Voice Production during a Weightlifting and Support Task

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Key Words

Phonation • Electroglottography • Aerodynamics •
Laryngeal valving • Effort closure

Abstract

Although effort closure techniques have a long history in the treatment of hypofunctional and psychogenic voice disorders, there have been surprisingly few studies of their specific laryngeal and phonatory effects. The present study was designed to provide preliminary data on physiologic changes in voice production associated with a weightlifting and support maneuver. Twenty vocally healthy subjects (10 men and 10 women) lifted hand-held weights and steadily supported them with outstretched arms as they either sustained comfortable phonation or repeated the syllable /pi/. Both the male and female subjects showed an increase in the electroglottographic contact quotient, long-term F_0 variability, and estimated laryngeal airway resistance attributable to an elevated driving pressure. Conversely, there were no significant changes in mean F_0 , pitch perturbation quotient (jitter), or phonatory airflow between the pre-lift and lift portions of their voice production, regardless of the amount of weight supported. The results of this study indicate that simultaneous phonation and weightlifting is associated with increased laryngeal airway resistance characterized by an elevation in driving pressure and medial compression of the vocal folds. Implications for an improved understanding of normal vocal physiology and for the therapeutic use of such air-trapping exercises are addressed.

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Introduction

The primary function of the larynx is to valve the flow of air into and out of the lower respiratory system [1]. By adjusting the glottal aperture, the vocal folds not only help protect and clear the airway, but also allow the entrapment and subsequent pressurization of air that helps stabilize the chest wall [2–7]. Restraining the collapse of the rib cage, this supportive closure allows the muscles of the trunk and limbs to perform with greater effectiveness. The maintenance of alveolar (and thus intratruncal) pressure during lifting has been shown to not only assist the support of the pectoral girdle, but also to alleviate part of the load on the vertebral column [8, 9]. Even moderate levels of physical exertion may be associated with this type of ‘adductory bias’ [10–12], which is why such effort closure or air-trapping activities as lifting, pushing, and pulling are commonly employed in therapeutic exercises for patients presenting with vocal hypofunction and/or glottal incompetence [13–21].

Yamaguchi et al. [22] reported that 3 patients with glottal inefficiency and inadequate glottal closure were able to increase both vocal intensity and airflow stability through the use of pushing exercises. In 1 case, the electroglottogram (EGG) from a patient with sulcus vocalis showed a more rapid increase in vocal-fold contact, a rounder peak, and a longer duration of contact following therapeutic pushing. Ramig and Scherer [23], Dromey et al. [24], Ramig and Dromey [25] and Ramig et al. [26] have also integrated such activities as ‘pushing the hands together or pushing down or lifting up on the arms of a

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1021–7762/08/0604–0188\$24.50/0

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chair or table while phonating' in their approach to voice treatment for hypokinetic dysarthria. Noting similar EGG changes, they have reported clinically significant improvement in vocal intensity and speech prosody for several of their patients. Still others [27–29] have claimed that the increased medial compression attained through this primitive closure mechanism can be used effectively to lower the speaking fundamental frequency (F_0) or to suppress inappropriate vocal behavior of functional origin.

Despite widespread clinical implementation, there have been few studies of the vocal effects of simultaneous upper-limb effort or other forms of physical exertion. Otis and Clark [30] and Doust and Patrick [10] have reported that vocalizations produced by normal subjects while running on a treadmill were typically louder, higher in pitch, and occasionally perceived to be more tremulous and breathy. Even for patients with glottal inefficiency, several authors [14, 17, 29] have warned of the potentially abusive consequences of inducing vocal hyperfunction through strenuous effort closure activities. Indeed, loud speech accompanied by rapid and effortful body movement may be largely responsible for the higher incidence of vocal fatigue and vocal-fold pathology among cheerleaders and aerobics instructors [31–35].

To determine if, when, and how an exercise is to be incorporated in voice treatment, it is necessary to document its specific physiologic effects. A better understanding of the normal response to pushing, pulling and lifting will allow a better prediction of how these maneuvers may or may not affect dysphonic speakers. In this way, clinicians will be able to refine techniques while tailoring exercises to meet a specific patient's vocal needs. This understanding may also assist us to find the best ways to maximize vocal performance when that performance is shared with other forms of physical labor. To date, there have been very few objective studies that document the effects of strenuous upper-limb activity on vocal function, in either dysphonic or normal speakers. The present investigation was designed to provide preliminary data on voice production for vocally healthy speakers engaged in a weight support task.

Method

Subjects

Ten men, ages 27–41 years (mean = 34.0 years, SD = 4.3) and 10 women, ages 25–39 years (mean = 32.2 years, SD = 5.0), served as subjects. All subjects were vocally healthy and none reported a history of respiratory, vocal or auditory pathology. None of the

subjects had received any formal vocal or athletic training. Each subject's height and weight were measured at the time of testing. The male subjects ranged in height from 1.73 to 1.83 m (mean = 1.78 m) and in weight from 70.8 to 95.2 kg (mean = 83.3 kg). The female subjects were between 1.65 and 1.78 m tall (mean = 1.72 m) and between 53.5 and 73.0 kg in weight (mean = 64.5 kg). All subjects were primarily mesomorphic in body type.

Experimental Procedure

Each subject stood erect while supporting a weight (fixed-weight dumbbell) in each hand. With arms held supine and straight before them, the subject first rested his or her hands on padded push switches attached to a crossbar that was adjusted to the subject's height at about the level of the umbilicus. Each subject sustained the vowel /a/ as steadily as possible at a self-selected comfortable pitch and loudness. After 3 s of phonation, the subject was instructed to lift the weights approximately 20 cm without interrupting phonation so that the arms remained straight, supine, and parallel to the floor. Phonation was continued for at least 3 s after the lift. Three randomized trials were obtained per subject for each of the following combined-weight conditions: 0, 3, 5, and 7 kg. For the 0-kg condition the subject performed the identical task with closed fists without dumbbells.

To allow a subsequent estimate of subglottal pressure and laryngeal airway resistance [36, 37], the subjects repeated the weightlifting task for each of the experimental conditions while repeating the syllable /pi/. A metronome, set for 92 beats per minute (andante), helped keep the repetition rate at a fairly constant 1.5 syllables per second.

Data Acquisition

The two-channel-average output of a model MC2-1 Glottal Enterprises (Syracuse, N.Y., USA) electroglottograph was used to obtain the subject's EGG. The EGG electrodes were positioned on the anterior neck at the level of the vocal folds and held in place by a firmly fitting flexible neckband. The linear phase circuitry of the instrument provided 20-Hz high-pass filtering that served to minimize baseline shift and nonvocal influences on the EGG waveform [37–39].

Phonatory airflow was measured by means of a circumferentially vented pneumotachograph (Rothenberg) mask and a PTW-1 pressure transducer supported by an elastic head harness. The transducer was connected to a Glottal Enterprises MSIF-2 preamplifier that low-pass-filtered the flow signal using a 50-Hz cutoff frequency. The airflow system was calibrated separately for each subject using a Glottal Enterprises MCU-2 calibration unit that includes a rotameter connected in series with a fitted holder for the mask assembly.

For those trials requiring /pi/-syllable repetition, a thin, short catheter was passed through a fitting in the face mask and positioned between the subject's lips to an approximate location directly behind the upper incisors. The other end of the catheter was connected to a differential pressure transducer (Glottal Enterprises) with a flat frequency response up to about 30 Hz to obtain the intraoral pressure signal. Calibration of air pressure was performed for each subject using a syringe and U-tube manometer [37].

An electret microphone inserted into the central handle of the mask was used to obtain the sound pressure signal for assistance with the subsequent identification of phonatory segments. All

Table 1. Means $\pm$ SD for the male subjects producing sustained phonation

Condition		F ₀ , Hz	F ₀ -CV, %	Jitter, PPQ, %	EGG CQ, %	Airflow, ml/s
0 kg	before lift	117.6 $\pm$ 9.9	0.86 $\pm$ 0.21	0.401 $\pm$ 0.133	53.3 $\pm$ 4.3	157.9 $\pm$ 20.8
	after lift	118.4 $\pm$ 9.7	0.91 $\pm$ 0.28	0.420 $\pm$ 0.147	53.3 $\pm$ 3.7	152.4 $\pm$ 15.0
3 kg	before lift	119.3 $\pm$ 10.8	0.82 $\pm$ 0.22	0.401 $\pm$ 0.131	52.8 $\pm$ 2.6	147.8 $\pm$ 16.3
	after lift	119.0 $\pm$ 10.7	0.94 $\pm$ 0.26	0.424 $\pm$ 0.172	54.9 $\pm$ 3.4	147.5 $\pm$ 15.5
5 kg	before lift	120.8 $\pm$ 11.0	0.80 $\pm$ 0.14	0.409 $\pm$ 0.141	52.8 $\pm$ 2.6	147.6 $\pm$ 11.0
	after lift	120.1 $\pm$ 10.9	1.07 $\pm$ 0.25	0.435 $\pm$ 0.175	56.2 $\pm$ 3.8	133.8 $\pm$ 15.6
7 kg	before lift	120.2 $\pm$ 10.3	0.74 $\pm$ 0.11	0.424 $\pm$ 0.154	53.0 $\pm$ 3.4	151.3 $\pm$ 15.7
	after lift	121.1 $\pm$ 10.5	1.46 $\pm$ 0.26	0.501 $\pm$ 0.116	58.5 $\pm$ 5.3	141.5 $\pm$ 20.9
Total	before lift	119.5 $\pm$ 10.3	0.80 $\pm$ 0.18	0.409 $\pm$ 0.135	53.0 $\pm$ 3.2	151.2 $\pm$ 16.2
	after lift	119.6 $\pm$ 10.1	1.10 $\pm$ 0.34	0.445 $\pm$ 0.152	55.7 $\pm$ 4.4	143.8 $\pm$ 17.7

signals (EGG, sound pressure, airflow, and air pressure) were sampled at 40 kHz using an Alamed (Vega, Tex., USA) SIU-2 signal interface and customized Alamed Acquire software running a 12-bit Data Translation DT2821G A/D converter.

Measurements

The subject's vocal F₀, fundamental frequency coefficient of variation (F₀-CV), and mean percent jitter were derived from the EGG signal. Reported data were obtained for a 1-second voice sample that concluded 1 s before weightlifting and for a 1-second sample that began 1 s after both weights had been lifted. The instant of weightlifting was identified via the crossbar armrest switches. Vocal cycles were demarcated by positive going (increasing vocal-fold contact) zero crossings using linear interpolation techniques. Jitter was defined as the 5-cycle averaged pitch perturbation quotient (PPQ). The EGG *contact quotient* (CQ), the vocal-fold contact duty cycle, was also measured. The CQ was defined as the percentage of the vibratory cycle above a variable zero cross of the interpolated 25% peak-to-peak EGG amplitude. This measure, sometimes called EGGW-25, has been shown to provide a reasonable index of vocal-fold adduction [37–41].

For sustained phonations, the mean phonatory airflow was determined from the calibrated flow trace for the same 1-second intervals used to derive the EGG-based measures. For those trials in which subjects were instructed to repeat the syllable /pi/, the subglottal pressure was estimated from the peak /p/ intraoral pressure, whereas the phonatory flow rate was averaged from the mid-vowel portion of the airflow trace [36, 37]. Pressure, flow, and the derived laryngeal airway resistance were averaged across 5 syllables produced before the lift and across 5 syllables produced during weight support.

Statistical Analysis

Data from the male and female subjects for the sustained phonation and syllable-repetition tasks were analyzed via a repeated measures analysis of variance (ANOVA) model using SPSS 14.0 for Windows software.

Results

Sustained Phonation

Summary data for the male and female subjects are shown in tables 1 and 2, respectively. The mean pre-lift F₀, long-term (F₀-CV) and short-term (PPQ) F₀ variation, EGG CQ, and phonatory airflow were consistent with previous studies of phonation sustained by normal men and women at a self-selected 'comfortable' pitch [37–44]. For the data obtained before the lift, neither group of subjects showed a statistical difference ($p > 0.05$) for any of the measures between the weight conditions. Therefore, measured phonatory characteristics were comparable prior to lifting and sustaining the differing weights, suggesting that the anticipation of effort did not have a substantive effect on phonatory behavior.

For data obtained during weight support, results were consistent for both the male and female subjects. The mean vocal F₀, PPQ, and phonatory airflow did not differ significantly ($p > 0.05$) from the pre-lift data or between weight conditions. CQ values, however, were significantly different between weight conditions for both the men [$F(3, 36) = 2.96$, $p < 0.05$] and women [$F(3, 36) = 5.74$, $p < 0.01$]. A more salient difference was seen for the coefficient of variation of vocal F₀. Long-term variation increased significantly by weight condition across male [$F(3, 36) = 12.29$, $p < 0.001$] and female [$F(3, 36) = 9.02$, $p < 0.001$] subjects.

Figure 1 shows representative data traces for a male subject during the 5-kg lift and support task. Note that approximately 150 ms prior to lifting the dumbbells from the supportive crossbar, there is an increase in F₀ instability, a drop in the mean flow rate, and an increase

Fig. 1. Partial data traces from a male subject sustaining phonation during the 5-kg task.

Table 2. Means $\pm$ SD for the female subjects producing sustained phonation

Condition		F_0 , Hz	F_0 -CV, %	Jitter, PPQ, %	EGG CQ, %	Airflow, ml/s
0 kg	before lift	212.7 ± 15.2	0.91 ± 0.20	0.456 ± 0.128	48.7 ± 5.1	133.9 ± 9.4
	after lift	213.4 ± 15.8	0.85 ± 0.18	0.458 ± 0.122	48.8 ± 4.8	137.9 ± 15.6
3 kg	before lift	214.7 ± 14.8	0.86 ± 0.17	0.473 ± 0.158	49.8 ± 5.2	134.9 ± 15.4
	after lift	214.9 ± 14.1	0.88 ± 0.12	0.509 ± 0.140	50.2 ± 4.7	139.6 ± 30.4
5 kg	before lift	213.8 ± 14.5	0.86 ± 0.17	0.479 ± 0.162	50.3 ± 4.7	131.5 ± 25.1
	after lift	224.0 ± 39.8	1.01 ± 0.25	0.495 ± 0.172	52.1 ± 5.4	128.9 ± 20.7
7 kg	before lift	215.5 ± 14.1	0.82 ± 0.16	0.465 ± 0.157	50.5 ± 5.4	128.7 ± 22.4
	after lift	216.5 ± 13.9	1.30 ± 0.16	0.524 ± 0.183	57.5 ± 6.4	126.6 ± 21.7
Total	before lift	217.2 ± 23.0	0.86 ± 0.17	0.468 ± 0.146	49.8 ± 5.0	132.2 ± 18.5
	after lift	212.7 ± 22.1	1.01 ± 0.25	0.496 ± 0.152	52.2 ± 5.9	133.3 ± 22.6

in the EGG contact duty cycle. As was the tendency for the majority of subjects at the higher weight conditions, the flow reaches a nadir shortly after the lift and then begins to increase toward its pre-lift status as the weight is supported. Conversely, the F_0 -CV and CQ do not demonstrate any substantial drift during weight support.

Syllable Repetition

Summary data for the male and female subjects obtained during the syllable-repetition task are shown in tables 3 and 4, respectively. As with the sustained phonation task, there were no significant differences in pressure, flow or resistance ($p > 0.05$) between weight conditions while the crossbar supported the subjects' hands. The estimated mean P_s , mid-vowel airflow, and derived

Table 3. Means $\pm$ SD for the male subjects repeating the syllable /pi/

Condition		Estimated P_s cm H ₂ O	Mid-vowel airflow, l/s	Estimated R_{law} cm H ₂ O/l/s
0 kg	before lift	6.50 $\pm$ 0.52	0.170 $\pm$ 0.033	39.3 $\pm$ 7.3
	after lift	6.42 $\pm$ 0.50	0.177 $\pm$ 0.025	36.9 $\pm$ 5.4
3 kg	before lift	6.50 $\pm$ 0.66	0.182 $\pm$ 0.032	36.5 $\pm$ 6.5
	after lift	6.86 $\pm$ 0.59	0.172 $\pm$ 0.019	40.0 $\pm$ 7.2
5 kg	before lift	6.62 $\pm$ 0.38	0.194 $\pm$ 0.031	34.6 $\pm$ 4.3
	after lift	7.20 $\pm$ 0.50	0.183 $\pm$ 0.036	40.2 $\pm$ 7.0
7 kg	before lift	6.60 $\pm$ 0.71	0.176 $\pm$ 0.034	38.7 $\pm$ 7.6
	after lift	8.73 $\pm$ 1.05	0.184 $\pm$ 0.038	48.4 $\pm$ 7.5
Total	before lift	6.55 $\pm$ 0.56	0.181 $\pm$ 0.032	37.3 $\pm$ 6.6
	after lift	7.30 $\pm$ 1.11	0.179 $\pm$ 0.030	41.4 $\pm$ 7.2

estimate of R_{law} were consistent with values obtained in previous investigations [36, 37, 44, 45].

As is common in syllable repetition and spontaneous speech, the mid-vowel airflow was slightly higher than the mean flow measured during sustained phonation [37]. Consistent with the subjects' flow data for prolonged phonation there were no significant differences ($p > 0.05$) in average mid-vowel flow across weight conditions for either sex. However, there was a significant increase in estimated P_s as the men [$F(3, 36) = 20.44$, $p < 0.001$] and women [$F(3, 36) = 12.29$, $p < 0.001$] supported heavier weights. Given the increased pressure in the face of a mid-vowel airflow that essentially went unchanged, it is not surprising that the derived R_{law} estimate was significantly different across weight-support conditions for both the male [$F(3, 36) = 6.77$, $p < 0.001$] and female [$F(3, 36) = 20.44$, $p < 0.001$] subjects. During an interview held with the subjects following study participation, it was generally reported that weightlifting while repeating syllables was more difficult and required more effort than when they were required to weightlift while sustaining phonation. The majority of subjects reported that lifting and supporting a combined weight of 7 kg was close to their limit given the posture and technique prescribed.

Discussion

According to Aronson [18], activities such as controlled coughing, grunting, pushing, and lifting trigger an 'effort closure reflex' that facilitates glottal competence. Wilson [17] attributes improved airway dynamics

Table 4. Means $\pm$ SD for the female subjects repeating the syllable /pi/

Condition		Estimated P_s cm H ₂ O	Mid-vowel airflow, l/s	Estimated R_{law} cm H ₂ O/l/s
0 kg	before lift	6.14 $\pm$ 0.76	0.144 $\pm$ 0.021	43.4 $\pm$ 8.2
	after lift	5.92 $\pm$ 0.89	0.139 $\pm$ 0.020	43.2 $\pm$ 7.4
3 kg	before lift	5.99 $\pm$ 0.90	0.141 $\pm$ 0.034	44.5 $\pm$ 10.5
	after lift	6.04 $\pm$ 0.76	0.139 $\pm$ 0.019	43.9 $\pm$ 7.0
5 kg	before lift	6.67 $\pm$ 0.57	0.153 $\pm$ 0.019	44.3 $\pm$ 7.8
	after lift	7.51 $\pm$ 0.57	0.156 $\pm$ 0.029	49.7 $\pm$ 10.5
7 kg	before lift	6.28 $\pm$ 0.67	0.134 $\pm$ 0.022	48.0 $\pm$ 8.8
	after lift	8.65 $\pm$ 1.32	0.155 $\pm$ 0.030	56.9 $\pm$ 8.2
Total	before lift	6.27 $\pm$ 0.75	0.143 $\pm$ 0.025	45.1 $\pm$ 8.7
	after lift	7.03 $\pm$ 1.45	0.147 $\pm$ 0.025	48.4 $\pm$ 9.8

to the resulting increase in laryngeal muscle tonus, whereas Yamaguchi et al. [22] assert that occluding the glottis is necessary to build sufficient thoracic pressure to perform such tasks effectively. Like sustained pushing and pulling against a resistant object, lifting and supporting hand-held weights represents a modified Valsalva maneuver that requires breath restraint while necessarily losing air volume owed to voice production.

Although active pushing, pulling, and various forms of isometric exercises have been employed in the treatment of several different vocal pathologies, there remains concern about the appropriateness of their use. Colton et al. [29], for instance, have questioned the efficacy of effort closure techniques except when used to treat a few carefully selected types of functional voice disorders, and only then when the patient performs them while producing a low-pitched 'forceful grunt' with the larynx positioned low within the neck. Although laryngeal height was not measured in the present study, it is interesting that the act of weightlifting did not, in and of itself, result in a significant change in mean vocal F_0 . However, it is also important to note that, unlike voice patients in a therapeutic setting, the present subjects were free of vocal pathology and were attempting to *maintain* their comfortable phonation *despite* the effort of lifting. Nonetheless, as had the asthenic patients performing Yamaguchi et al.'s [22] pushing exercise, the subjects in this study did evince an increase in relative vocal-fold contact duration upon weightlifting.

An increase in EGG CQ suggests that upper-limb weight support resulted in greater medial compression during phonation. Along with CQ changes, the subjects

showed a significantly greater laryngeal airway resistance attributable to an increased driving pressure rather than to a reduction in mean phonatory airflow. These results are consistent with experimental evidence that suggests that the flow rate serves as a control parameter in speech [10, 46]. Although the EGG reflects consequent changes in vocal-fold contact behavior, the technique is insensitive to the types of glottal adjustments [37] that could be employed to maintain the aerodynamic integrity of the speech system. Unknown also is whether the present subjects applied any significant supraglottal airway compensation as has been reported by some investigators for subjects performing breath-holding or other tasks requiring forced closure [7, 18, 47]. Of particular note, however, is the observation that the normal subjects tested by Beaty et al. [48] consistently showed supraglottic *dilation* during 'progressively strenuous' exercise.

Data traces from the subjects clearly suggested that the most dramatic vocal changes occurred during and just after the act of lifting the dumbbells, and indeed, many voice clinicians [e.g., 12–15] have stressed the importance of coordinating a patient's phonation with the point of maximal physical effort for the technique to be effective. This is different from the isometric steady-state lift in the present experiment or the push or pull against an immovable object as is commonly employed in voice therapy [e.g., 22, 26–28]. Naito and Niimi [11] endoscopically observed the laryngeal behavior of 12 healthy subjects as they performed various strenuous activities that involved the upper limbs, such as pushing themselves up onto a horizontal bar and striking an object. They noted glottal closure consistently at the moment of maximum exertion, but reported far greater variability in airway status during intervals of constant effort.

Conclusion

The results of this study indicate that phonation produced during weightlifting is associated with increased laryngeal airway resistance characterized by an elevation in driving pressure and medial compression of the vocal folds. There was no significant change in mean F_0 , jitter, or phonatory airflow between the pre-lift and lift portions of the subjects' sustained phonation, regardless of the amount of weight supported. Unlike the other variables measured, the phonatory flow rate tended to decrease during the lifting maneuver, but then rebounded as the task became one of stable support.

Additional work is needed to extend this investigation to other forms of physical effort, to compare the effects of static isometric and dynamic isotonic exercises, and to begin systematic study of dysphonic speakers. In doing so, it may be useful to track changes beyond laryngeal airway resistance and vocal-fold medial compression. The combined use of EGG and techniques such as photoglottography and high-speed video endoscopy, for instance, may provide valuable insight regarding glottal dynamics and the speed of vocal-fold approximation that are likely to be important in the development of many types of vocal pathology as well as in its management.

Acknowledgments

Portions of this research study were conducted at Memorial Sloan-Kettering Cancer Center in New York and at Hunter College of the City University of New York. The author would like to thank Prof. Harm K. Schutte and 2 anonymous reviewers for their careful overview of the manuscript and helpful comments.

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