Vocal Assessment Before, After, and the Day After Opera Performance

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Summary: Objective. To explore aerodynamic, acoustic, and laryngeal changes surrounding opera performance.
Study Design. Prospective preperformance, postperformance, and day after performance.
Methods. The laryngeal and vocal function of five male and five female classically trained singers was assessed immediately before, immediately after, and 1 day after an actual operatic performance. Phonatory threshold pressure was obtained. In addition, during a full-voice singing task, aerodynamic and acoustic measures included estimated subglottal pressure, airflow during voicing, laryngeal resistance, and sound pressure level (SPL). Expert listeners in the audience judged performers' voice quality at the beginning and the end of the performance. Laryngeal visualization was performed immediately before performance and the day after performance.
Results. Laryngeal stroboscopy revealed allergy symptoms with no change in vocal fold edges for all men. Women were less impacted by allergies. For all singers, perceptual judgments of expert listeners in the audience corresponded well with laryngeal findings. The men whose voices were perceived to be balanced and strong across the performance demonstrated increased airflow and reduced laryngeal resistance after performance. The two women who did not sing in church the morning after the performance demonstrated increased airflow and reduced laryngeal resistance. The two men who did sing in church the morning after the performance demonstrated noticeably reduced SPL and increased laryngeal resistance the day after performance.
Conclusions. It appears most useful to describe the complexity of vocal performance with a variety of acoustic, aerodynamic, and perceptual measures. The findings further suggest that vocal rest the day after performance may facilitate recovery.
Key Words: Fatigue–Aerodynamics–Singing–Laryngeal.

INTRODUCTION

Opera is a highly demanding art form, requiring an extensive vocal range, unamplified projection, and emotionally nuanced interpretation, all within the realm of "bel canto" or "beautiful singing." Opera singers are among a group of professionals required to vocalize for their livelihood. Their work requires not only endurance during rehearsals and demanding performances but also an aesthetically pleasing vocal quality throughout their range.

The negative effects of excessive vocal demands have been documented for a variety of professions, each with requirements specific to their occupation.[1–10] The vocal demands of opera singers may be less apparent than those for the typical occupational voice user and, as with other vocal performers, go far beyond the stage. In the Moores School of Music, rehearsals for operas encompass 9 weeks, with 3-hour rehearsals, 3 days a week. This is in addition to lessons, studio classes, and repertoire coaching. Graduate voice students in this program typically have private teaching loads consisting of 5–10 voice students in addition to church jobs requiring 3-hour rehearsals once per week and two church services on Sundays. All the student participants had such additional hours of voice use each week. Participant T2 was a full-time Professor of Voice, teaching 16 applied voice students in addition to teaching a graduate level academic course. Studies of vocal loading suggest that fatigue with extensive voice use would be common. It is expected, however, that after years of classical training, a singer can produce a beautiful voice effortlessly, regardless of performance demands. In fact, training does seem to provide protection against vocal damage. Enflo et al[11] investigated how training mitigated the effects of a vocal loading task. Phonating at 80 dB for 20 minutes were 10 individuals, four of whom had formal singing training. Although nonsingers demonstrated increases in both phonatory threshold pressure (PTP) and collision threshold pressure, the singers' values remained constant.

Carroll et al[12] collected vocal dose data from seven semiprofessional and professional singers in a 2-week period before a performance. In addition to dosimetry data, the participants rated self-perceived vocal effort and their inability to produce soft voice (IPSV). As expected, the authors found increased vocal effort and IPSV ratings on days with high vocal demands. The authors also noted the importance of vocal rest, finding that when a high vocal demand day followed days of vocal rest, there was less impact on the singer, and the ratings of effort and IPSV were lower. Furthermore, greater demand on consecutive days resulted in a cumulative effect of increased ratings.

The value of recovery time was corroborated by Hunter and Titze[13] in a study of a vocal fatiguing task. They compared the recovery trajectory to that of wound healing, highlighting the need for adequate time for complete recuperation. If demands persist, the vocal tissues require virtually constant repair. Classically trained singers may encounter inadequate recuperation

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time in the weeks leading to performances and during the run of the show. In addition, the singers do not rely on electronic amplification to enhance vocal loudness, further increasing vocal demands.

Although researchers have investigated various aspects of singer development and training,[14–20] as well as vocal use in the weeks before performance,[12] no work to date has assessed changes in the voice with actual operatic performance. The present work was designed to investigate changes with performance in acoustic, aerodynamic, and laryngeal characteristics of the voice in highly trained opera singers.

METHODS

The study was approved by the Committee for the Protection of Human Subjects at the University of Houston. All participants signed an informed consent before beginning the study.

Participants

Participants were five male and five female classically trained singers. Participation selection criteria included singing principal or significant roles with wide ranges, requiring dynamic variety while maintaining audibility and clear declamation above the full orchestra. The men comprised one light lyric tenor, one experienced professional lyric tenor, one very light lyric baritone, and two baritones. The men ranged in age from 23 to 67 years, with a mean of 34 (standard deviation [SD], 19). The number of years of consistent, private instruction for the men ranged from 6 to 20, with a mean of 9.6. The women were a lyric soprano with high extension, two light lyric sopranos, and two mezzo-sopranos. Women ranged in age from 22 to 25 years, with a mean of 24 (SD = 1). The number of years of consistent, private instruction for the women ranged from 6 to 9, with a mean of 6.8. None of the singers smoked or had a history of smoking. All the singers were in good health, with the exception of seasonal allergy. Seasonal allergies were not an exclusion criteria because the goal was to document real-life performance demands.

Tasks

Within 3 hours before the performance and the day after the performance, the participants underwent laryngeal videostroboscopy. Although typically accomplished with a rigid scope, two participants were unable to tolerate the rigid scope, and nasal endoscopy was performed.

Before the preperformance data acquisition, participants warmed up to "performance-ready" status. A typical warm-up the morning of a performance would be total of 20 minutes warm-up in light phonation and dynamics, using yawn sighs and lip trills that move from low range (chest), sliding into higher range (head and/or falsetto); light phonation descending scales (that do not go higher than secondo passaggio in women and primo passaggio in men) for 3–5 minutes; increase range but not exceeding four semitones in women and not higher than secondo passaggio in men for 5 additional minutes; repeat yawn sighs and lips trills; low humming exercises; and arpeggios that encompass octaves from chest through passaggio to head voice. Warm-up during afternoon of the performance would be 25 minutes repeat morning procedures and then add musical segments from the performance, use humming exercises to relax. At the theater, just before entrances, use lip trills and humming exercises but avoid loud phonation and then add arpeggios that encompass the range of the role. Finally, select two to four phrases that include the extremes of the range and extremes of dynamic requirements and sing them in full voice.

After the previously described warm-up, participants said three sets of seven /pi/ syllable trains as softly as possible at their typical speaking pitch, while wearing a mask over the nose and mouth, with an oral pressure sensing tube just behind the teeth. Participants then sang the same series of /pi/ syllable trains in full voice, as though they were performing on stage in an auditorium. For tenors, the pitch was a minor third below the singer's primo passaggio. For baritones, it was a major third below. For lyric sopranos, the target note was a half-step lower than their secondo passaggio, and for the two mezzo-sopranos, it was one step lower. The note was constant for each singer across recording sessions.

For the day after (DA) performance condition, there were two distinct groups. If the DA performance was Saturday, the singers were not warmed up before recording. If the DA performance was Sunday, the participants had sung in a church choir.

Instrumentation

All data were collected in a quiet room with background noise less than 50 dB sound pressure level (SPL). Audio samples were recorded with a head-mounted microphone (AKG Acoustics GmbHLaxenburger Straβe 254A-1230 Vienna, Austria) positioned about 2.5 cm perpendicular to the lips and digitized at 50KHz (*Computerized Speech Laboratory*, Model 4500; KayPENTAX, New Jersey). A microphone attenuator was used for full-voice productions. Aerodynamic data were captured and analyzed with the *Phonatory Aerodynamic System* (*PAS*, Model 6600; KayPENTAX).

Measures

The following measures were obtained with the PAS: PTP, prephonatory inspiratory volume, intraoral pressure, airflow during voicing, SPL, and laryngeal resistance. For each expiratory measure, the first and the last syllable of the train were discarded. The automated demarcation of the pressure peaks and steady state airflow was used when possible. If not, these features were manually marked. All measures were averaged across the three trials. For the full-voice productions, complete bilabial closure was verified by zero airflow. If this was not achieved, the production was not included in the analysis. This occurred in one instance.

Perceptual judgments were also obtained regarding singing voice quality at the beginning and the end of the opera. Judgments were recorded on prepared spreadsheets by the evaluators seated in the audience during the live performances. Judges were three professors in the Moores School of Music with a minimum of 20 years of professional performance experience in addition to their teaching experience. Examples of quality ratings were "balanced," "breathy," and "pressed."

The laryngeal videostroboscopy images were reviewed by all three investigators and judged for any deviation from normal,

TABLE 1.
Female and Male Phonatory Threshold Pressure (PTP) in cm H_2O

Female	Stroboscopy Pre	Stroboscopy DA	Pre PTP	Post PTP	DA PTP	Male	Stroboscopy Pre	Stroboscopy DA	Pre PTP	Post PTP	DA PTP
S1 (N)	Right swollen	Bilateral swelling	3.2	2.7	3.9	(T1) (N)	Excess mucous	Bilateral pink	4.7	4.8	3.9
S2 (S)	Clear with straight edges	Same	2.6	2.9	3.3	(T2) (N)	Posterior vf redness, thick mucous	Same	3.2	2.7	3.1
S3 (S)	Clear with straight edges	Same	4.2	5.0	4.1	(B1) (N)	Thick mucous/right fold pink	Bilateral redness	5.4	4.8	5.8
M1 (N)	Slightly pink with straight edges	Same	3.8	5.4	4.3	(B2) (S)	Edges red, but straight, with excess mucous	Same	5.3	4.4	3.9
M2 (S)	Posterior pink/ straight edges	Clear with straight edges	4.0	4.4	4.0	(B3) (S)	Straight edges, left fold pink	Bilateral redness	3.2	3.6	3.5

Notes: S and N, respectively, indicate sang or did not sing, in a church choir before data acquisition.
Notes: DA is day after performance, when stroboscopy was performed.

including indices of allergies such as redness or thick mucus. A unanimous consensus was reached in all observations.

Reliability

Data were remeasured for one man and one woman at each of the three recording times. For the aerodynamic data, mean differences between original and repeated measures were as follows: PTP, 0.2 cm H_2O; prephonatory inspiratory volume, 5 cm^3; intraoral pressure, 0.5 cm H_2O; airflow, 8 cm^3; SPL, 0.4 dB; and laryngeal resistance, 2.2 cm H_2O/LPS. Reliability data are not reported for the impressions singing voice quality or of stroboscopy images because a consensus was reached for each measure.

RESULTS

Women and men data will be discussed separately. There was a marked difference between the women and the men in the initial condition of the vocal folds, with the men much more affected by allergies than the women. All participants reported having completed their typical vocal warm-up, described previously, and were "performance ready" at the preperformance recording. Data will be discussed in terms of preperformance to postperformance changes and postperformance to DA performance changes.

Phonatory threshold pressure

To interpret Table 1, recall that stroboscopy was performed before the performance and the day after the performance. Thus, predata and DA data reflect the stroboscopic laryngeal condition. For S1, the only woman with any notable laryngeal pathology, it can be seen that the DA PTP was more than double that of postperformance. S2 demonstrated a slight increase, with no change in laryngeal condition. The remaining three women demonstrated reduced PTP during DA data acquisition. There is not a clear pattern relating to whether the individual had sung in a choir before recording.

For the men, all of whom had some indication of allergies typical of the season in Houston, data interpretation is more challenging. It should be noted that none of the laryngeal symptoms in either preobservation or DA observation involved swelling or changes in the vocal fold edges. The most marked changes in PTP are for T1 and B1, neither of whom sang in a choir before data acquisition. T1's PTP decreased from 4.7 to 3.9 cm H_2O, whereas B1's PTP markedly increased.

TABLE 2.
Female Aerodynamic Measures and Audience Rating for Full-Voice Production Preperformance to Postperformance

Singer	Pre SPL	Post SPL	Pre Insp.	Post Insp.	Pre P_o	Post P_o	Pre Flow	Post Flow	Pre Res.	Post Res.	Expert Audience Rating Beginning	Expert Audience Rating Ending
S1 (N)	94.7	95.6	0.83	0.83	13.2	14.5	200	200	63.2	68.2	Breathy	Breathy
S2 (Y)	92.5	96.6	1.78	2.21	20.0	19.2	240	200	81.7	92.6	Balanced	Strong
S3 (S)	94.3	93.3	.75	.75	19.9	19.0	120	140	149.8	128.9	Balanced	Solid
M1 (N)	94.4	95.2	1.66	1.27	24.0	28.2	310	310	75.0	87.2	Balanced	Strong
M2 (S)	97.5	98.3	0.99	0.90	28.2	26.8	230	300	117.6	85.0	Balanced	Good

Abbreviations: SPL, sound pressure level in dB; Insp., inspiration in cm^3; P_o, estimated subglottal pressure in cm H_2O; Res., laryngeal resistance in cm H_2O/LPS.
Notes: S and N, respectively, indicate sang or did not sing, in a church choir before data acquisition.

TABLE 3.
Male Aerodynamic Measures and Audience Rating for Full-Voice Production Preperformance to Postperformance

Singer	Pre SPL	Post SPL	Pre Insp.	Post Insp.	Pre P_o	Post P_o	Pre Flow	Post Flow	Pre Res.	Post Res.	Audience Rating	
											Beginning	Ending
T1 (N)	92.9	91.4	1.58	1.89	23.7	20.9	270	230	82.4	85.8	Hyper (pressed)	Fatigued
T2 (N)	88.0	87.0	0.24	0.23	17.5	17.8	180	260	89.7	63.8	Balanced	Balanced/strong
B1 (N)	90.0	91.2	1.02	1.43	18.1	22.3	290	320	59.9	67.0	Hyper (pressed)	Hyper/fatigued
B2 (S)	93.3	96.3	1.47	1.80	25.7	22.9	250	290	95.6	77.3	Balanced	Balanced/strong
B3 (S)	86.3	91.1	0.92	0.48	15.2	12.8	330	140	182	153	Hyper (pressed)	Hyper/fatigued

Abbreviations: SPL, sound pressure level in dB; Insp., inspiration in cm^3; P_o, estimated subglottal pressure in cm H_2O; Res., laryngeal resistance in cm H_2O/LPS.
Notes: S and N, respectively, indicate sang or did not sing, in a church choir before data acquisition.

Women, preperformance to postperformance

Table 2 illustrates acoustic, aerodynamic, and perceptual data for full-voice production for the women's preperformance to postperformance. Four of five women (all except S1) were perceived by expert listeners in the audience to be vocally strong throughout the performance. These singers demonstrated relatively little change from preperformance to postperformance. S2 is of interest because of her 4 dB SPL increase. She supported this increase with greater prephonatory inspiration, with a decrease in airflow and increased laryngeal resistance. By contrast, M2, who increased SPL by roughly 1 dB, demonstrated a 70 cm^3/s increase in airflow and a resultant marked decrease in resistance from 117 to 85 cm H_2O/LPS.

Men, preperformance to postperformance

As mentioned previously, the men were much more affected by allergies than the women. This likely contributed to the perception that three of five demonstrated a pressed voice, with fatigue at the end of the performance. In Table 3, it can be seen that the aerodynamic values of the two singers who were perceived to produce a balanced, strong voice (T2 and B2) are very different from those who became fatigued. Both T2 and B2 increased airflow and reduced laryngeal resistance in the postperformance recording. By contrast, T1 and B3 decreased airflow and B1 increased resistance as a result of greater estimated subglottal pressure. It should be noted that the small prephonatory inspirations demonstrated by T2 represent catch breaths, reportedly perceived by the experienced singer to meet the demands of the phonatory task.

Women, DA performance

If the singers were recorded the day after a Friday performance, they did not sing before data acquisition. Three of the five women were recorded the day after a Saturday performance, and they sang in their respective church choirs before data acquisition. Table 4 illustrates the data. For these three singers (S2, S3, and M2), it can be seen that airflow stayed the same, increased modestly, or decreased, with each singer demonstrating increased laryngeal resistance. For the two singers who did not sing on Sunday morning, airflow increased and laryngeal resistance decreased.

Men, DA performance

These data are presented in Table 5. Only two men sang in a church choir before data acquisition. It is of particular interest that both of these men demonstrated noticeably reduced SPL and increased laryngeal resistance the day after performance. By contrast, the three men who did not sing the day after performance demonstrated either an increase or only a minimal change in SPL.

DISCUSSION

This study was designed to assess aerodynamic and acoustic changes in the voice associated with opera performance. The circumstances under which data were collected represent real life, with a "the performance must go on" mind set.

TABLE 4.
Female Aerodynamic Measures for Full-Voice Production After Performance and the Day After (DA) Performance

Singer	Post SPL	DA SPL	Post Insp.	DA Insp.	Post P_o	DA P_o	Post Flow	DA Flow	Post Res.	DA Res.
S1 (N)	95.6	98.9	0.83	1.3	14.5	18.9	200	280	68.2	64.4
S2 (S)	96.6	99.2	2.21	1.53	19.2	22.9	200	200	92.6	105.5
S3 (S)	93.3	95.6	0.75	0.81	19.0	22.7	140	160	128.9	140.7
M1 (N)	95.2	95.6	1.27	1.55	28.2	29.4	310	380	87.2	73.9
M2 (S)	98.3	98.2	0.90	0.87	26.8	28.1	300	260	85.0	101.6

Abbreviations: SPL, sound pressure level in dB; Insp., inspiration in cm^3; P_o, estimated subglottal pressure in cm H_2O; Res., laryngeal resistance in cm H_2O/LPS.
Notes: S and N, respectively, indicate if the individual had sung (S) or not (N), in a Sunday choir before recording.

TABLE 5.
Male Aerodynamic Measures for Full-Voice Production After Performance and the Day After (DA) Performance

Singer	Post SPL	DA SPL	Post Insp.	DA Insp.	Post P_o	DA P_o	Post Flow	DA Flow	Post Res.	DA Res.
T1 (N)	91.4	94.0	1.89	2.08	20.9	*	230	*	85.8	*
T2 (N)	87.0	86.2	0.23	0.31	17.8	17.6	260	240	63.8	68.9
B1 (N)	91.2	92.8	1.43	1.64	22.3	26.9	320	370	67.0	69.3
B2 (S)	96.3	92.8	1.80	1.37	22.9	28.4	290	330	77.3	82.9
B3 (S)	91.1	86.2	0.48	0.58	12.8	18.6	140	100	153.0	182.0

Abbreviations: SPL, sound pressure level in dB; Insp., inspiration in cm^3; P_o, estimated subglottal pressure in cm H_2O; Res., laryngeal resistance in cm H_2O/LPS.
Notes: S and N, respectively, indicate if the individual had sung (S) or not (N), in a Sunday choir before recording.
* Indicates unable to obtain because of flow above 0 cm^3 during bilabial closure.

Thus, some singers, particularly the men, performed with less than ideal laryngeal conditions. For the women, perceptual judgments of expert listeners in the audience corresponded well with laryngeal condition observed by stroboscopy. For the men, the pattern was less clear. One singer, T2, likely relied on many years of experience to produce a strong, balanced voice despite posterior vocal fold redness and thick mucus. The other male singer, who was perceived similarly, demonstrated excellent prephonatory inspiration and airflow to support his voice. It is of interest that the three singers who were perceived to produce a pressed quality initially were perceived to be fatigued at the end of the performance.

At the outset of the study, it was thought that PTP would be a sensitive indicator of change across the performance. It was, however, very difficult to find a logical pattern of change in PTP over time or in correspondence to laryngeal condition.

It appears that the most revealing assessment of vocal change surrounding performance involves several interrelated measures. Given the complexity of voice production, particularly with vocal demands such as opera, this makes sense. Because damage to the vocal folds occurs as a result of high collision forces, it is conceptually reasonable to use SPL as a referent. Healthy increases in SPL, providing the optimal conversion of aerodynamic to acoustic energy, will be characterized by greater prephonatory inspiration, greater airflow (without becoming breathy), and resultant reduced laryngeal resistance. In highly trained singers, upper vocal tract modification to optimize resonance will further increase SPL beyond the aerodynamic components.

The difference in vocal production the day after performance has important implications for vocal rest after performance. This is particularly evident for the female singers. S1, who had vocal fold swelling, increased SPL the day after performance by increasing prephonatory inspiration and airflow and reducing laryngeal resistance. M1, although not demonstrating such a marked increase in SPL, showed the same healthy pattern. By contrast, the men who sang in church services (section leaders and soloists) on Sunday before the DA recording showed a pattern highly reflective of vocal fatigue. They produced noticeably reduced SPL and increased laryngeal resistance the day after performance. These findings, although based on few data points, suggest that vocal rest the day after a performance may facilitate laryngeal recovery. This recommendation warrants further investigation in the context of real-life vocal demands.

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