*F*-ratio	*p-value*	*F*-ratio	*p-value*
/ɑ/ f0	3.659	0.065	2.034	0.164	8.995	0.005
/ɑ/ jitter	0.172	0.681	3.360	0.076	8.864	0.006
/ɑ/ shimmer	0.466	0.500	1.050	0.313	2.766	0.106
/ɑ/ NHR	1.275	0.268	0.326	0.572	0.123	0.728
/ɑ/ VTI	0.271	0.606	0.800	0.378	0.013	0.911
/ɑ/ SPI	6.266	0.018	0.116	0.736	0.287	0.596
/i/ f0	2.474	0.126	2.719	0.109	4.976	0.033
/i/ jitter	0.328	0.571	0.882	0.355	0.270	0.607
/i/ shimmer	1.394	0.247	0.161	0.691	4.104	0.051
/i/ NHR	0.172	0.681	4.307	0.046	0.480	0.494
/i/ VTI	0.711	0.406	0.856	0.362	0.081	0.777
/i/ SPI	6.367	0.017	0.618	0.438	0.044	0.835
/u/ f0	3.759	0.062	2.327	0.138	6.104	0.019
/u/ jitter	0.003	0.956	0.034	0.855	0.509	0.481
/u/ shimmer	3.403	0.075	1.068	0.310	1.362	0.252
/u/ NHR	0.504	0.483	1.476	0.234	0.326	0.572
/u/ VTI	0.001	0.972	0.009	0.927	0.698	0.410
/u/ SPI	13.029	0.001	0.220	0.642	0.500	0.485

Table 10

Results of Repeated Measures ANOVA for Selected Acoustic Measures

Condition	Prepost		prepost*treatment group		prepost*gender	
	F-ratio	*p-value*	*F*-ratio	*p-value*	*F*-ratio	*p-value*
Mono LT *M*	0.627	0.434	1.974	0.170	0.805	0.377
Mono LT *SD*	0.005	0.945	0.182	0.672	2.023	0.165
Mono f0 *M*	0.248	0.622	0.960	0.335	0.004	0.950
Mono STSD	0.001	0.970	3.673	0.065	0.541	0.468
Rain LT *M*	0.069	0.795	0.568	0.457	0.989	0.328
Rain *SD*	0.041	0.841	0.972	0.332	0.007	0.933
Rain f0 *M*	1.128	0.296	0.101	0.753	0.047	0.830
Rain STSD	0.029	0.866	0.141	0.710	2.465	0.127
MPT	2.498	0.124	0.667	0.420	0.890	0.353
Low pitch	3.389	0.076	0.847	0.365	1.879	0.181
High pitch	0.373	0.546	1.511	0.229	3.395	0.075

Note. Mono = monologue; LT *M* = long term average spectral mean; LT *SD* = long term average spectral standard deviation; f0 *M* = fundamental frequency mean; STSD = semitone standard deviation; Rain = rainbow passage; MPT = maximum phonation time.

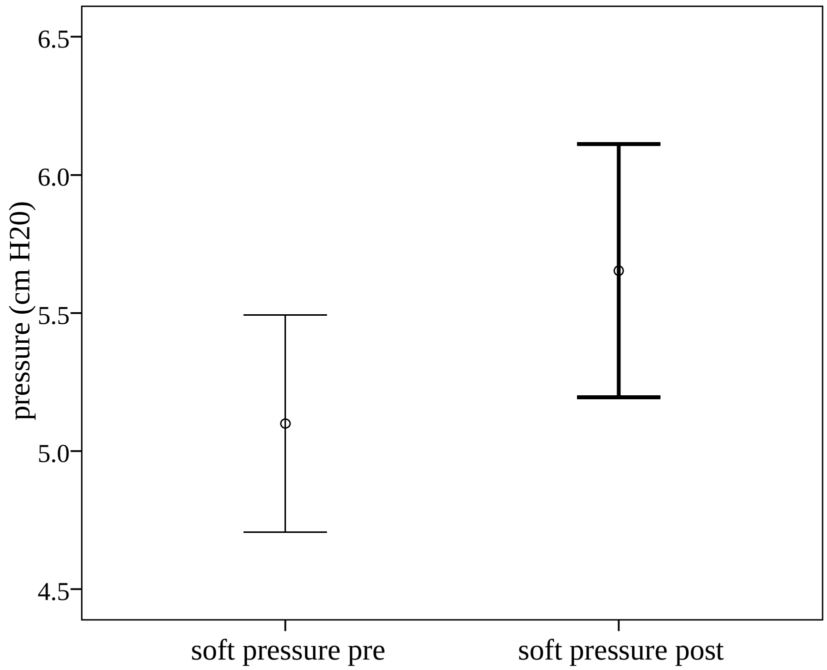

Figure 1. Mean and 95% confidence intervals for estimated subglottic pressure (Psub) for all speakers in the soft condition.

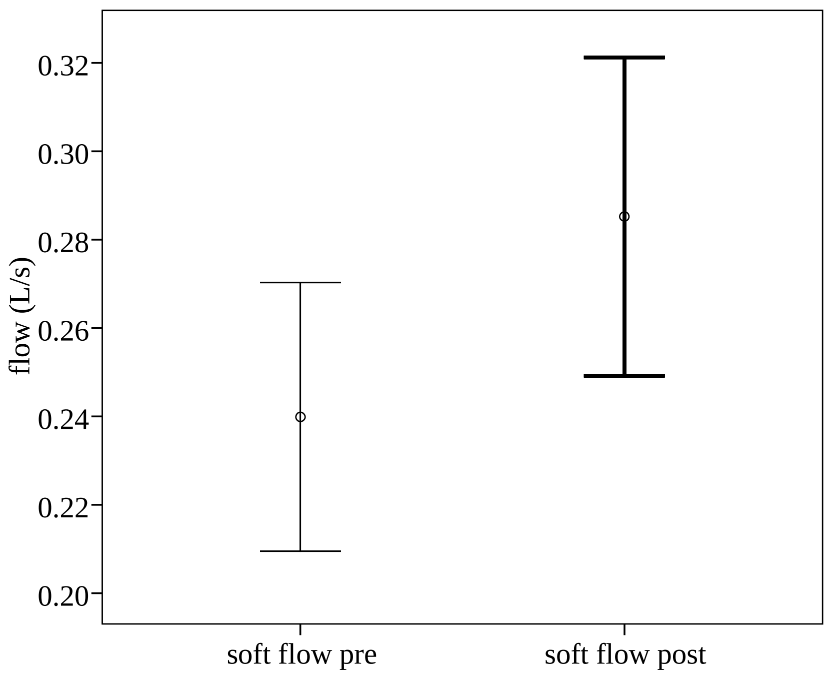

Figure 2. Mean and 95% confidence intervals for mid-vowel airflow for all speakers in the soft condition. Mid-vowel airflow axis is in units of L/sec.

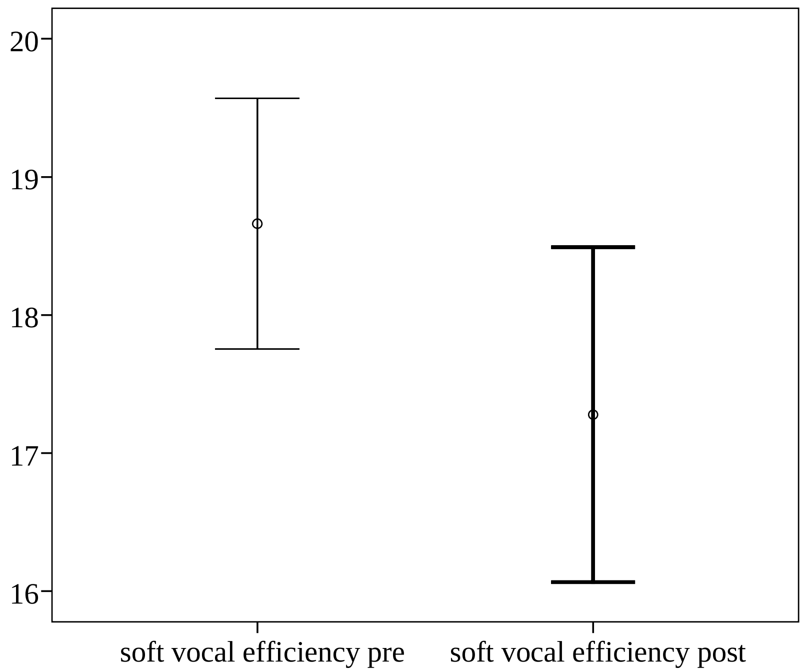

Figure 3. Mean and 95% confidence intervals for vocal efficiency for all speakers in the soft condition.

Figure 4, Psub was found to increase more for the female participants of both treatment groups than for the males, $F(1, 26) = 5.183$, $p = .031$. Laryngeal resistance was also found to have a significant pre-post by gender interaction effect, $F(1, 22) = 3.541$, $p = .073$. Females showed a slight increase in laryngeal resistance post-treatment, whereas males showed a larger decrease (see Figure 5). There was also a significant pre-post by gender interaction effect for SPL, $F(1, 26) = 5.509$, $p = .027$. It showed an increased SPL for female participants post-treatment and a decreased SPL for males (see Figure 6). Finally, vocal efficiency decreased post-treatment more for the male than the female participants of both treatment groups (see Figure 7), resulting in a significant pre-post by gender interaction effect, $F(1, 22) = 5.102$, $p = .034$.

Loud condition. Results of the repeated measures ANOVA revealed a significant pre-post main effect for mid-vowel airflow, laryngeal resistance, and vocal efficiency. There was a significant increase in mid-vowel airflow post-treatment, $F(1, 25) = 7.117$, $p = .013$ (see Figure 8). Laryngeal resistance, $F(1, 25) = 6.923$, $p = .014$, decreased significantly from pre-treatment to post-treatment, as shown in Figure 9. Lastly, vocal efficiency post-treatment showed a significant decrease, $F(1, 25) = 5.110$, $p = .03$ (see Figure 10).

Sustained Vowel Acoustic Analyses

/a/ vowel. Repeated measures ANOVA testing showed a significant pre-post main effect for fundamental frequency, $F(1, 31) = 3.659$, $p = .065$ (see Figure 11). It also revealed a significant pre-post by gender interaction effect for fundamental frequency, $F(1, 31) = 8.995$, $p = .005$. This resulted from an increase in fundamental frequency for female participants and decrease in fundamental frequency for male participants following treatment, as shown in Figure 12.

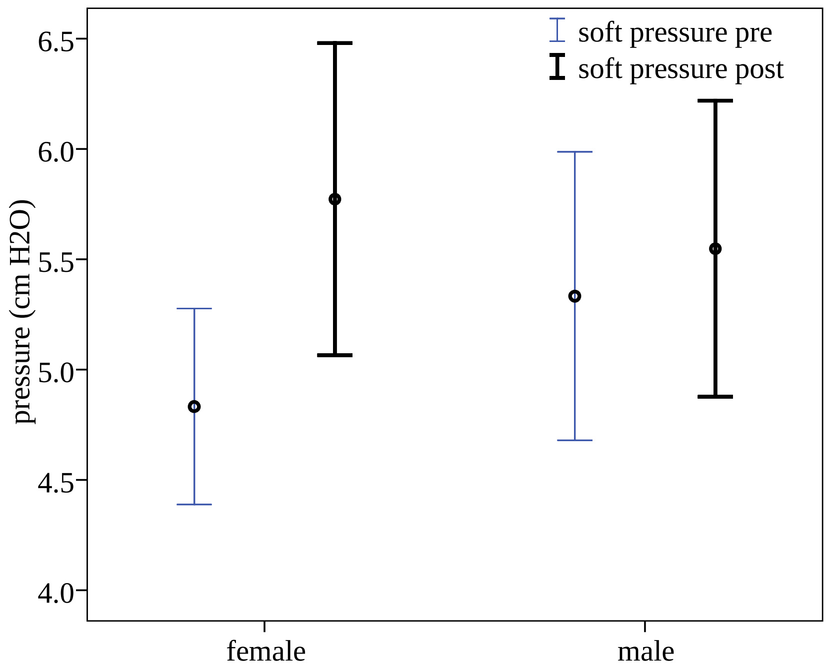

Figure 4. Mean and 95% confidence intervals for estimated subglottic pressure (Psub) for female and male speakers in the soft condition.

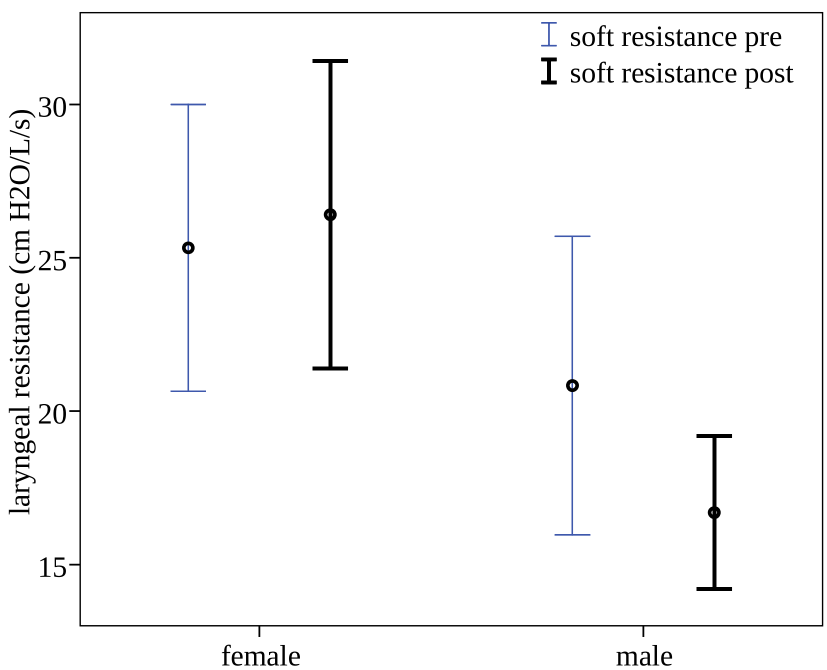

Figure 5. Mean and 95% confidence intervals for laryngeal resistance for female and male speakers in the soft condition.

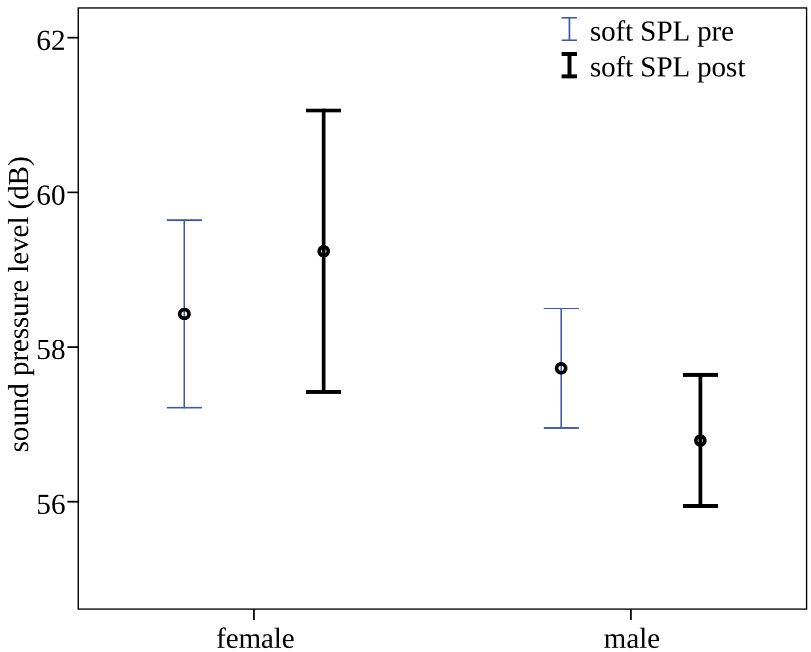

Figure 6. Mean and 95% confidence intervals for sound pressure level (SPL) for female and male speakers in the soft condition.

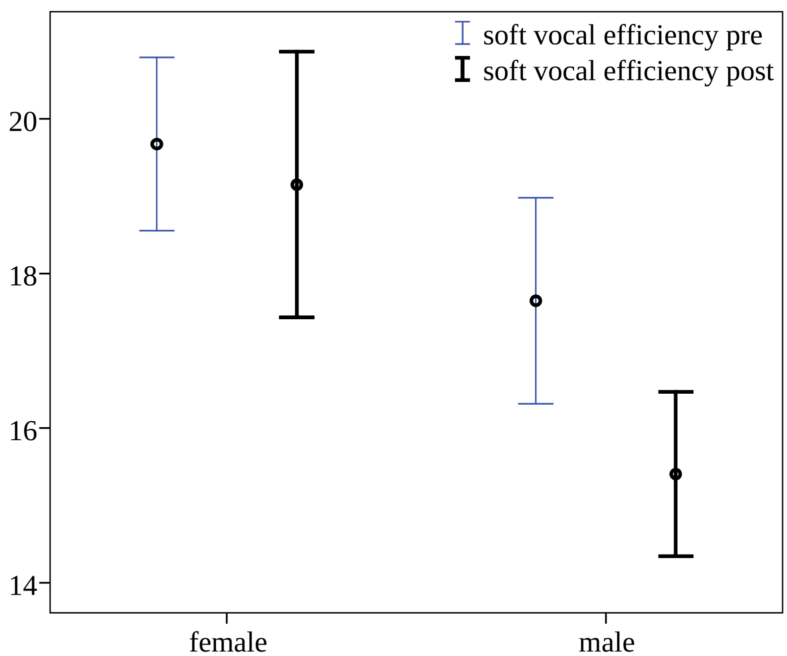

Figure 7. Mean and 95% confidence intervals for vocal efficiency for female and male speakers in the soft condition.

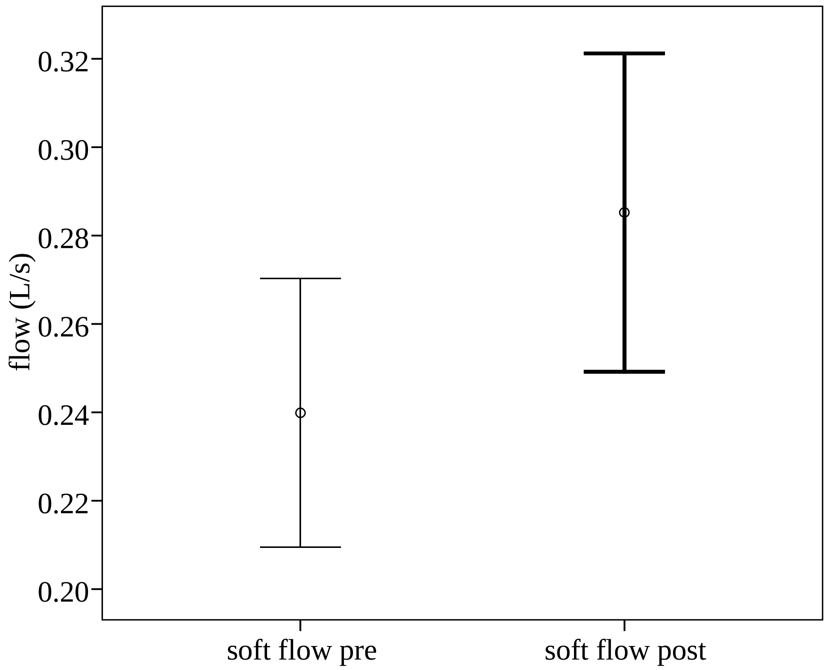

Figure 8. Mean and 95% confidence intervals for mid-vowel airflow for all speakers in the loud condition.

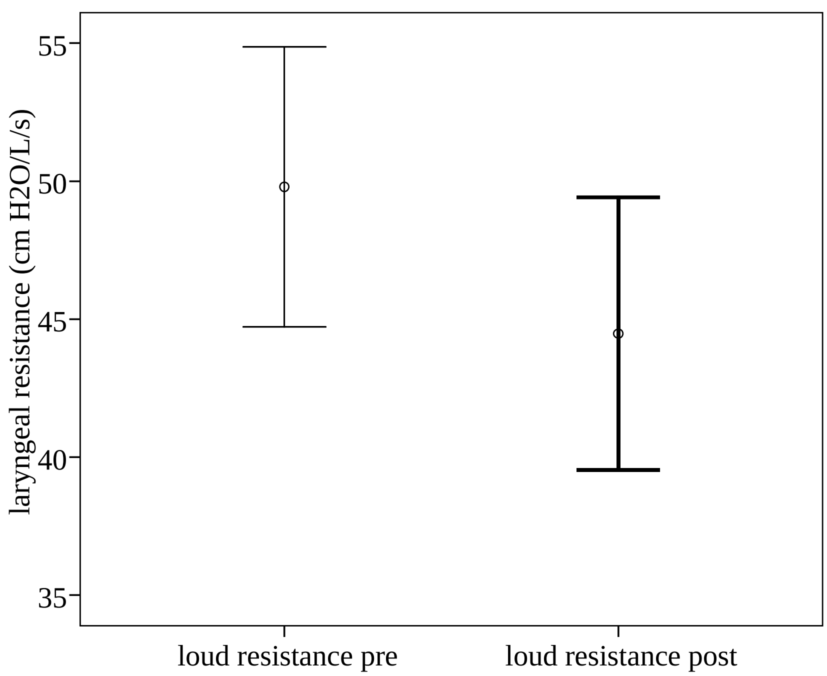

Figure 9. Mean and 95% confidence intervals for laryngeal resistance for all speakers in the loud condition.

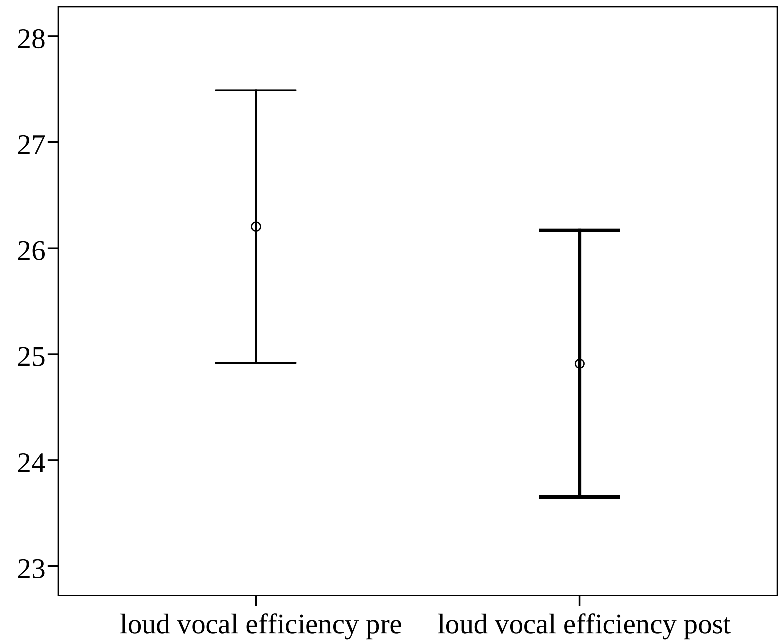

Figure 10. Mean and 95% confidence intervals for vocal efficiency for all speakers in the loud condition.

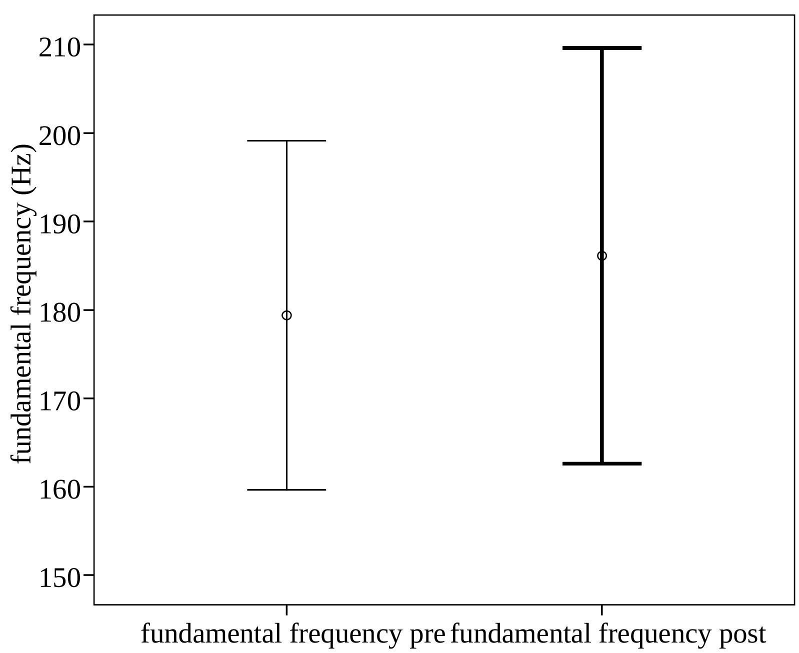

Figure 11. Mean and 95% confidence intervals for /ɑ/ fundamental frequency (f0) for all speakers.

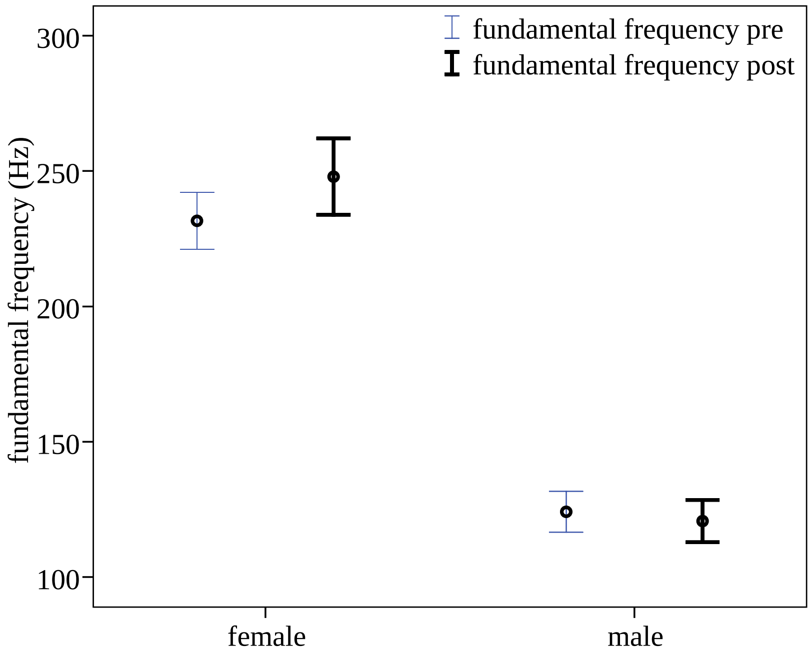

Figure 12. Mean and 95% confidence intervals for /ɑ/ fundamental frequency (f0) for female and male speakers.

Repeated measures ANOVA showed a significant pre-post by treatment group interaction effect, $F(1, 31) = 3.360$, $p = .076$ for jitter. As shown in Figure 13, the VFE group decreased, whereas the breathing group increased on this measure following treatment. There was also a pre-post by gender interaction effect, $F(1, 31) = 8.864$, $p = .006$ for jitter. There was a decrease in jitter values in female participants and an increase in jitter values in male participants following treatment (see Figure 14).

Testing also revealed significant pre-post by treatment group by gender interaction effect for shimmer, $F(1, 31) = 3.105$, $p = .088$ (see Figure 15 and Figure 16). Finally, it showed a significant pre-post effect SPI, $F(1, 31) = 6.266$, $p = .018$. SPI increased significantly from pre-treatment to post-treatment, as shown in Figure 17.

/i/ vowel. Results of the repeated measures ANOVA found a significant pre-post by gender interaction effect for vowel fundamental frequency, $F(1, 31) = 4.976$, $p = .033$. There was an increase in vowel fundamental frequency for female participants and a slight decrease for male participants (see Figure 18). There was also a significant pre-post by gender interaction effect for shimmer, $F(1,31) = 4.104$, $p = .051$. As shown in Figure 19, female participants showed a decrease values while male participants showed an increase in shimmer values.

The repeated measures ANOVA also revealed a significant pre-post by treatment group interaction effect for noise-to-harmonics ratio (NHR), $F(1, 31) = 4.307$, $p = .046$. There was an increase in NHR for the VFE group and a decrease for the breathing group (see Figure 20). Lastly, there was a significant pre-post main effect for SPI, $F(1, 31) = 6.377$, $p = .017$. SPI increased significantly post-treatment for both groups, as shown in Figure 21.

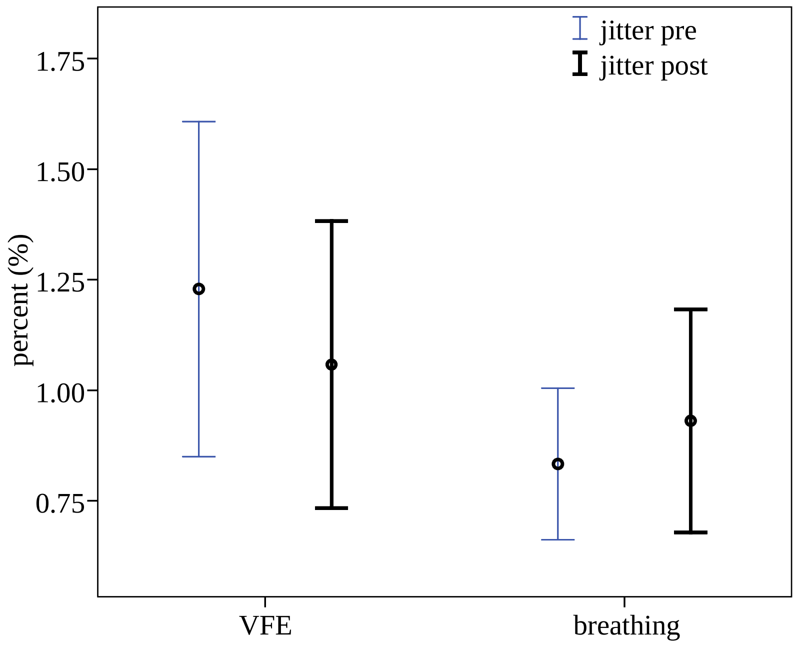

Figure 13. Mean and 95% confidence intervals for jitter for the VFE and Respiration treatment groups for the /ɑ/ vowel.

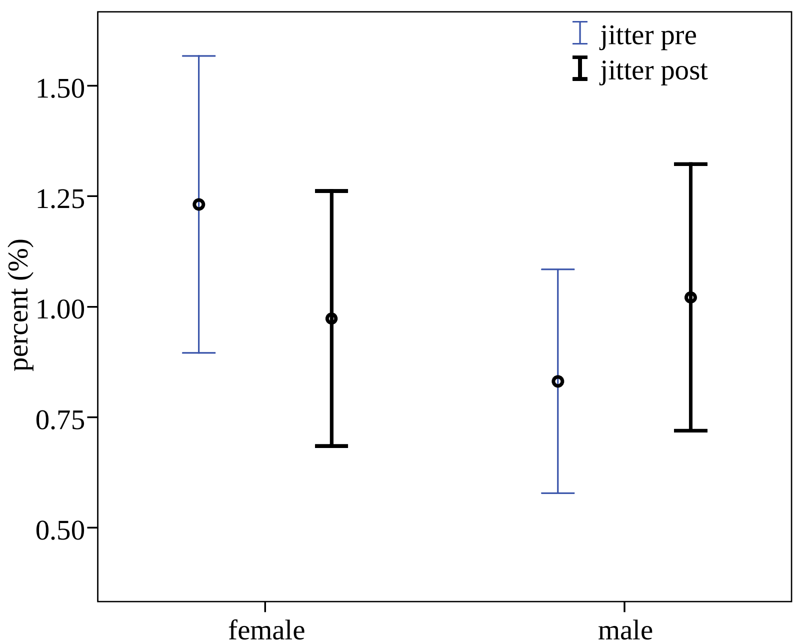

Figure 14. Mean and 95% confidence intervals for jitter for female and male speakers for the /ɑ/ vowel.

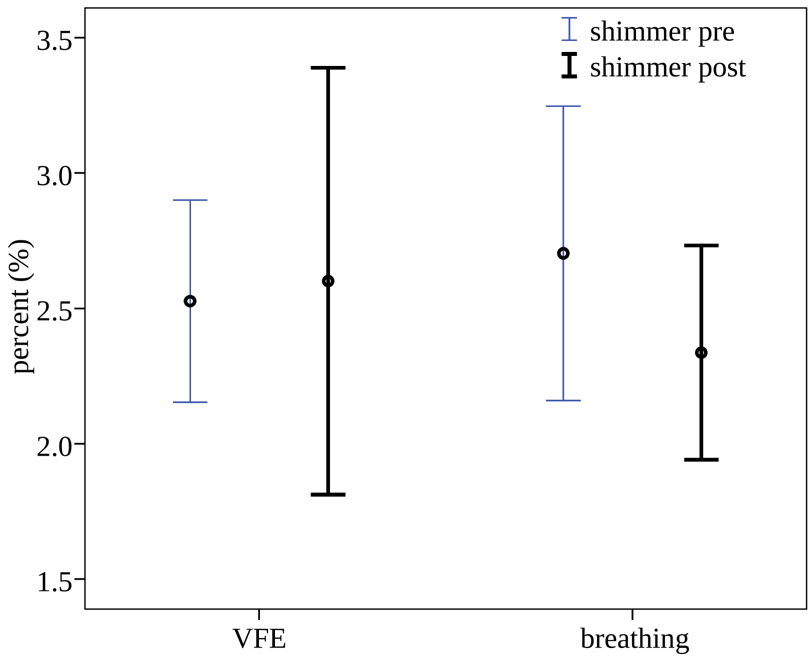

Figure 15. Mean and 95% confidence intervals for shimmer for speakers in the VFE and Respiration treatment groups for the /ɑ/ vowel.

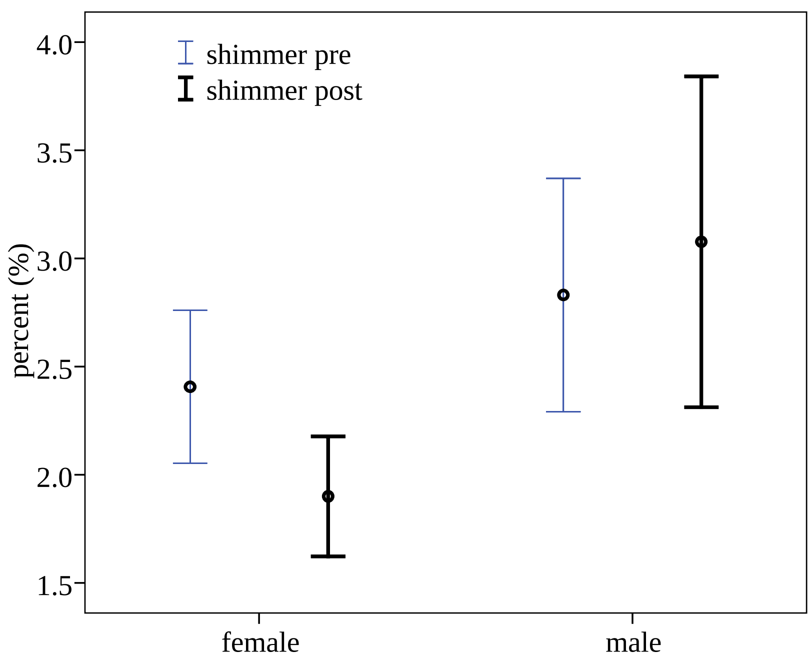

Figure 16. Mean and 95% confidence intervals for shimmer for female and male speakers for the /ɑ/ vowel.

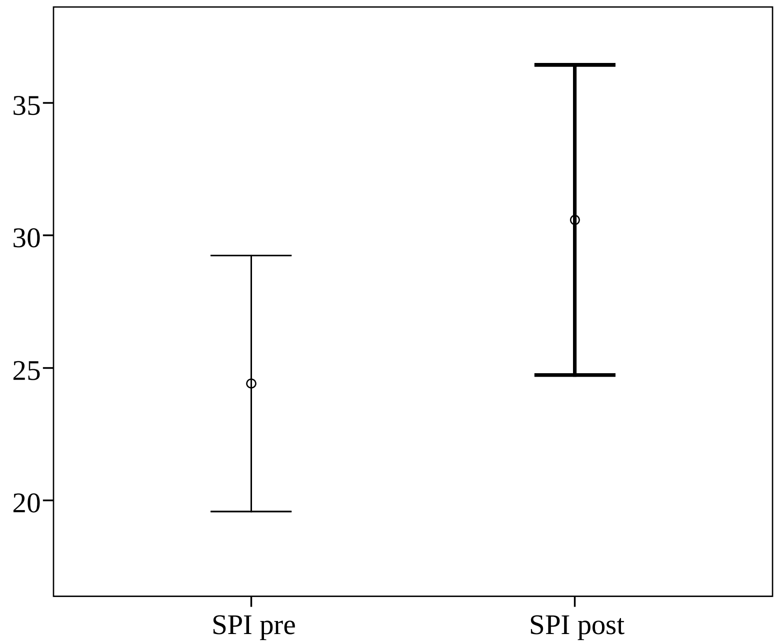

Figure 17. Mean and 95% confidence intervals for soft phonation index (SPI) for all speakers for the /ɑ/ vowel.

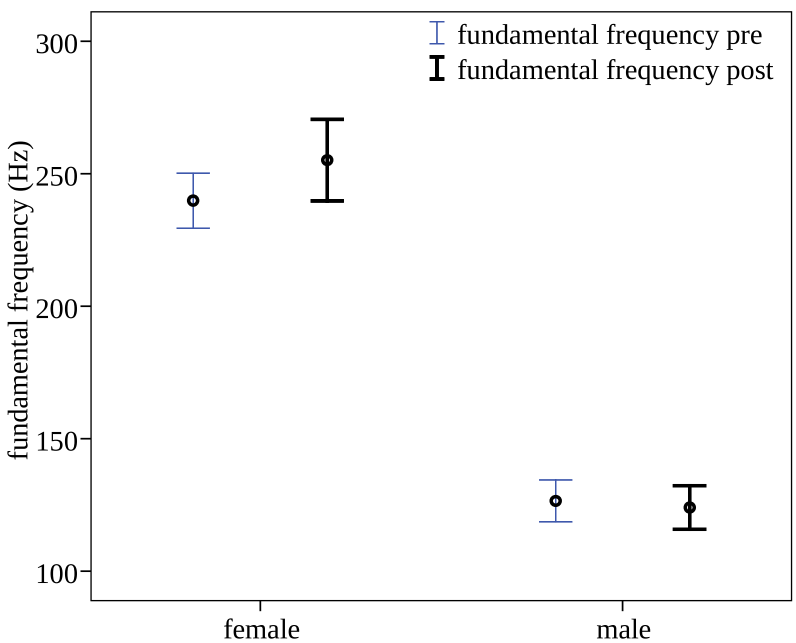

Figure 18. Mean and 95% confidence intervals for /i/ fundamental frequency (f0) for female and male speakers.

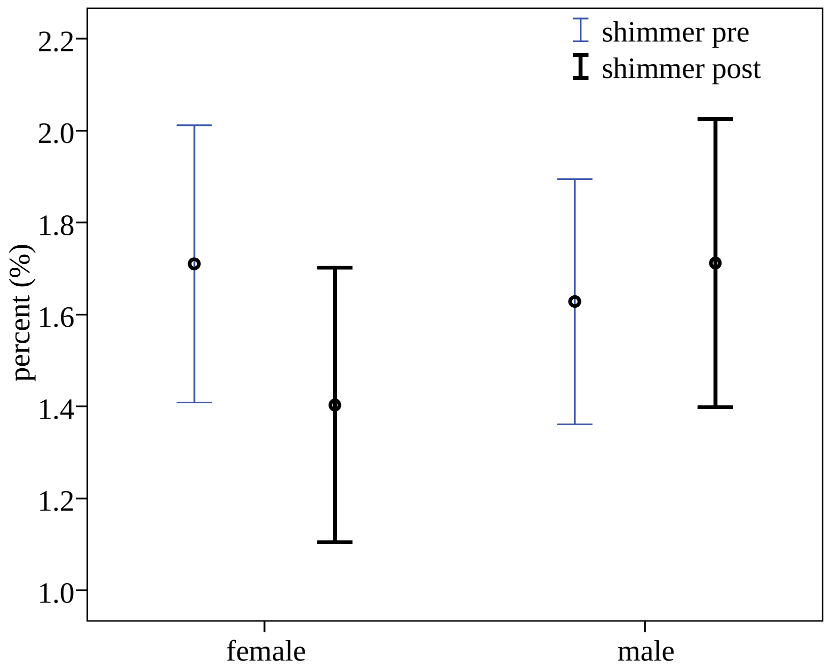

Figure 19. Mean and 95% confidence intervals for shimmer for female and male speakers for the /i/ vowel.

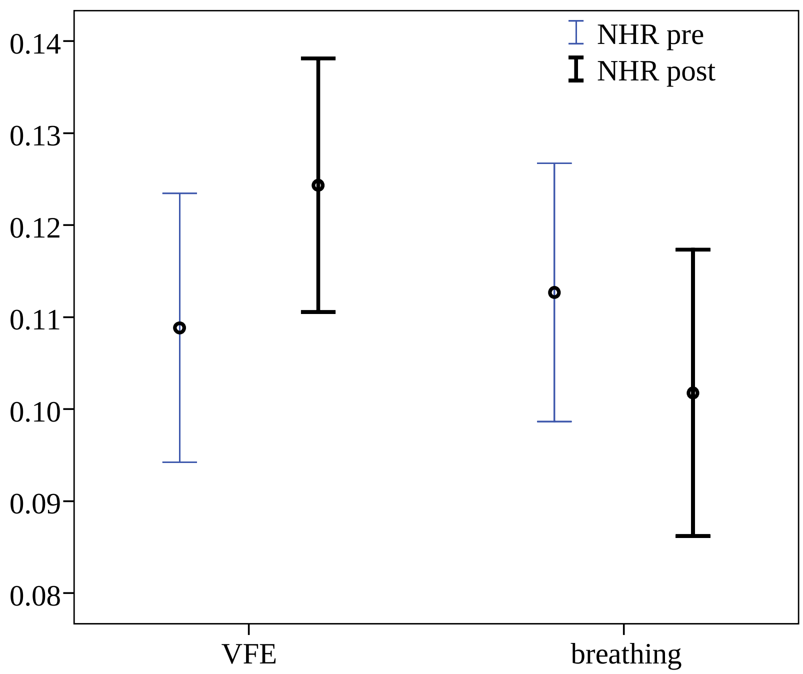

Figure 20. Mean and 95% confidence intervals for noise-to-harmonics-ratio (NHR) for all speakers of the VFE and Respiration treatment group for the /i/ vowel.

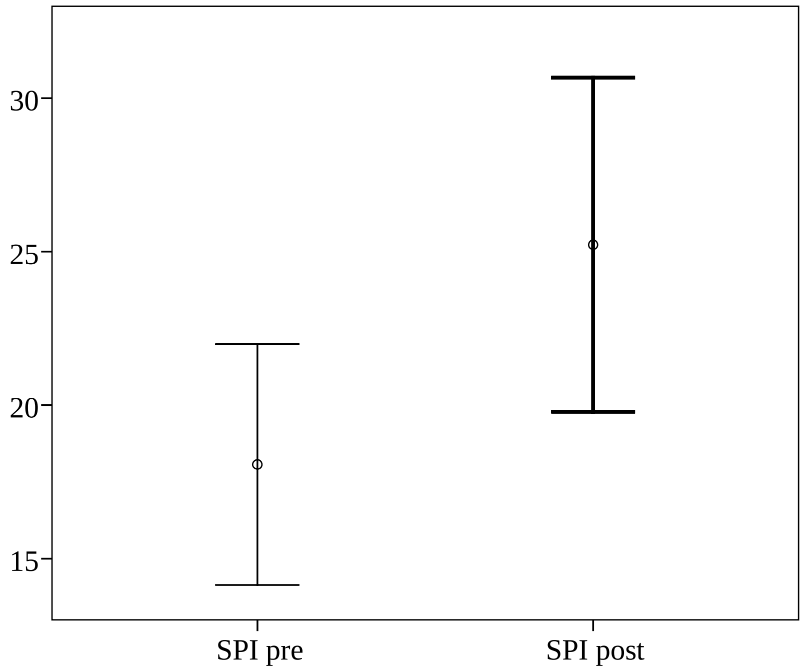

Figure 21. Mean and 95% confidence intervals for soft phonation index (SPI) for all speakers for the /i/ vowel.

/u/ vowel. Results of the repeated measures ANOVA found a significant pre-post main effect for vowel fundamental frequency (see Figure 22). It showed a significant increase post-treatment, $F(1, 31) = 3.759$, $p = .062$. There was a pre-post by gender interaction because of an increase in female fundamental frequency post-treatment with slight decrease for the males $F(1, 31) = 6.104$, $p = .019$ (see Figure 23). Testing also revealed a significant pre-post main effect for shimmer, $F(1, 31) = 3.403$, $p = .075$, and SPI, $F(1,30) = 13.029$, $p = .001$. Shimmer and SPI were found to increase significantly post-treatment (see Figure 24 and Figure 25).

Remaining Acoustic Analyses

30-second monologue. Results of the repeated measures ANOVA revealed a significant pre-post by treatment group interaction effect for monologue semitone standard deviation (STSD), $F(1, 31) = 3.673$, $p = .065$. As shown in Figure 26, participants of the VFE group showed an increase in monologue STSD while participants of the breathing group showed a decrease in monologue STSD.

Rainbow passage. The repeated measures ANOVA found a pre-post by treatment group by gender interaction effect for the rainbow passage spectral mean, $F(1, 31) = 3.11$, $p = .086$ (see Figure 27 and Figure 28).

Pitch range. Results of the repeated measures ANOVA revealed a significant pre-post main effect for low pitch, $F(1, 30) = 3.389$, $p = .076$. As shown in Figure 29, there was a significant decrease in low pitch post-treatment across male and female participants in both treatment groups. Testing also revealed a significant pre-post by gender interaction effect for high pitch, $F(1, 30) = 3.395$, $p = .075$. The female participants' high pitch decreased post-treatment while male participants' high pitch increased slightly post-treatment (see Figure 30).

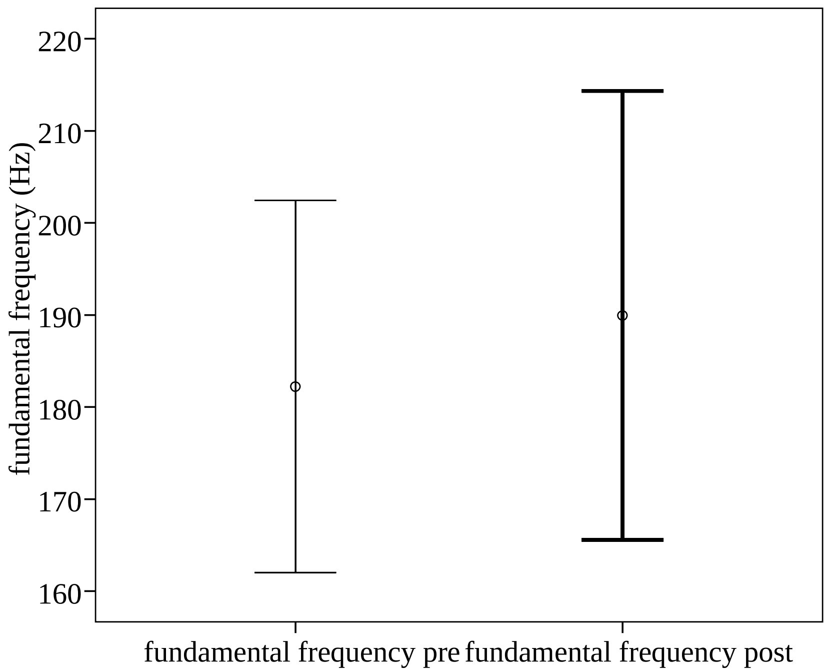

Figure 22. Mean and 95% confidence intervals for /u/ fundamental frequency (f0) for all speakers.

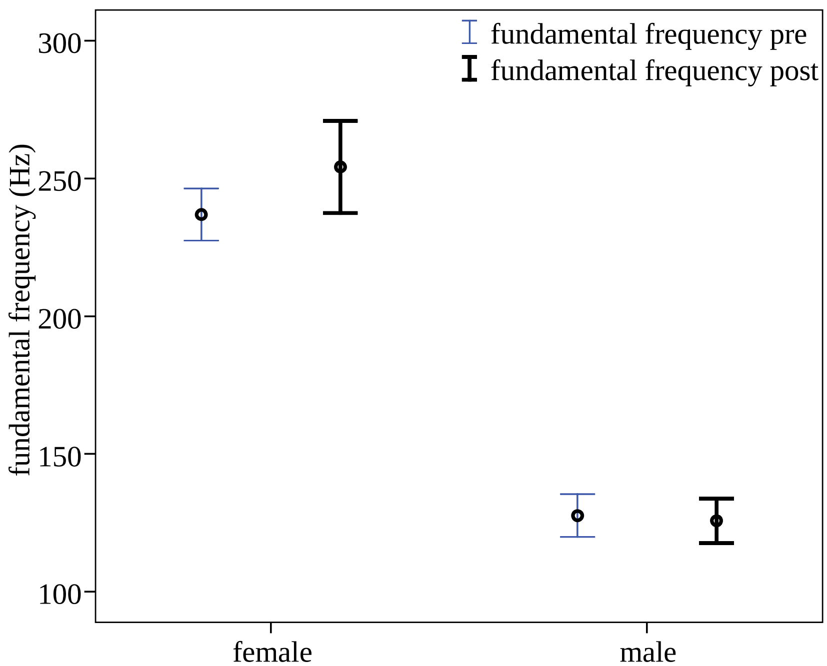

Figure 23. Mean and 95% confidence intervals for /u/ fundamental frequency (f0) for female and male speakers.

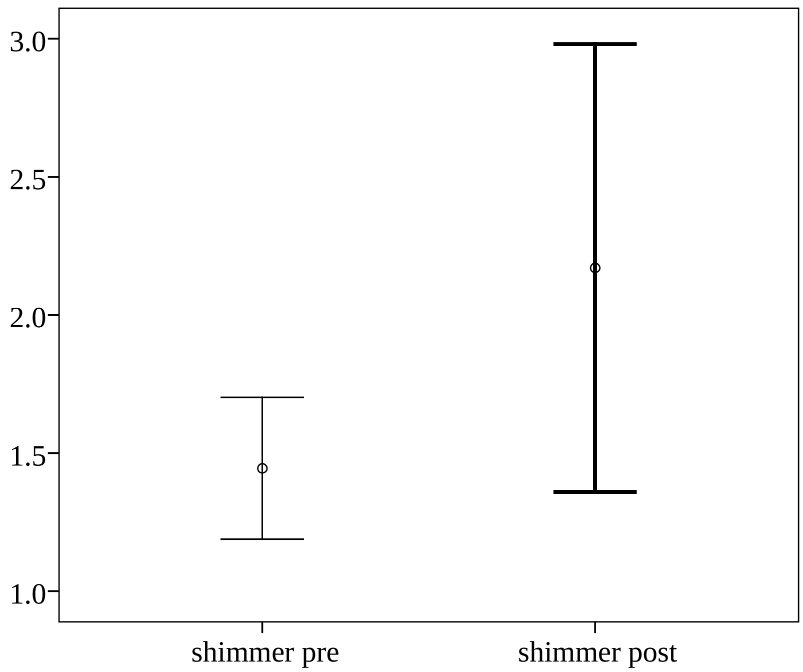

Figure 24. Mean and 95% confidence intervals for shimmer for all speakers for the /u/ vowel.

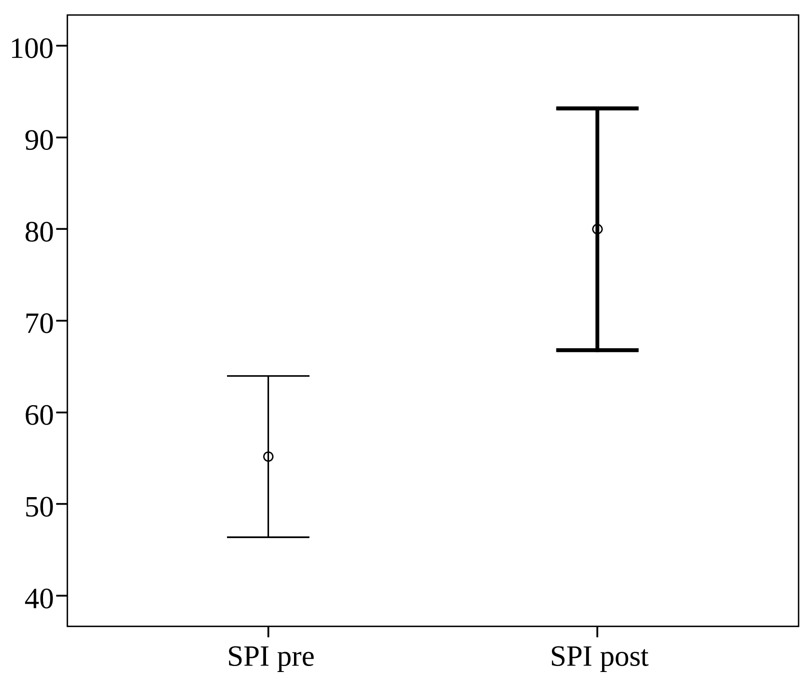

Figure 25. Mean and 95% confidence intervals for soft phonation index (SPI) for all speakers for the /u/ vowel.

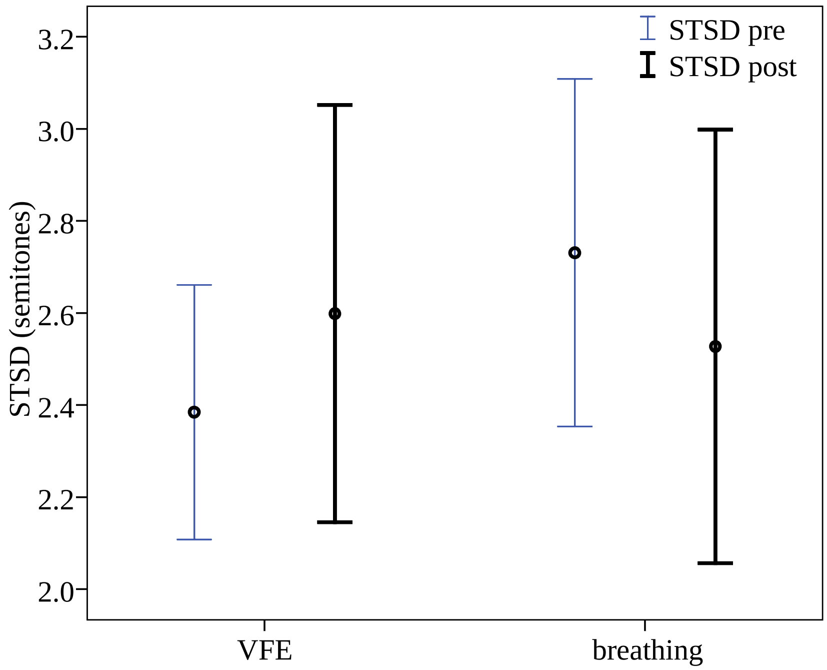

Figure 26. Mean and 95% confidence intervals for monologue semitone standard deviation (STSD) for speakers in the VFE and Respiration treatment groups.

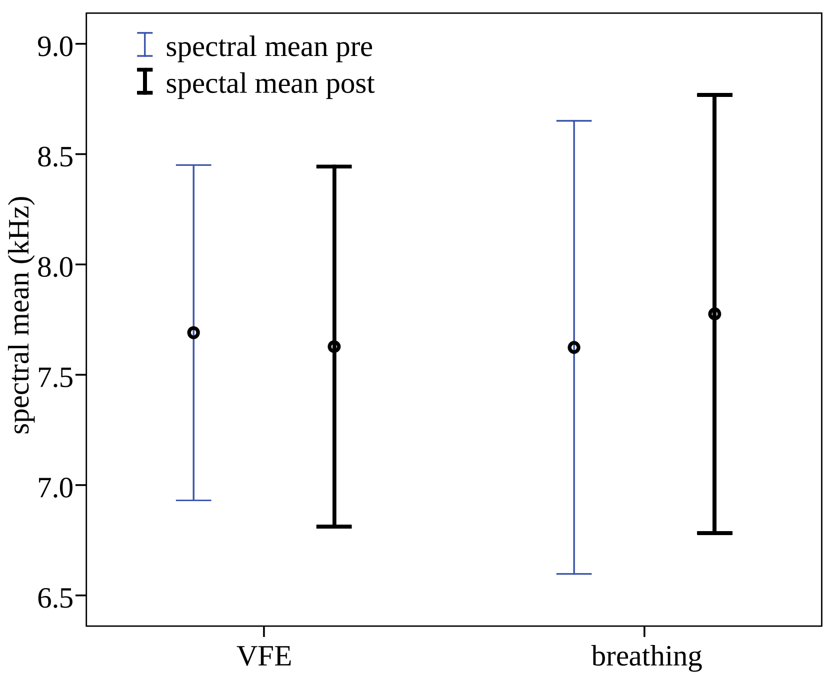

Figure 27. Mean and 95% confidence intervals for rainbow passage spectral mean for speakers in the VFE and Respiration treatment groups.

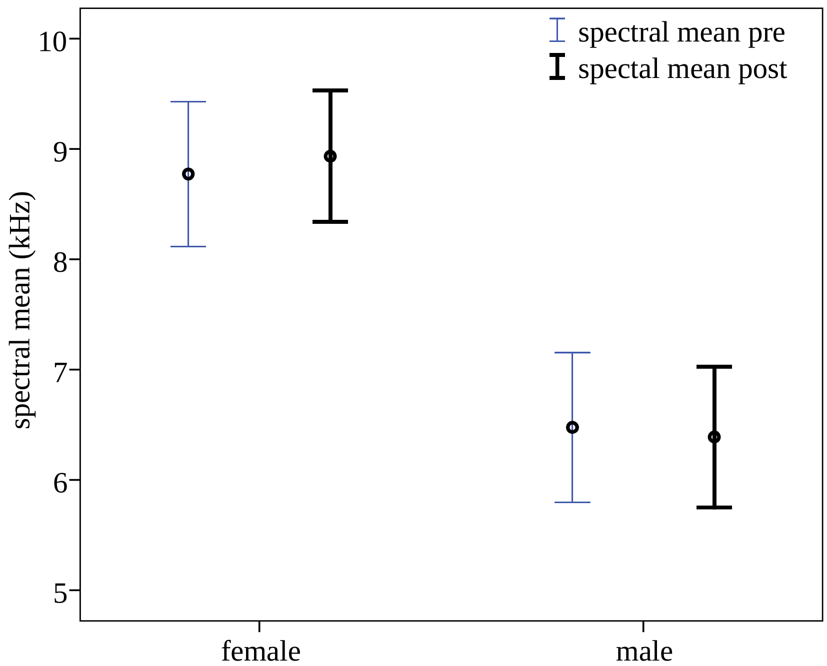

Figure 28. Mean and 95% confidence intervals for rainbow passage spectral mean for female and male speakers.

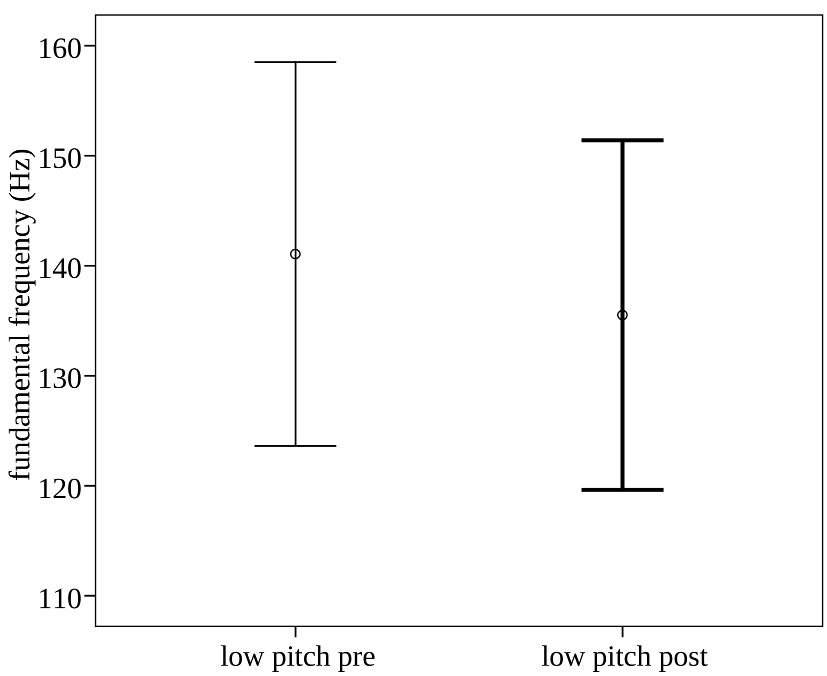

Figure 29. Mean and 95% confidence intervals for low fundamental frequency (f0) for all speakers.

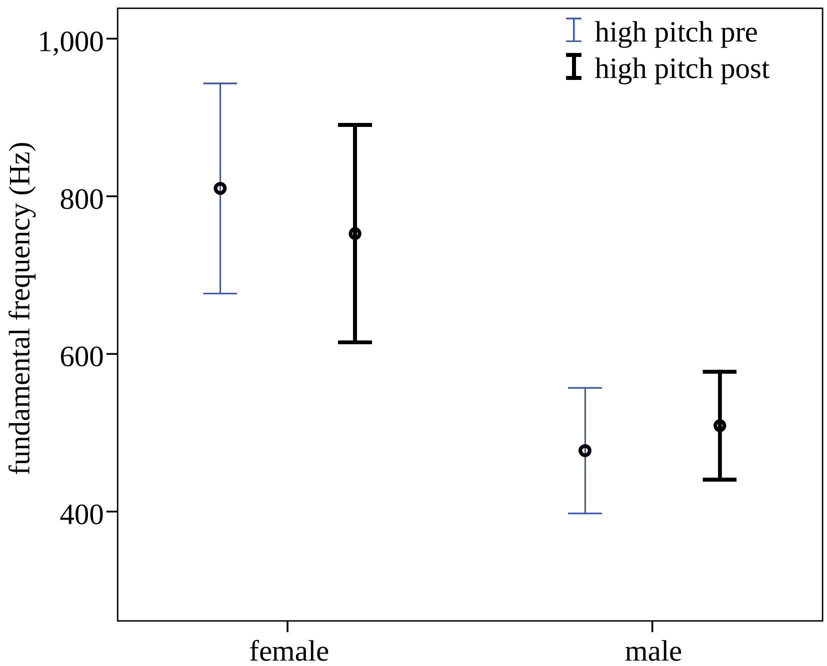

Figure 30. Mean and 95% confidence intervals for high fundamental frequency (f0) for female and male speakers.

Discussion

The purpose of this study was to replicate and extend the findings of the study conducted by Stemple et al. (1994) to better understand the effect of VFE on the normal voice in more naturalistic tasks that did not require intensity and frequency matching. Stemple et al. found significant improvements in phonation volume (amount of air available for sustained phonation), flow rate, maximum phonation time, and frequency range in young female adults after following a four-week VFE program, suggesting that participation in the VFE program has the ability to enhance normal vocal function. After adhering to a four-week VFE program, male and female young adults of the present study did not demonstrate clear improvements in aerodynamic and acoustic properties of normal voice production.

Aerodynamic Measures

Estimated subglottic pressure (Psub). It was hypothesized that VFE would lead to an increase in Psub after following a four-week VFE regimen. Gorman (2002) found that Psub increased after a 12-week VFE program in elderly men. He speculated that Psub increased in this population due to improved glottal closure. With improved closure, it requires a greater build up of pressure to drive vocal fold vibration. In the present study, it was found that VFE did not lead to a greater increase in Psub in the experimental group in the normal and loud condition after completing the exercise program. The results showed the post-treatment Psub measurements remained similar to the pre-treatment measures. However, in the soft condition, the Psub actually increased in participants of both groups. In the soft condition, Psub increased for both males and females, but more for the females. The changes in post-treatment Psub measurements may reflect slight variations in vocal effort. In attempting to elicit natural performance, the experimenters did not require that the participants match specific intensity targets during data collection. Sundberg, Fahlstedt and Morell (2005) stated “that variation in vocal loudness is normally achieved by changes in subglottal pressure…” and such changes affect the voice source by increasing amplitude, among other factors (p. 879). Thus the increase in Psub in the soft condition may be associated with slight increases in SPL in the soft condition rather than improved glottal closure.

Mid-vowel airflow. The present study found that airflow did not change in the normal condition, but increased in the soft and loud conditions across the VFE group and respiration group. Stemple et al. (1994) found that there were no significant differences in airflow rate during the production of comfortable and low pitches, but found that airflow rate decreased significantly during the production of high pitches in 35 adult women with normal voices after a period of four weeks using VFE. Sabol et al. (1995) found similar significant changes in flow rate during the production of high pitches in trained voices after a period of four weeks using VFE. They speculated the decreased airflow rates at high pitches resulted from an increase in the strength and balance of the laryngeal musculature.

It was hypothesized that VFE could lead to a decrease in mid-vowel airflow for the loud and soft conditions following a four-week VFE regimen. Loud phonation requires higher lung pressures and thus would subsequently increase airflow for any given level of laryngeal resistance. Higher airflow values may be expected in soft condition due to looser vocal fold adduction during soft phonation. Improvements in laryngeal muscle tone as a result of the exercises would likely result in lower airflow rates in both the loud and soft conditions. The discrepancy between the hypothesis and the results may result from a lack of compliance to the exercise program by the participants in the VFE group. Or possibly, the muscular changes resulting from the VFE program did not affect loud and soft phonation as anticipated.

Laryngeal resistance. Laryngeal resistance is calculated by dividing the pressure by the flow values. It was hypothesized that VFE would lead to an increase in laryngeal resistance due to improved tone and balance of the laryngeal musculature following a four-week VFE regimen. Results of the study demonstrated that laryngeal resistance decreased in the loud condition across participants in both treatment groups. The contributor to the change in laryngeal resistance is likely due to higher flow values recorded during the loud and soft condition, thus resulting in a decrease in laryngeal resistance. In the soft condition, male participants demonstrated a decrease in resistance while female participants did not. Thus, VFE did not result in an increase in laryngeal resistance in this group of young men and women.

Vocal efficiency. This study examined whether VFE might contribute to increased vocal efficiency in normal voices of young female and male participants. In 1995, Sabol et al. found significant physiologic improvements with singers using VFE after a four-week period. The physiologic effects of the exercises were evident through changed phonation volumes, airflow rates, and maximum phonation time. These alterations of the vocal mechanism appeared to result in less wasted energy suggesting that their experimental participants demonstrated an increase of glottal efficiency. It must be understood that glottal efficiency in this context was not a measure of acoustic power output, but a term they used to indicate that the larynx appeared to working better.

Vocal efficiency in the present study is an index of how efficiently the larynx is able to use the aerodynamic power from the lungs and convert it into acoustic power. Vocal efficiency is the ratio of dB output to the aerodynamic power input. Aerodynamic power is computed by multiplying Psub by airflow. When aerodynamic power to the larynx increases with no change in the acoustic power output, the ratio gets smaller, thus lowering vocal efficiency The results of the current study appear to be inconsistent with the findings of Sabol et al., in that there were no significant changes in vocal efficiency after participants followed a VFE regimen. Participants of both the experimental and control groups showed no change in vocal efficiency for the normal condition, whereas significant decreases emerged in the soft and loud conditions. The decrease in vocal efficiency in the soft and loud conditions is likely due to the significant increases in Psub and mid-vowel airflow with the absence of change in dB output.

The technique used in this study to measure flow and estimate driving pressure involved a Glottal Enterprises flow mask. The technique requires the participant to hold the mask tightly to the face while producing syllable strings with moderate jaw opening, in this case, /pae/ syllable strings. During recordings, it is important that the mask make a tight seal against the face to avoid air leaks and inaccurate measurement of airflow. Ladefoged et al. (1988) point out that the technique using the face mask to gather aerodynamic data is quite difficult to use in the field. It requires a perfect seal against the face, since a leak would seriously affect the measurement.

In the present study, several of the participants' measurements were discarded due to flow leak in the mask. This flow leak may be attributed to the fact that the experimenters only had two masks sizes: a larger one to be used with the male participants and a smaller one to be used by the females. It is possible that the mask used did not allow a perfect seal because the participants' faces were not uniform in size and shape. A flow leak may also be attributed to participants not holding the mask firmly enough against the face.

The speech task was limited to a specific utterance with moderate jaw opening, namely the /pae/ syllable. When producing the syllable string, the participants needed to speak at a slow rate with a monotone or flat production. Several of the participants were unable to properly complete the task, regardless of the instructions offered by the experimenter. This performance inability may have affected the measurements taken.

Acoustic Measures

Sustained vowels. Acoustic analysis of the sustained vowels included measurements of fundamental frequency, jitter, shimmer, NHR, VTI, and SPI. It was hypothesized that the participants in the VFE group would have decreased perturbation, decreased NHR, and decreased VTI in the post-treatment recordings. Acoustic analysis on the sustained vowels did not reveal any clear trends or improvement in the voices of participants in the VFE group on these measures. The results reflected an increase in fundamental frequency (more for females than males) on two of the vowels, and increases in SPI across participants in both treatment groups. These findings may suggest that the participants were not consistent in their pre- and post-treatment performance on the task. This suggests that post-treatment participants were phonating louder and at a higher pitch. The differences in performance reflect the variable nature of speech tasks. The changes could also be attributed to the fact that the participants of the experimental group were conditioned to matching pitch after following the four-week VFE program.

The present study did not have participants match fundamental frequency or intensity targets on the sustained vowel task, because more naturalistic performance was the target. Rammage, Morrison, and Nichol (2001) state that the goal when collecting aerodynamic and acoustic data is to "elicit phonatory behavior that is representative of an individual's typical speech patterns, with minimal opportunity to match the clinician's pitch, loudness, or effort level" (p. 26). However, this may have affected the reliability of acoustic data collected.

MPT. It was hypothesized that the VFE group would increase their MPT while the respiration group's MPT would remain the same post-treatment. However, the present study found no significant changes in MPT post-treatment in the VFE group or respiration group. Week by week, all subjects in both groups showed small increases in length of time they were able to sustain the exercises. However, these weekly improvements did not reflect significant changes in MPT. These results conflict with the results of Stemple et al. (1994) and Sabol et al. (1995) which demonstrated significant improvements in MPT in participants of the VFE group post-treatment.

Increasing MPT is not related to the ability to sustain or hold breath; rather, it is related to improvement in closing the glottis more efficiently at low lung volumes (Sabol et al., 1995). These authors concluded that VFE resulted in longer MPT due to increased inspiratory strength and increased expiratory muscular coordination, strength, and endurance. These changes allowed participants to inspire to higher percentages and expire to lower percentages of their total lung volume, resulting in an increased amount of air available for phonation.

The lack of strict adherence to the VFE program may have limited the amount of physiologic change and length of MPT in the VFE group. The majority of the participants were busy college-age volunteers who did not strictly adhere to the VFE as outlined by Stemple. Participants were not compensated for their efforts and may have lacked the commitment and dedication needed to see significant changes. However, these results represent a realistic view of the performance and limited improvement of a client who may not completely understand the impact VFE can have on voice production.

Monologue. The results revealed significant changes in semitone standard deviation (STSD) post-treatment. The participants of the VFE group increased their monologue STSD while participants of the respiration group showed a decrease in monologue STSD. This measure reveals increased fundamental frequency variability during speech following the treatment, and may be reflective of increased pitch flexibility in the voices of the VFE group participants.

Fundamental frequency range. It was hypothesized that the VFE would result in an increase in pitch range. Results of the present study revealed a significant decrease in low pitch across both groups and a decrease in high pitch for female participants and an increase for male participants. Participants in both groups demonstrated similar results post-treatment, indicating that VFE did not lead to significant change in frequency range. These results contrast with the significant decrease (M = 15 Hz) in the low end of participants' frequency range the VFE groups reported by Stemple et al (1994).

Each participant was instructed to glide three times from mid-range to as high as they could and then glide three times from mid-range to as low as they could. The best production was used in each case. It was observed that post-treatment participants of the

VFE group did not seem to push their voices as far as they could and the data collected confirmed the observation. While practicing the VFE, steps two and three instruct the participants to glide to a comfortable high and a comfortable low. Post-treatment, rather than pushing their voices, they stopped at a comfortable high and a comfortable low. The variable nature of the task may have led to an underestimate of the true benefit these exercises had on the frequency range.

Limitations of the Present Study

One limitation is that the analysis relied on indirect measurements of the behavior of the larynx to document possible changes due to VFE. In 1994, Stemple et al. measured changes in acoustic, aerodynamic, and videostroboscopic variables, which allowed both indirect and also more direct measures of laryngeal performance. The acoustic and aerodynamic data in the present study did not reveal consistent improvement in the participants of the VFE group. It would have been valuable to document whether there were any changes in the muscles of the larynx, via techniques such as electromyography.

Another factor which may have influenced the results was that the experimenters did not require that the participants match specific intensity and fundamental frequency targets on the sustained vowel task because more naturalistic performance was a goal during data collection. The variable nature of the task may have affected the reliability of acoustic data.

Also, the participants were not compensated for their efforts. The participants were recruited by classroom announcements and volunteered their time. Due to the voluntary nature of participation in the study, the participants may not have been committed to strictly follow the exercises, which may have resulted in an underestimate of the potential benefits of the VFE. VFE have a strict protocol that requires the participant to be dedicated and diligent in doing the exercises twice daily. In order to help the participants invest more effort in the program and complete the exercises as outlined, a compensation program would be helpful. If participants are compensated, a more realistic measurement of the benefit VFE have on voice production could be made.

Directions for Future Research

The findings of this study indicate a need for further research in understanding the effects VFE have on systems of speech production including respiration, phonation, and resonance. Research could focus on different techniques of measuring change, effects on specific disordered populations, length and intensity of the exercise program, and compare the amount of change between VFE and another method designed to improve one of the three systems of speech production.

Laryngeal performance can be assessed via direct or indirect methods. Direct methods include flexible and rigid laryngoscopy and videostroboscopy. These methods allow the experimenter to look directly at the larynx and would be useful in documenting any visible changes in vocal fold behavior post VFE treatment. Stemple et al. (1994) and Sabol et al. (1995) used videostroboscopy to confirm the absence of laryngeal pathology in their participants. Post-treatment, videostroboscopy revealed significant differences in the phase symmetry in their participants in the 1994 study. However, these findings were not exclusively limited to the participants in the VFE group. Sabol et al. (1995) found no significant changes in the vocal folds post test. Further research could seek to understand more clearly the effect VFE have on vocal fold behavior. This exploration would help to put into context the changes seen in previous studies.

One indirect measure technique that allows insight into laryngeal muscle function is electromyography (EMG). EMG is a technique for quantifying and recording electrical activity in and thus the neural drive to the muscles of the larynx. The pattern, amplitude and duration of the electrical activity are measured. EMG data could be collected pre- and post-treatment of VFE to document any direct changes in the muscular function of the larynx.

Stemple argued that just as physical therapy employs systematic exercise to rehabilitate the body, speech therapy can also employ systematic exercise to rehabilitate the voice. The VFE program consists of a series of systematic exercises designed to rehabilitate the voice. Gillivan-Murphy et al. (2006) and Roy et al. (2001) documented improvements in the voices of teachers with documented and self-reported voice disorders after participating in the VFE program. Gorman (2002) demonstrated improved aerodynamic and acoustic parameters of the voice as well as improved voice quality in elderly men. Currently there is no research on the effectiveness of VFE with any other disordered populations. Future research could investigate the potential benefit VFE have on muscle tension dysphonia or vocal abuse and misuse.

A study conducted by Gorman (2002) found improved phonation in elderly men after a 12-week exercise period with no plateau effect. Roy et al. (2001) documented improvement in voice disordered teachers following a treatment period of six weeks. Stemple et al. (1994) and Sabol et al. (1995) documented performance of these participants with healthy normal and trained voices within those studies plateaued at two and three weeks, respectively. Future research could document the effect VFE have over extended periods of time and at what point participants experience a plateau effect. It could also determine the optimum length and intensity of the exercise program to gain maximum benefit.

In the normal process of aging, even the elderly who are healthy show significant losses in muscular strength (Skelton, Grieg, Davies, & Young, 1994). Gorman (2002) found improvement in the aerodynamic voice parameters in 24 healthy elderly men after adhering to a 12-week VFE program. Expiratory muscle strength training (EMST) has been found effective in increasing expiratory muscle strength resulting in an increase of the expiratory driving pressure used for speech, cough, and swallow (Kim and Sapienza, 2005). However, there has been little research done to evaluate the benefits of EMST in the healthy elderly population. Future research could explore and compare the potential benefits of VFE and EMST in training the muscles of respiration. It could document the effectiveness of these techniques in preventing or treating normal age-related respiratory muscle weakness.

In summary, there is still a need for more research to explore the value of VFE in improving phonation. The present study may have underestimated the true benefit of VFE on the normal, untrained voices of young male and female adults due to lack of compliance with the program. However, the limited benefit of VFE on the participants in this study is highly reflective of the limited benefit to clients who are not willing to strictly comply with the requirements of the program. It remains clear that further research is needed to better understand the potential benefit VFE have on improving the respiration, phonation, and resonation systems of speech production. A clearer understanding of the true benefit of VFE will provide valuable information to help clinicians to provide effective treatment.

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Consent to be a Research Participant

Introduction

You are invited to participate in a research study, designed to help us learn more about how Vocal Function Exercises improve normal voice production. Your participation will provide valuable information about how voice production improves following a four week period of exercises. This study is being conducted by Karen H. Thomas, a graduate student at Brigham Young University under the supervision of Dr. Christopher Dromey, an associate professor in the Communication Disorders Department. You were selected for participation because you are an average, native English voice user with no history of speech, language, or hearing disorders.

Procedures

You will be assigned to one of two groups: exercise group A and exercise group B. All members of each group will be asked not to engage in any unnecessary vocally damaging behaviors during the four weeks of the study.

Exercise group A

Members of the exercise group will be trained to complete a series of voice exercises that will be performed twice each day (once in the morning, once in the evening). You will tape record yourself performing the exercises three times weekly and meet with a graduate student clinician once weekly for 30 minutes. You will record your exercises in a daily log which will be submitted to the clinician each week. You will be asked to participate in two 1-hour data collection sessions, once before the exercise phase and once at the end of the exercise phase.

Exercise group B

If you were selected for exercise group B, you will be asked to participate in two 1-hour-data collection-sessions on separate days (four weeks intervening). During the intervening four weeks you will complete deep breathing and lip trill exercises twice a day as instructed. You will record your exercises in a daily log which will be submitted to the clinician each week.

Data-collection-session

All members of each group will be seated in a sound booth and complete a series of speech tasks. You will perform each speech task three times. Measurement of your performance will involve the use of audio recordings. A head-mounted microphone located four cm from the mouth will be used to pick up the speech signal. An airflow mask will also be used during the tasks to measure oral airflow and pressure. Your performance on each task will be recorded and compared.

Risks/Benefits

There are no known risks associated with participation in this study. All the equipment we use in this study has been used here and elsewhere without any problems. If you are assigned to exercise group A, you may notice subtle improvements in your voice. If you are assigned to exercise group B, there may be subtle breathing changes following the study. In either case, the results will provide valuable information about the effects of vocal and breathing exercises on the normal voice. This may eventually contribute to advances in out treatment of disordered communication.

Confidentiality
There will be no reference to your identity in paper or electronic records at any point during the research. An identification number will be used to organize the date we collect.

Participation and Questions
Participation in this research study is voluntary. You have the right to withdraw at anytime or refuse to participate entirely without jeopardy to your standing with the university. If you have any questions about this study, you may contact Dr. Christopher Dromey at (801) 422-6461, dromey@byu.edu. If you have questions you do not feel comfortable asking the researcher, you may contact Dr. Renea Beckstrand, IRB Chair, (801) 422-3873, 422 SWKT, renea_beckstrand@byu.edu.

Signatures
I have read the above and understand what is involved in participating in this study. My questions have been answered and I have been offered a copy of this form for my personal records. I understand that I may withdraw my participation at any time. I agree to participate in this study.

__________________________ __________________________

Signature Date Age