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# Respiratory and Laryngeal Function During Spontaneous Speaking in Teachers With Voice Disorders

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**Purpose:** To determine if respiratory and laryngeal function during spontaneous speaking were different for teachers with voice disorders compared with teachers without voice problems.

**Method:** Eighteen teachers, 9 with and 9 without voice disorders, were included in this study. Respiratory function was measured with magnetometry, and laryngeal function was measured with electroglottography during 3 spontaneous speaking tasks: a simulated teaching task at a typical loudness level, a simulated teaching task at an increased loudness level, and a conversational speaking task. Electroglottography measures were also obtained for 3 structured speaking tasks: a paragraph reading task, a sustained vowel, and a maximum phonation time vowel.

**Results:** Teachers with voice disorders started and ended their breath groups at significantly smaller lung volumes than teachers without voice problems during teaching-related speaking tasks; however, there were no between-group differences in laryngeal measures. Task-related differences were found on several respiratory measures and on one laryngeal measure.

**Conclusions:** These findings suggest that teachers with voice disorders used different speech breathing strategies than teachers without voice problems. Implications for clinical management of teachers with voice disorders are discussed.

**KEY WORDS:** voice, voice disorders, respiratory system, larynx

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Teachers represent an estimated 5.09% of the U.S. workforce<sup>1</sup> (U.S. Bureau of Labor and Statistics, 2006) and rely on their voice as a primary tool of trade (Titze, Lemke, & Montequin, 1997). Teaching involves extended periods of voice use and is considered an occupational risk factor for voice disorders (Roy, Merrill, Thibeault, Gray, & Smith, 2004; Thibeault, Merrill, Roy, Gray, & Smith, 2004; Titze et al., 1997; Verdolini & Ramig, 2001). Relative to other occupations, teaching is over-represented in voice clinics (Roy, Merrill, Thibeault, Parsa, et al., 2004; Smith, Lemke, Taylor, Kirchner, & Hoffman, 1998). Prevalence rates for voice disorders in teachers range from 20% to 50% (Russell, Oates, & Greenwood, 1998; Sapir, Keidar, & Mathers-Schmidt, 1993; Smith, Lemke, Taylor, Kirchner, & Hoffman, 1998). These voice disorders have a negative impact on job performance, work attendance, emotion, and communication (Smith, Gray, Dove, Kirchner, & Heras, 1997; Verdolini & Ramig, 2001; Yiu & Ma, 2002). In a study comparing teaching with other occupations (Smith et al., 1997), approximately 20% of teachers versus 0% of nonteachers had

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<sup>1</sup>Number estimated from May 2006 U.S. Bureau and Labor Statistics, using the general category of “education, training, and library occupations” and subtracting all nonteaching subprofessions from the overall number.

missed work days because of their voice problems. The annual cost to the United States for lost work time and treatment of teachers' voice problems has been estimated at \$2 billion (Verdolini & Ramig, 2001).

Research on voice disorders in teachers has primarily addressed prevalence rates, vocal symptoms, and impact of their voice problems (Gotaas & Starr, 1993; Kostyk & Rochet, 1998; Roy, Merrill, Thibeault, Gray, & Smith, 2004; Roy, Merrill, Thibeault, Parsa, et al., 2004; Russell et al., 1998; Sapir et al., 1993; Smith et al., 1997, 1998). Symptoms such as effort to speak, vocal fatigue, changes to voice quality, and limited loudness range have been noted in several studies (Roy, Merrill, Thibeault, Gray, & Smith, 2004; Sapir et al., 1993). However, these symptoms and their relative prominence in teachers with voice problems have varied across studies (Kostyk & Rochet, 1998; Roy, Merrill, Thibeault, Gray, & Smith, 2004; Sapir et al., 1993; Smith et al., 1998). This variability is due, in part, to the difficulty in operationally defining voice disorders in teachers. In several treatment studies, a voice disorder has been defined by self-report of current or previous problems with the voice, without description of specific symptoms, frequency of symptoms, or laryngeal pathology (Roy et al., 2001, 2002, 2003). Frequency of certain vocal symptoms has also been used to differentiate teachers with and without voice problems (Kostyk & Rochet, 1998). One core characteristic that seems to be universally experienced by teachers and others with voice disorders is the perception of increased effort associated with speaking (Eustace, Stemple, & Lee, 1996; Gotaas & Starr, 1993; Kitch & Oates, 1994; Kostyk & Rochet, 1998; McCue, Barkmeier, & Story, 2001; Roy, Merrill, Thibeault, Gray, & Smith, 2004; Sapir et al., 1993; Scherer et al., 1987; Smith et al., 1997; Welham & Maclagan, 2003). Effort ratings correlate well with several variables associated with physiologic changes (Cafarelli, 1982; Chang & Karnell, 2004; Gandevia, Killian, & Campbell, 1981), and can be quantified and reliably estimated (Colton & Brown, 1973; Somodi, Robin, & Luschei, 1995; Wright & Colton, 1972). Furthermore, effort ratings may differentiate people with voice problems from those who are not experiencing voice difficulties (K. Verdolini, personal communication, November 5, 2004).

Although increased effort may be a core symptom of voice disorders in teachers, the mechanisms underlying this and other reported symptoms in teachers have been minimally explored. In fact, only one study has provided physiological data on laryngeal function in teachers (Kostyk & Rochet, 1998), and no studies that have provided data on respiratory function in this population. Understanding the physiology of voice disorders in teachers is critical to determining the etiology of their voice problems and implementing appropriate treatment techniques. Potential physiological sources of voice problems are the respiratory and laryngeal subsystems

(Aronson, 1990; Koufman & Blalock, 1988; Morrison & Rammage, 1993). Many voice therapy techniques involve manipulation of respiratory and laryngeal parameters based on presumed physiologic differences between people with and without voice disorders (Koufman & Blalock, 1988; Stemple, Glaze, & Klaben, 2000). Kostyk and Rochet (1998) suggested that inefficient coordination of respiratory and laryngeal adjustments during speech production may contribute to symptoms of vocal fatigue in teachers, yet simultaneous, objective assessment of these subsystems in teachers has not been conducted. Voice disorders in teachers often occur in the absence of laryngeal pathology (Sulkowski & Kowalska, 2005; Kostyk & Rochet, 1998; Preciado, Perez, Calzada, & Preciado, 2005), and laryngeal pathology may alter speech breathing behavior (Sapienza & Stathopoulos, 1994; Sapienza, Stathopoulos, & Brown, 1997). Therefore, studying respiratory and laryngeal function in teachers who do not have laryngeal pathology would provide insight into the contributions and interactions of both subsystems in teachers with voice disorders.

Studies of respiratory function associated with voice disorders have primarily focused on individuals with documented laryngeal pathology, and none of these studies specifically investigated teachers. Several studies addressed lung volume patterns during speech in adults and children with and without vocal nodules (Sapienza & Stathopoulos, 1994; Sapienza et al., 1997). These results demonstrated greater lung volume excursion in adults and children with vocal nodules as compared with control participants. Differences were likely associated with trends of larger (higher) lung volume initiations and smaller (lower) lung volume terminations in those with vocal nodules compared with healthy controls. The authors suggested that individuals with vocal fold nodules exhibited these respiratory patterns as a compensation for inadequate laryngeal valving resulting from incomplete vocal fold closure associated with the presence of the vocal nodules. Similarly, Schaeffer, Cavallo, Wall, and Diakow (2002) found smaller lung volume terminations in individuals with mixed vocal fold pathology (i.e., vocal polyps, vocal nodules, contact ulcers, edema) during a reading task using long sentences. Only one single case study investigated respiratory kinematics in an individual with a voice problem unrelated to laryngeal pathology or neurologic disease (Hixon & Putnam, 1983). This case is relevant because the individual was a weather reporter and therefore used her voice extensively in her work, as teachers do. When asked to speak as though giving an actual weather report on the nightly news, the weather reporter was found to use smaller lung volume initiations, smaller lung volume terminations, larger lung volume excursions, and reduced frequency of inspiratory replenishment. The authors identified this as a functional misuse of the respiratory apparatus and

concluded that this misuse was contributing to her voice disorder.

Most research on laryngeal function in teachers has focused on the acoustic manifestations of laryngeal function rather than the specific study of laryngeal behavior. One exception is an investigation that compared aerodynamic measures obtained from teachers with and without symptoms of vocal fatigue (Kostyk & Rochet, 1998). Teachers with symptoms of vocal fatigue showed no significant group differences in laryngeal resistance compared with teachers without voice disorders. Laryngeal behavior has been more specifically studied in voice-disordered individuals of mixed occupations, with and without laryngeal pathology. Individuals with muscle tension dysphonia showed increased supraglottic constriction (Behrman, Dahl, Abramson, & Schutte, 2003; Stager et al., 2001; Stager, Bielamowicz, Regnell, Gupta, & Barkmeier, 2000). Individuals with symptoms of vocal fatigue demonstrated increased anterior opening of the vocal folds during vibration and increased rate of airflow in males (Eustace et al., 1996). Hillman, Holmberg, Perkell, Walsh, and Vaughan (1989) have also proposed that individuals with voice disorders may present with aberrant laryngeal closure patterns. The first of these is identified as *adducted hyperfunction*, associated with laryngeal pathology such as vocal nodules. This laryngeal closure pattern is characterized by increased vocal fold stiffness, vocal folds that are approximated tightly, high velocity of tissue movement, increased vocal fold collision forces, and a strained voice quality. The second laryngeal closure pattern is identified as *nonadducted hyperfunction*, associated with symptoms of vocal fatigue but without vocal fold pathology. It is characterized by increased stiffness and tension of the vocal folds but incomplete vocal fold adduction.

Assessment of vocal fold adduction has typically been done through judgments of degree of vocal fold and supraglottic constriction from nasal or oral endoscopic evaluation. There are several limitations to these methods, however. Researchers have shown that it is difficult to obtain reliable subjective ratings and that signs of laryngeal constriction may not differentiate participants with and without voice disorders (Sama et al., 2001). To improve reliability, ratings are often made during extended vowels rather than during continuous speech production to provide a consistent and steady-state context; however, laryngeal dynamics (Stager et al., 2000) and acoustic characteristics (Brown, Morris, & Murry, 1996; Fitch, 1990; Nittrouer, McGowan, Milenkovic, & Beehler, 1990) may differ when comparing sustained vowels with continuous speaking tasks.

*Electroglottography* (EGG) is a noninvasive tool that has been used to assess laryngeal adduction characteristics and may be useful in characterizing voice disorders.

Several studies have shown that *contact quotient*, a measure of relative vocal fold contact duration, varies for pressed versus normal or breathy voice quality (Peterson, Verdolini-Marston, Barkmeier, & Hoffman, 1994). This measure may relate to hyperfunctional voicing patterns, such as medial compression or laryngeal constriction (Kitzing, 1985; Motta, Cesari, Iengo, & Motta, 1990; Scherer, Vail, & Rockwell, 1995). Verdolini, Chan, Titze, Hess, and Bierhals (1998) showed that EGG contact quotient had a high, positive correlation with measures of vocal fold impact stress in excised canine larynges. *Contact index*, a measure of the relative symmetry of the contact phase of vocal fold vibration, may also be useful in characterizing vocal fold tonus (Baken & Orlikoff, 2000). Therefore, EGG could provide a useful tool for assessing changes to laryngeal adduction patterns in individuals with voice disorders such as those proposed by Hillman et al. (1989). EGG contact measures could be either increased or decreased in voice-disordered individuals relative to control participants, depending on the particular pattern of hyperfunction. The application of EGG to continuous speaking for extracting measures other than fundamental frequency is novel, and, for comparison to normative values, would require the inclusion of structured speaking tasks that have previously been used with EGG.

In addition to the individual contributions of the respiratory and laryngeal subsystems to voice production, functional interactions between the two are known to exist during speaking. For example, smaller lung volumes are associated with a more constricted laryngeal configuration, increased vocal fold approximation (Iwarsson, Thomasson, & Sundberg, 1998; Milstein, 1999), and a pressed, effortful, and strained voice quality (Milstein & Watson, 2004). Furthermore, when increasing loudness, individuals may vary whether they accomplish this via the respiratory versus the laryngeal system or both (Finnegan, Luschei, & Hoffman, 2000; Stathopoulos & Sapienza, 1993). On the respiratory side, individuals can increase loudness by capitalizing on passive recoil forces of the respiratory apparatus by increasing lung volume initiation level and/or by increasing their active expiratory muscle pressure (Hixon, Goldman, & Meade, 1973). On the laryngeal side, loudness increases can be associated with increased laryngeal resistance to produce the pressure differential needed (Tanaka & Tanabe, 1986; Isshiki, 1964). Teachers report a frequent need for increased loudness during teaching (Smith et al., 1998). Simultaneous assessment of respiratory and laryngeal behavior in teachers with and without voice disorders during typical and increased loudness would help determine any differences in each group's use of the laryngeal and respiratory systems.

The purpose of this study was to determine if respiratory and laryngeal function during spontaneous

speaking were different for teachers with voice disorders in the absence of laryngeal pathology as compared with teachers without voice problems. Specific study hypotheses were as follows: (a) teachers with voice disorders speak at smaller lung volumes than teachers without voice problems, (b) teachers with voice disorders show differences in vocal fold adduction relative to teachers without voice problems, (c) respiratory and laryngeal differences are most pronounced for teaching versus conversational speaking, and (d) teachers with voice disorders use different strategies to achieve increased loudness as compared with teachers without voice problems.

## Method

### Participants

Permission for research and recruitment was obtained from local school districts and the University of Arizona Institutional Review Board (IRB). All individuals gave informed consent and were paid for their participation. Those with voice disorders were offered free voice therapy services at the completion of the study. Eight of the 9 voice-disordered participants enrolled in therapy upon completion of the study.

Flyers were disseminated to teachers throughout several school districts to recruit potential participants. Teachers who responded were then screened to determine basic eligibility for the voice-disordered or control group. Eighteen teachers, 9 with voice disorders (voice-disordered

group) and 9 without (control group), served as participants. The voice-disordered group included 2 men and 7 women, ranging in age from 31 to 56 years ( $M = 48$ ,  $SD = 7.4$ ). The control group also included 2 men and 7 women, ranging in age from 22 to 53 years ( $M = 36$ ,  $SD = 9.8$ ). Kindergarten through 12th grade and university-level teachers were included in this study. Table 1 summarizes participant gender, age, grade level taught, average class size, percentage of talking time during teaching, number of years teaching, and level of background noise in the classroom.

All participants reported (a) good general health with no history of neurologic, cardiovascular, or pulmonary disease; (b) no history of vocal fold pathology, laryngeal trauma, or surgery; (c) nonsmoker status for at least 5 years prior to their participation; (d) no symptoms of cold or allergies on the day of testing; (e) no history of previous voice therapy or professional singing or voice training; and (f) English as their primary language. All participants demonstrated (a) a body mass index below the obese range of 30 or greater; (b) adequate hearing skills as determined by passing a hearing screening bilaterally (40 dB HL at 1, 2, and 4 kHz) to rule out profound hearing loss, which may affect voice (Forner & Hixon, 1977; Lane, Perkell, Svirsky, & Webster, 1991); (c) no evidence of laryngeal pathology as determined by videostroboscopic evaluation and review of videostroboscopy recordings by an otolaryngologist who was blind to each participant's group designation; and (d) normal speech (including articulation, intelligibility, and fluency) and

**Table 1.** Teacher characteristics for participants with voice disorders (VDis) and control (Con) participants.

Participant	Gender	Age	Level of teaching	Class size	% talking time when teaching	No. of years teaching	Background noise in classroom
VDis1	M	50	ES	25 to 33	27	26	Low
VDis2	F	56	MS	10 to 35	53	33	Moderate
VDis3	F	46	MS	8 to 22	47	3	Low
VDis4	F	48	MS	27	67	3	Low
VDis5	F	31	University	25	50	8	Low
VDis6	F	50	MS	28 to 31	80	26	High
VDis7	F	48	ES	25	53	7	Moderate
VDis8	F	51	HS	30	67	28	Moderate
VDis9	M	56	MS	26	40	10	Low
Con1	F	37	HS	25	67	8	Low
Con2	F	53	MS	18 to 25	53	11	Low
Con3	F	30	HS	30	40	2	Moderate
Con4	F	22	ES	18	73	1	Moderate
Con5	F	27	University	18 to 25	40	2	Low
Con6	M	34	University	25 to 200	38	12	Low
Con7	M	43	University	5 to 500	60	17	Low
Con8	F	30	University	27	60	8	Low
Con9	F	45	ES	22	53	21	Low

Note. ES = elementary school; MS = middle school; HS = high school.

language skills, as determined by unanimous, binary (normal/abnormal) judgment by two certified speech-language pathologists with expertise in voice and voice disorders who were blind to participants' group designations.

Participants in the voice-disordered group met the following additional criteria: (a) current problems with their voice or vocal mechanism (Verdolini & Ramig, 2001), including vocal symptoms that related to the general symptom category of effort/work to speak or weak/tired voice; (b) frequent symptom occurrence, defined as once or more weekly; (c) onset of these symptoms 1 year or more prior to testing; and (d) increased speaking effort during teaching. Speaking effort during teaching was measured on a 100-mm visual analog scale (VAS) bounded by the descriptors of *no effort* (0 mm) and *extreme effort* (100 mm). Increased speaking effort during teaching was indicated when participants reported a 15-mm or greater difference between what they rated as a comfortable level of effort (CL) and what they rated as their actual level of effort (AL) during teaching.

This minimum difference score was based on a pilot survey distributed to 100 university-level teachers, with 41 surveys completed and returned. The survey included questions regarding (a) whether teachers had problems with how their voice sounds or feels when teaching, (b) the frequency of these problems, (c) a VAS to rate their average speaking effort when teaching, and (d) a VAS to rate what they felt was a comfortable level of speaking effort when teaching. A mean VAS AL – CL score difference of 14.75 mm ( $N = 7$ ,  $SD = 16$ ) occurred for teachers replying “yes” to sometimes having voice problems when teaching, and a mean AL – CL score difference of 21.71 mm ( $N = 8$ ,  $SD = 16.4$ ) occurred for teachers replying “yes” to often having voice problems when teaching. In contrast, the mean score for those denying voice problems was 1.17 mm ( $N = 26$ ,  $SD = 13.6$ ). The 15-mm difference criterion was chosen using the descriptive results of the pilot survey to balance the need for a lower difference score to ensure that the control participants were not experiencing voice problems and the need for a higher difference score to ensure that the voice-disordered participants were experiencing voice problems. The average AL – CL difference for the participants with voice disorders in this study was 33.6 mm, with a range of 23.5 to 49.0 mm. Dysphonia was not an inclusion criterion for the voice-disordered group, and voice screening recordings were rated as within normal limits for all teachers in this group. Open-ended descriptors of voice problems provided by these teachers included the following statements regarding their voice/vocal mechanism: “feels weak,” “feels tired,” “low volume,” “decreased projection,” “sounds hoarse,” “sounds rough,” “feels scratchy,” “feels sore,” “have to push to get voice out,” and “hard to control pitch.”

Participants in the control group (without voice problems) met the following additional criteria: (a) no problems

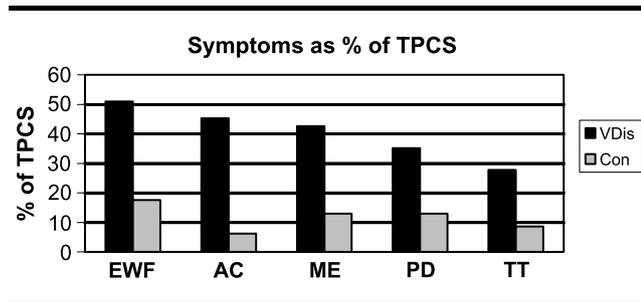
with the voice or vocal mechanism while teaching and (b) indication of minimal or no VAS AL – CL speaking effort score difference (i.e., less than 15 mm difference). The mean VAS AL – CL speaking effort difference for control participants was  $-2.4$  mm, with a range of  $-35.0$  to 13.5 mm.

The Voice Activity Participation Profile (VAPP; Ma & Yiu, 2001) was completed by all participants to determine their perception of the impact of any voice difficulties on various areas of their life. Mean VAPP score for the voice-disordered group was 44.4 cm ( $SD = 41.0$ ). Mean VAPP score for the control group was 1.3 cm ( $SD = 1.2$ ) and was significantly different from the voice-disordered group,  $t(8) = 3.15$ ,  $p = .014$ , equal variances not assumed,  $d = 1.48$ , as assessed with a  $t$  test for independent samples.

All participants were also given a list of symptom descriptors and asked to select those that they experience during teaching and how frequently those symptoms occur (see Appendix A). Symptoms on this checklist were gathered from existing literature on percepts of vocal fatigue (Kitch & Oates, 1994; Kostyk & Rochet, 1998; Sapir et al., 1993; Scherer et al., 1987) and were selected to represent five broad categories of fatigue percepts across the respiratory and laryngeal subsystems: (a) pain/discomfort, (b) tightness/tension, (c) work/effort/weakness/fatigue, (d) mental fatigue, and (e) auditory changes to voice. An ordinal scale was used to compute scores on this measure (0 = *never/rarely*, 1 = *sometimes*, 2 = *often*, 3 = *always*). In Appendix A, symptoms are listed in order of descending frequency of sum scores for the voiced-disordered group, with comparison scores listed for the control group. Also listed in Appendix A is the category into which each symptom was grouped and the probable subsystem involved (laryngeal, respiratory, or both). Although the articulatory subsystem may also contribute to these symptoms, only the laryngeal and respiratory subsystems were considered here. The sum score for the voice-disordered group was 290 of a maximum 729. Throat/voice mechanism feeling tired, throat feeling dry, needing to use more effort to speak, needing to work harder to speak, and hoarse/husky voice quality were the five most frequently occurring symptoms for the voice-disordered group. The sum score for the control group was 76 and was significantly different from that of the voice-disordered group ( $p < .001$ ,  $d = 1.79$ ), as assessed with a Mann-Whitney  $U$  test. Rankings of the first four symptoms were the same for the control group as they were for the voice-disordered group, although actual scores were much lower.

To characterize the degree to which different categories were represented and the differing scores for each group, scores were calculated for each symptom as a percent of the total possible score for that category. Sums of those symptom scores for both groups are displayed in Figure 1.

**Figure 1.** Sum symptom scores, by category, as a percentage of the total possible category score (TPCS) for the voice-disordered and control groups. EWF = effort/work/fatigue; AC = auditory changes; ME = mental effort; PD = pain/discomfort; TT = tightness/tension.



## Procedures and Equipment

The session included screening procedures (to determine that the participant qualified for the study) and experimental procedures. All experimental procedures were conducted with participants in a seated position and were videotaped.

**Respiratory recordings.** Lung volume change was determined from surface motions of the rib cage and abdomen. The theoretical framework for estimating lung volume through displacements of the chest wall was outlined by Konno and Mead (1967), and its methods were applied to speech breathing assessment by Hixon et al. (1973) as well as many other investigators (Hoit & Hixon, 1987; Hoit, Hixon, Altman, & Morgan, 1989; Milstein & Watson, 2004; Sapienza et al., 1997; Stathopoulos & Sapienza, 1993; Winkworth, Davis, Adams, & Ellis, 1995). Coil pairs of linearized magnetometers (GMG Scientific, Burlington, MA) were attached to the rib cage at the level of sternum and the abdomen just above the umbilicus to sense anterior–posterior diameter changes of each part. An oscilloscope was used to monitor the respiratory signals on an X–Y display. A 9.0-liter respirometer (Warren E. Collins, Boston, MA) was used to calibrate lung volume. Calibration of the respirometer was checked every 2 weeks with a 3.0-liter calibration syringe (CDX Corporation, Providence, RI).

Maneuvers similar to those described by Hixon et al. (1973) were used for calibrating respiratory signals. Calibration maneuvers included assessment of (a) vital capacity (VC) to measure the participant's largest manipulable range of lung volume and to normalize lung volume across participants (performed three times), (b) 1 liter above and below each participant's measured resting expiratory level (REL) for calibration of voltage range to absolute lung volumes, and (c) isovolume maneuvers (performed at REL) to determine the relative motion relationships between the two parts of the chest wall (rib cage and abdomen) for a calibration factor from which lung volumes levels could then be calculated.

**Laryngeal recordings.** EGG was used to assess laryngeal adduction characteristics during continuous speaking. A Kay Elemetrics Model 4338 electroglottograph (Kay Elemetrics Corporation, 1995) was used to assess changes in vocal fold contact area over time during phonation. This entailed placement of two electrodes overlying each thyroid cartilage lamina that were secured with a Velcro collar in the position that resulted in the greatest signal amplitude.

**Speech recordings.** The audio signal (used only for transcription purposes) was recorded with an omnidirectional, electret condenser lapel microphone (Radio Shack, Model 33-3013). All four data channels (audio, EGG, and rib cage and abdomen respiratory channels) were simultaneously recorded on an eight-channel digital audio tape (DAT) recorder (SONY) and a computer-based multi-channel acquisition system, DATAQ, DI-720 Series (DATAQ Instruments, 2000). A Larson-Davis System 824 calibrated sound-level meter (SLM) with a remote, high-performance condenser microphone and real-time analyzer was used to monitor sound pressure level (SPL; weighting scale A). The SLM microphone was mounted on a stand at a 45° angle and 18 in. from the speaker's mouth. The SLM was calibrated weekly during testing using a pure-tone generator. SPL was recorded (in writing) by a research assistant (RA) who read the values off the SLM every 30 s.

**Speaking tasks.** Three spontaneous speaking tasks were performed (the order was counterbalanced across participants): (a) a conversational speaking task (CONV); (b) a mock teaching task (MOCK); and (c) a mock teaching task at increased loudness level (MLOUD). For each task, the participant was instructed to speak for 3 min as cued by an experimenter and to minimize body movements (to avoid signal artifacts). Participants were told that they were being videotaped so that a group of students could later rate their organization, content, clarity, and interest level of the material. This deception component was included to create some of the stressors that are associated with teaching. Participants were debriefed at the end of the experiment and were reconsented in accordance with IRB specifications. Prior to recording the speaking tasks (regardless of order), a 45-s practice of the MOCK task was conducted to determine the average SPL (SPL was recorded every 15 s). This was used to determine the target SPL for the MLOUD task.

For the CONV task, the participant was instructed to describe a favorite vacation and to speak at a comfortable pitch and loudness as if talking to a friend. An RA sat 5 ft in front of the participant and served as a listening partner. For the MOCK task, the participant was instructed to deliver a segment of a lecture and to speak as if teaching to a class of approximately 20 students. The RA sat 10 ft in front of the participant and acted as though she were a student in the class, taking notes throughout the mock lesson. For the MLOUD task,

the participant was instructed to speak as if teaching to a large class of at least 100 students, projecting to an audience at least 20 ft away. The RA sat at a 20-ft distance from the participant and acted like a student in the class, taking notes throughout the lesson. The target SPL range was at least 10 dB greater than the mean SPL recorded during the 45-s MOCK practice task. If SPL fell below that level, the second RA signaled the participant to increase loudness.

Following the spontaneous speaking tasks, three structured speaking tasks were performed: (a) sustained /a/ for 8 s, (b) sustained maximum phonation time (MPT) /a/ following a maximum inspiration, and (c) reading aloud a predominantly voiced passage. For all structured tasks, participants were instructed to use a comfortable pitch and loudness, and for the MPT task, participants were instructed to start with a full breath and extend their phonation as long as possible. Because of the need to limit the testing session time, only one trial of each of the structured tasks was performed. The structured speaking tasks provided a context in which to compare the novel EGG applications (in continuous speaking) to previously tested EGG applications. The reading passage provided a standardized phonemic context for comparison, which was considered important after initial pilot testing indicated that EGG measures sometimes varied across different vowels. The MPT vowel provided a standardized utterance to extract EGG measures for which all participants proceeded from larger to smaller lung volume levels.

*Effort level.* Immediately following each of the three spontaneous speaking tasks, participants were asked to rate the amount of speaking effort that they just experienced on a 100-mm VAS (same VAS as described earlier). Markings were made on the same VAS (in different colors) for the three speaking tasks so that participants could make comparative judgments of effort.

## Measures and Data Analysis

*Respiratory measures and analysis.* REL for each participant was determined from the VC maneuver and the expiratory reserve volume (ERV/VC). For analysis of each speaking task, tidal breathing prior to speech initiation was used to reference all measures to REL. All respiratory measures were reported as a percent of VC (%VC) to normalize for differences in height and torso size. For speech breathing, the following dependent variables were assessed: (a) lung volume initiation, referenced to the participant's REL (LVI-R, in %VC); (b) lung volume termination, referenced to the participant's REL (LVT-R, in %VC); (c) lung volume excursion (LVE, in %VC); and (d) lung volume expenditure per syllable (in %VC/syl).

The middle 2 min of each speaking task were analyzed. Utterances with one or two syllables were excluded from the analysis, as atypical lung volume patterns

(which would skew average measures) were often seen with these utterances. This resulted in 112 of 1,693, or 6.6%, discarded breath groups for all participants across the three spontaneous speaking tasks, with 5.9% in the voice-disordered group and 7.3% in the control group. LVI-R and LVT-R were calculated from each utterance, measured at the start and end of each breath group. For the structured speaking tasks, the full reading sample was analyzed (representing approximately 1 min of speech), with any one- to two-syllable breath groups deleted. This resulted in 3.2% of discarded breath groups for all participants, with 4.8% in the voice-disordered group and 1.3% in the control group. For the sustained /a/ and MPT /a/, LVT-R was assessed at 7 s postonset of vocalization for the sustained /a/ and 3 s prior to the end of the MPT utterance to match the end-analysis point for the EGG signal (see explanation in *EGG measures and analysis* section). Respiratory data were analyzed using a custom software function with LabView (National Instruments Corporation, Austin, TX). Means for each participant, for each task, were calculated for each of the dependent variables. Group means and standard deviations were then calculated and compared for each dependent variable.

*EGG measures and analysis.* The contact quotient (CQ) and contact index (CI) were tracked over the time course of the EGG signal as follows: The digitized signal was first low-pass filtered (300 tap, finite-impulse response filter) with a cutoff frequency of 1000 Hz. The fundamental frequency ( $F_0$ ) was estimated from differences between the harmonic frequencies detected in a fast Fourier transform-based amplitude spectrum of the filtered signal. This estimated  $F_0$  was then converted to glottal cycle length (in terms of time samples). The minimum amplitude was detected within each glottal cycle. These points were used to generate an estimate of the low-frequency (<20 Hz) variation inherent in the recorded EGG signal. This signal was then subtracted from the filtered EGG signal to remove the low-frequency variation. From this new signal, CQ and CI values were computed for each glottal cycle on the basis of the methods described by Orlikoff and colleagues (Orlikoff, 1991; Orlikoff, Baken, & Kraus, 1997). A baseline criterion of 25% of the peak-to-peak EGG signal amplitude was used as the criterion to define the minimum level of the contact phase. From the filtered EGG signal, two variables were assessed: CQ, a measure of relative contact phase duration, and CI, a measure of relative symmetry of the contact phase.

For EGG analysis, the same middle 2-min segment of each spontaneous speaking task that was used for respiratory analysis was analyzed. All files were first translated from WINDAQ to MATLAB and WAV files using a custom function in MATLAB Version 7.0.4 (The MathWorks, 2004). WAV files were then analyzed manually in Praat (Boersma & Weenink, 2005) to isolate all

voiced segments into sequential files from the initial 120-s sample of continuous speech. Three 15-s segments were then sampled to provide a distribution over the beginning, middle, and end of each 120-s sample (i.e., portions 0–15 s, 60–75 s, and 105–120 s). During development of this procedure, mean CQ and CI levels measured for a 45-s subset were found to be within 0.20 (CQ) and 0.01 (CI) of those measured for the entire 120 s of the EGG sample.

To isolate the voiced segments, simultaneous display of the EGG signal, the acoustic signal, and the narrow band spectrogram were used during analysis. Voiced segments were selected if there was a periodic EGG signal, a periodic acoustic signal, and at least three distinct harmonics in the narrow band spectrogram. Thus, the initial and final two to five EGG cycles of each voiced segment were often excluded because one or more of the above conditions was not met. Segments were analyzed only if they contained 10 or more EGG cycles in the original signal. When the original continuous speech EGG signal contained multiple silent periods during the analyzed portion, an extra 2 s of analysis time was added to the end of that 15-s analysis segment. Sequential files were obtained for the voiced segments of each analyzed portion of the continuous speaking tasks, typically 90–100 files per participant per task. These sequential files were then read by a custom software function under MATLAB, which also performed the filtering function described above. Means and standard deviations for each participant per task were then calculated with this MATLAB function.

Analysis of the structured speaking tasks was developed in accordance with existing guidelines for sustained vowel analysis (Orlikoff, 1991) and in an effort to obtain phonemically controlled content across participants. For the paragraph reading task, analysis of a standard middle section that represented approximately 20 s of speech was performed. Therefore, phonemic content for this analysis was the same for all participants. To assess the interaction of lung volume and EGG measures during continuous speaking, an utterance that was produced on one breath group for most participants was selected for analysis from the reading passage. This utterance therefore represented decreasing lung volume. Consecutive, segmented voiced files from this utterance were then analyzed to assess how CQ and CI changed over time as lung volume decreased during continuous speaking, providing a more realistic context for changes in lung volume.

Finally, for analysis of the sustained vowels, procedures were adopted using Orlikoff's (1991) guidelines. For the 8-s sustained vowel, the first and last second of the sample were excluded from the /a/, resulting in 6 s of analyzed voicing. The MPT vowel was analyzed for change in CQ and CI over time as lung volume progressively decreased. To capture EGG signals that represented large lung volume levels, EGG analysis was initiated for the

MPT vowel near the start of phonation, as soon as the signal became highly periodic, at approximately 10 EGG cycles after voice onset. Analysis was ended 3 s prior to the completion of each participant's MPT voicing because voicing and the EGG signal often became intermittent or irregular in the final portion of the MPT vowel. An additional median filter was applied to the EGG signal for the MPT vowel because during this extended length of signal, spurious peaks sometimes occurred that were clearly signal artifacts. A separate MATLAB function was used to calculate and depict CQ and CI as a changing contour of values across time. Mean CQ and CI values for the first and last 5% of the total duration of the MPT vowel were also generated by this program. From these individual means for the start and end of the MPT vowel, group means and standard deviations were calculated and compared. The segmented, voiced files that represented the continuous speech utterance produced on one breath group were analyzed sequentially in the same manner.

*Reliability and inferential statistical analysis.* To assess interrater reliability of respiratory and VAS measurements, 2 participants from each group (representing 21% of the total participants) were randomly selected and analyzed by a second investigator. Pearson product-moment correlation coefficients, mean difference scores, and standard error of the mean (*SEM*) were calculated for the two sets of measures.

Repeated measure multivariate analysis of variance (MANOVA) was performed for respiratory and laryngeal data (two MANOVAs total). When the omnibus MANOVA was significant, follow-up repeated measures analyses of variance (ANOVAs) were performed to determine between-participant (group) effects, within-participant (task) effects, and Task  $\times$  Group interaction effects. When interaction effects were significant, follow-up post hoc tests using Tukey's honestly significant difference (HSD) were implemented. An alpha of .05 was used to define significance.

Group differences in participant characteristics, including SPL, speaking rate, and effort ratings, were tested with repeated measures ANOVAs with follow-up Tukey's HSD, when appropriate. To assess differences in EGG measures that occurred from the beginning to the end of an utterance, repeated measures ANOVAs were also implemented. SPSS Version 13.0 software was used for all statistical analyses.

## Results

### Reliability

The respiratory variables (LVI-R, LVT-R, LVE, and %VC/syl) showed reliability coefficients ranging from .98 to 1.0, with all mean difference scores less than 1.0 %VC and *SEM* ranging from 0.19 to 0.01. The three

VAS measurements showed reliability coefficients of 1.0, with mean difference scores of 0.25 mm or less for the effort ratings and 0.06 cm for the VAPP and SEM ranging from 0.13 to 0.03.

## Respiratory Measures

Measures of lung volume initiation (LVI-R) and lung volume termination (LVT-R) were referenced to each participant's REL, such that REL represented 0% for all participants. Group means and standard deviations for each speaking task are presented in Table 2.

A MANOVA for the four respiratory dependent variables revealed a significant, omnibus between-groups difference,  $F(3, 14) = 4.05, p = .029$ ; within-groups difference for task,  $F(6, 11) = 3.39, p = .038$ ; and a significant Group  $\times$  Task interaction,  $F(6, 11) = 3.30, p = .041$ . Follow-up repeated measures ANOVAs showed significant between-groups differences in LVI-R,  $F(1, 16) = 9.08, p = .008, d = 1.29$ , and LVT-R,  $F(1, 16) = 11.86, p = .003, d = 1.44$ . No significant between-groups differences were found for LVE,  $F(1, 16) = 0.07, p = .794$ , and %VC/syl,  $F(1, 16) = 1.94, p = .182$ . Significant within-groups differences were found in LVT-R,  $F(2, 32) = 3.46, p = .044, d = 0.45$ , and in %VC/syl,  $F(2, 32) = 7.78, p = .002, d = 0.52$ . No within-groups differences were found for LVI-R,  $F(2, 32) = 0.66, p = .524$ , or for LVE,  $F(2, 32) = 2.93, p = .068$ . Significant Group  $\times$  Task interactions were found in LVI-R,  $F(2, 32) = 4.58, p = .018$ , and in LVE,  $F(2, 32) = 6.04, p = .006$ , but

not for LVT-R,  $F(2, 32) = 1.44, p = .252$ , or for %VC/syl,  $F(2, 32) = 1.72, p = .196$ .

Assessment of the main effects for task using Tukey's HSD tests revealed significant within-groups differences in LVT-R between the CONV and MOCK tasks ( $p = .036$ ), with LVT-R being significantly smaller for the CONV task than for the MOCK task. For %VC/syl, significant within-groups differences were found between the CONV and MLOUD tasks ( $p = .001$ ), with %VC/syl being significantly greater for the MLOUD task than for the CONV task.

Assessment of Group  $\times$  Task interaction effects for LVI-R with Tukey's HSD revealed significant between-groups differences for the MOCK ( $p = .025$ ) and MLOUD ( $p < .001$ ) tasks but not for the CONV task ( $p = .275$ ). LVI-R was significantly smaller for the voice-disordered group than for the control group on the MOCK and MLOUD teaching tasks. Although LVI-R was smaller, on average, during the CONV task for the voice-disordered group than for the control group, these differences did not reach statistical significance ( $p = .275$ ). Post hoc tests using Tukey's HSD revealed no significant differences for the measure of LVE.

**EGG measures.** Group means for EGG measures across the five speaking tasks are presented in Table 3. Both CQ and CI tended to be lower for the voice-disordered group than for the control group.

A MANOVA for the two laryngeal dependent variables revealed a nonsignificant, omnibus between-groups difference,  $F(2, 15) = 1.49, p = .258$ ; a significant within-groups difference for task,  $F(8, 9) = 11.12, p = .001$ ; and no significant Group  $\times$  Task interaction. Follow-up repeated measures ANOVAs for CI showed significant within-groups differences,  $F(4, 39.8) = 6.75, p = .002$ , with Greenhouse-Geisser adjustment,  $d = 0.86$ , whereas CQ did not show significant within-group differences,  $F(1.7, 27.3) = 2.16$ ,

**Table 2.** Group means for respiratory measures.

Variable	Group means for respiratory measures (%VC)			
	Voice-disordered		Control	
	M	SD	M	SD
LVI-R CONV	13.70	8.71	21.46	12.55
LVI-R MOCK	13.55	7.87	26.01	12.38
LVI-R MLOUD	9.38	9.87	29.30	11.58
LVT-R CONV	-7.96	7.19	1.68	9.97
LVT-R MOCK	-5.15	4.13	7.91	10.34
LVT-R MLOUD	-8.04	8.67	7.46	11.24
LVE CONV	21.66	5.33	19.78	8.34
LVE MOCK	18.71	5.55	18.11	4.33
LVE MLOUD	17.42	4.03	21.84	5.45
%VC/syl CONV	1.25	0.38	0.93	0.30
%VC/syl MOCK	1.33	0.53	1.04	0.32
%VC/syl MLOUD	1.36	0.44	1.22	0.36

Note. LVI-R = lung volume initiation-referenced to resting expiratory level (REL); CONV = conversational task; MOCK = mock teaching task; MLOUD = mock loud teaching task; LVT-R = lung volume termination-REL; LVE = lung volume excursion; %VC/syl = percent vital capacity per syllable.

**Table 3.** Group means for electroglottography (EGG) measures.

Variable	Group means for EGG measures	
	Voice-disordered M (SD)	Control M (SD)
CQ CONV	56.12 (3.43)	56.87 (2.10)
CQ MOCK	56.28 (4.31)	57.21 (1.82)
CQ MLOUD	58.28 (3.09)	59.48 (3.42)
CQ READ	56.09 (3.66)	56.34 (2.60)
CQ /a/	53.82 (5.26)	58.82 (7.53)
CI CONV	-0.54 (0.05)	-0.52 (0.06)
CI MOCK	-0.54 (0.06)	-0.49 (0.07)
CI MLOUD	-0.49 (0.04)	-0.46 (0.10)
CI READ	-0.52 (0.04)	-0.49 (0.07)
CI /a/	-0.45 (0.11)	-0.47 (0.10)

Note. CQ = contact quotient (in %); CI = contact index; READ = paragraph reading task; /a/ = sustained /a/ vowel.

$p = .140$ . Follow-up Tukey's HSD tests for CI revealed that only the comparison for the CONV to /a/ task showed significant task differences ( $p = .017$ ), with more negative, or lower, CI during the CONV task as compared with the /a/ vowel.

To directly explore the interaction between lung volume and EGG measures, the MPT vowel and paragraph reading task were analyzed for differences in CQ and CI from the beginning to the end of the utterance. The MPT vowel represented a standard, sustained vowel utterance in which lung volume was initiated at a large level and was terminated at a small level. A 55% (control group) to 60% (voice-disordered group) lung volume change was demonstrated from start to end of the MPT vowel. The sentence selected from the paragraph reading represented a standard, continuous speech utterance in which lung volume progressively decreased. A 13% (control group) to 15% (voice-disordered group) lung volume change was demonstrated from start to end of the sentence.

A repeated measures ANOVA for CQ showed no significant between-groups differences,  $F(1, 16) = 0.02, p = .882$ , or within-groups differences,  $F(1, 16) = 2.01, p = .175$ . A repeated measures ANOVA for CI showed no significant between-groups differences,  $F(1, 16) = 0.11, p = .745$ , but did show significant within-groups differences,  $F(1, 16) = 21.43, p < .001, d = 1.37$ . As the utterance progressed in time (decreasing lung volume), mean CI became significantly more negative, with a mean across participants of  $-0.45$  ( $SD = 0.09$ ) at the start of the sentence and  $-0.57$  ( $SD = 0.09$ ) at the end of the sentence—that is, there was greater asymmetry between the contact-closing and contact-opening phases of vocal fold vibration at the end of the sentence.

**Effort ratings.** Group means for the effort ratings on the CONV, MOCK, and MLOUD tasks, respectively, were as follows: voice-disordered group, 20.6 ( $SD = 15.1$ ), 28.4 ( $SD = 18.6$ ), and 48.5 ( $SD = 14.4$ ); control group, 11.2 ( $SD = 10.0$ ), 13.8 ( $SD = 11.1$ ), and 39.1 ( $SD = 24.1$ ). Although mean scores for effort ratings were almost twice as high for the voice-disordered group compared with the control group on the CONV and MOCK tasks, a repeated

measures ANOVA showed no significant between-groups differences or interaction effects for the three speaking tasks ( $p = .070$ ) but did show significant within-groups task differences,  $F(2, 32) = 23.18, p < .001, d = 1.65$ . Follow-up Tukey's HSD tests showed that the comparisons of the CONV to MLOUD task and MOCK to MLOUD task were significant ( $p < .001$ ), with higher effort ratings for the MLOUD task compared with the other two tasks.

**Speech characteristics.** Some differences in speech characteristics were noted between groups. Table 4 summarizes the average SPL (db HL, weighting scale A, 18-in. mouth-to-microphone distance) and speaking rate for both groups over the five speaking tasks.

For SPL, a repeated measures ANOVA showed significant between-groups differences,  $F(1, 16) = 5.00, p = .040, d = 1.12$ , and significant within-participant task differences,  $F(4, 64) = 53.36, p < .001, d = 2.82$ , with no significant interaction effect ( $p = .083$ ). Between groups, SPL was significantly lower for the voice-disordered group. Follow-up Tukey's HSD tests showed that comparisons of the CONV to MLOUD task ( $p < .001$ ), CONV to READ task ( $p = .013$ ), CONV to /a/ task ( $p < .001$ ), MOCK to MLOUD task ( $p < .001$ ), MOCK to /a/ task ( $p = .011$ ), MLOUD to READ task ( $p < .001$ ), and MLOUD to /a/ task ( $p < .001$ ) were significant. Within groups, SPL for the CONV task was significantly lower than for the READ, /a/, and MLOUD tasks. SPL for the MOCK task was significantly lower than for the MLOUD and /a/ tasks. SPL for the READ and /a/ tasks was significantly lower than for the MLOUD task.

Because of the significant between-groups differences in SPL, Pearson product-moment correlation coefficients were calculated to determine the relationship between SPL and the respiratory and laryngeal dependent variables. For the respiratory variables of LVI-R, LVT-R, LVE, and %VC/syl, correlation coefficients were nonsignificant for the CONV and MOCK tasks. For the MLOUD task, SPL was significantly, positively correlated to LVI-R ( $p = .043$ ) and LVE ( $p = .004$ ). For the laryngeal variables of CQ and CI, correlation coefficients were nonsignificant for the CONV and MOCK tasks.

**Table 4.** Sound pressure level (SPL; in dB HL) mean and speaking rate (in syllables per minute) mean for the five speaking tasks.

Task	Voice-disordered		Control	
	SPL <i>M</i> ( <i>SD</i> )	Speaking rate <i>M</i> ( <i>SD</i> )	SPL <i>M</i> ( <i>SD</i> )	Speaking rate <i>M</i> ( <i>SD</i> )
CONV	58.00 (4.83)	229.46 (16.79)	61.68 (4.59)	245.01 (34.35)
MOCK	59.38 (2.74)	215.35 (27.18)	64.28 (5.54)	239.12 (39.09)
MLOUD	69.81 (1.41)	214.36 (26.01)	74.33 (3.78)	238.82 (33.84)
READ	62.76 (3.06)	222.35 (27.87)	62.96 (3.49)	234.10 (31.47)
/a/	62.8 (4.08)	N/A	67.01 (5.76)	N/A

Note. N/A = not applicable.

For the MLOUD task, SPL was significantly, positively correlated to CI ( $p = .024$ ). A repeated measures ANOVA for speaking rate revealed no significant between-groups ( $p = .138$ ) or within-groups ( $p = .280$ ) differences.

## Discussion

This was the first study to report on respiratory function in teachers, the first to investigate respiratory function in people with voice disorders but without laryngeal pathology, and the first to include EGG (vocal fold contact and symmetry) data from continuous speaking. Results indicated that respiratory function during spontaneous speaking was different for teachers with voice disorders when compared with teachers without voice problems, but laryngeal function was not. Discussion of these results centers on vocal symptoms in teachers, respiratory function in teachers, laryngeal function in teachers, and the interaction between the respiratory and laryngeal subsystems.

## Vocal Symptoms in Teachers

Teachers with voice disorders reported vocal symptoms at a frequency nearly four times higher than teachers without voice problems. Specific category scores and relative category prominence also differed between the two teacher groups. The most highly represented category for both groups of teachers was that representing symptoms of effort, work, and fatigue associated with talking, but the frequency was nearly three times higher for the voice-disordered group than for the control group. Therefore, whereas low levels of effort, work, and fatigue may be components of the general teaching experience, frequency of those symptoms seems to be important in distinguishing teachers with voice disorders. Auditory changes to the voice were also frequently reported by the teachers with voice disorders, whereas this was the least frequently reported category for teachers without voice problems.

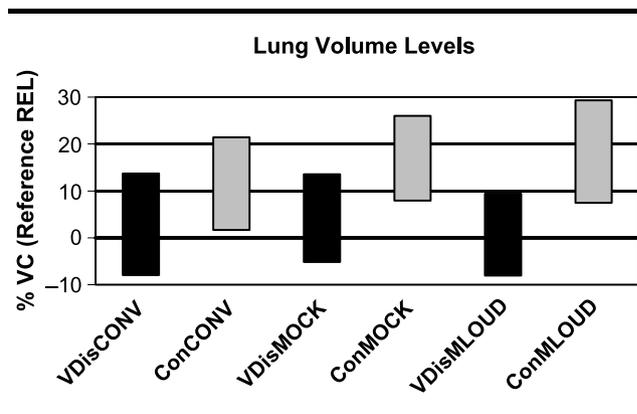
Although effort ratings given after each speaking task for the voice-disordered group were approximately twice as high as those of the control group on two of the three speaking tasks, overall group differences for each task did not reach statistical significance. High degrees of within-group variability may have contributed to the nonsignificant findings. As most teachers were tested at the end of the work day, cumulative vocal effort or fatigue would be expected for the teachers with voice disorders during testing. However, most teachers had had 1–2 hr of vocal rest between the end of their teaching day and the start of testing. Furthermore, it is likely that the 3-min speaking tasks used in this study did not evoke the same symptoms that an entire teaching day or a 1-hr lecture would invoke.

## Respiratory Function in Teachers

As predicted at the outset of the study, teachers with voice disorders, when compared with those without voice problems, started and ended their breath groups at significantly smaller lung volumes. These differences were more pronounced during simulated teaching than during conversation. Figure 2 provides a descriptive presentation of these differences, showing lung volume initiation, lung volume termination, and lung volume excursion for each group and task.

Speech breathing in these teachers differed somewhat from speech breathing of nonteachers, as determined through comparisons with previously published data (Hixon et al., 1973; Hoit & Hixon, 1987; Hoit et al., 1989; Winkworth et al., 1995). The data on nonteachers show that during spontaneous speaking, utterances are usually initiated 10%–25% above the resting expiratory level and terminated at or near resting expiratory level. In the present study, teachers with voice disorders started and ended their breath groups at the low end of these previously reported ranges, whereas teachers without voice problems were at the high end of previously reported ranges. Sapienza and colleagues (Sapienza & Stathopoulos, 1994; Sapienza et al., 1997) have found that people with vocal nodules show increased lung volume excursion as compared with people without vocal nodules. These authors noted that the increased lung volume excursion is contributed to by trends of increased lung volume initiation and decreased lung volume termination, which may be a compensation for a leaking laryngeal valve due to the presence of bilateral vocal fold nodules. In the present study, speech breathing differences in teachers with voice problems were not a compensatory response to laryngeal structural pathology.

**Figure 2.** Lung volume events for the voice-disordered (VDis) and control (Con) groups across the three spontaneous speaking tasks, referenced to resting expiratory level. CONV = conversational task; MOCK = mock teaching task; MLOUD = mock loud teaching task; %VC = percent vital capacity.



Teachers with voice disorders showed atypical respiratory behavior when they spoke at increased loudness. Previous research findings for healthy participants show that when voice loudness is increased, most participants initiate speech at lung volumes 10%–20% greater than those produced at typical loudness levels (Hixon et al., 1973; Hixon, Mead, & Goldman, 1976; Huber, Chandrasekaran, & Wolstencroft, 2004; Stathopoulos & Sapienza, 1993). The teachers without voice disorders exhibited the same general pattern of difference. By contrast, teachers with voice disorders in this study actually decreased their lung volume initiations and termination when they performed the same task (simulated teaching) at a louder level. This indicates that teachers with voice disorders did not capitalize on increased expiratory recoil forces that are available at larger lung volume levels (Hixon et al., 1973) and that they had to use greater expiratory muscular pressure to speak, especially near the end of breath groups where they had to counteract the inspiratory recoil pressure.

Speaking at smaller lung volumes has been described as more costly relative to muscle expenditure (Forner & Hixon, 1977) because greater expiratory muscular pressure is required than at larger lung volumes where expiratory recoil pressure is greater. Use of strategies that increase demands on expiratory muscles may be problematic for individuals who are faced with an occupation that requires extended periods of talking, often at greater-than-conversational loudness. Strategies that increase muscular work on the expiratory side of the speech breathing cycle might be more costly than those that increase muscular work on the inspiratory side because the expiratory side of the speech breathing cycle is so much longer than the inspiratory side. For the teachers in this study, average expiratory time was approximately eight times greater than inspiratory time across speaking tasks. The increased work on the expiratory side may contribute to the frequent symptoms of effort, work, and fatigue that teachers with voice disorders reported during teaching. Interestingly, however, the effort symptoms that were most salient for teachers were those related to the laryngeal, not respiratory, system.

Respiratory strategies that relied on the use of small lung volumes may have carried an additional acoustic cost to teachers with voice disorders. The reduced reliance on expiratory recoil pressure may have influenced the driving pressure used for speaking. Indirect evidence that the teachers with voice disorders used lower driving pressures than those without voice disorders was found in the observation that their speech SPL was significantly lower (in the two teaching tasks, approximately 5 dB lower than that of the teachers without voice disorders). The lower SPL for the teachers with voice disorders also provides objective support for reports of decreased loudness

by the teachers with voice disorders, as evidenced in their responses to the symptom checklist.

The results of the present study show that smaller lung volume initiations and terminations are associated with voice disorders in teachers. Whether these speech breathing differences have the potential to contribute to the development of laryngeal pathology in teachers is unknown. However, the increased cost of speaking at small lung volumes relative to muscular expenditure (Forner & Hixon, 1977), voice quality changes (Milstein & Watson, 2004), and laryngeal configuration (Iwarsson et al., 1998) is likely to compound the voice problems that these teachers are experiencing. Based on the respiratory strategies evidenced by teachers in this study, future investigation of respiratory treatment effects may need to focus on altering patterns of lung volume initiation and lung volume termination levels. Many clinicians currently include respiratory-based techniques in their voice therapy treatment programs, but studies that document the effects of respiratory training are generally limited to voice disorders with neurogenic origin (Huber, Stathopoulos, Ramig, & Lancaster, 2003; Ramig & Countryman, 1995; Thompson-Ward, Murdoch, & Stokes, 1997) or have focused on inspiratory or expiratory muscle training (Cerny, Panzarella, & Stathopoulos, 1997; Roy et al., 2003; Ruddy et al., 2004) rather than on lung volume levels during speech production.

## ***Laryngeal Function in Teachers***

The hypothesized difference in laryngeal function between teachers with and without voice disorders as assessed with EGG was not supported. This result was surprising, as previous research has shown differences in vocal fold adduction patterns for people with voice disorders (Eustace et al., 1996; Hillman et al., 1989; Hillman, Holmberg, Perkell, Walsh, & Vaughan, 1990). Mean values for both EGG measures in this study fell within normative ranges (Orlikoff, 1991; Orlikoff et al., 1997) for the teachers in the voice-disordered and control groups across all speaking tasks.

There are several possible reasons for the lack of between-group differences in laryngeal function as assessed with EGG. The most obvious explanation is that laryngeal function was not different for the teachers with voice disorders compared with those without such disorders. Alternatively, it is possible that the EGG signal and/or the measurements made from it were not sensitive to differences in laryngeal function. Initial pilot testing of EGG sensitivity indicated that both CQ and CI would register change for variations in voice quality; CQ varied between 25% and 60%, and CI varied between 0.05 and –0.60 for an adductory glide. Previous research has also shown that CQ is higher for a pressed

versus a breathy voice quality (Peterson et al., 1994). However, both the pilot testing and previous EGG studies were conducted with sustained vowel utterances, whereas the present study also included continuous speaking. Analysis of continuous speaking, which includes a great deal of intra- and interparticipant variation, may cancel out any specific differences when means are assessed over the course of a speaking task and across participants. Supraglottic constriction rather than adductory changes at the level of the vocal folds may have contributed to teachers' voice problems. Differences in supraglottic configuration, including articulatory configuration, could also have assisted the teachers with voice disorders in achieving increased loudness during the simulated loud teaching task, as they did not implement increased lung volume initiation levels for this task. It is also possible that laryngeal muscle activation may have differed between the two teacher groups, whereas their adductory patterns did not. Direct laryngeal muscle measurement via electromyography would be needed to explore the relation between lung volume and laryngeal muscle activation, as well as any differences in laryngeal muscle dynamics between teachers with and without voice disorders. Fundamental frequency is another possible factor that may contribute to teachers' voice problems. Although differences in average fundamental frequency and frequency range have not been consistently demonstrated in people with voice disorders (Eustace et al., 1996), some investigators have produced changes in fundamental frequency after inducing vocal fatigue in healthy participants (Stemple et al., 1995).

Differences in EGG measures across speaking tasks indicated that symmetry of vocal fold contact (CI) was lower (more negative) during a conversational speaking task than during the sustained vowel task. Thus, greater asymmetry between the contact-closing and contact-opening phase was demonstrated during conversational, continuous speaking task as compared with the sustained vowel task. This may reflect a greater degree of vocal fold tension (Orlikoff, 1991) during the continuous speaking task. During continuous speech production, the vocal folds must continually stop and start vibration in a matter of milliseconds. It is possible that the need for rapid onset and offset of vocal fold vibration may mandate a steady-state increase in vocal fold tone. Previous research supports the notion that voice characteristics such as supraglottic activity (Stager et al., 2000) and acoustic measures (Brown, Morris, & Murry, 1996; Fitch, 1990; Nittrouer et al., 1990) are different for sustained vowels as compared with continuous speaking. In this study, the patterns of vocal fold asymmetry that characterized the conversational speaking task may be more indicative of the patterns typically evidenced during everyday speaking.

It is not clear why the only significant task-related difference was between the sustained vowel task and the conversational speaking task. The varying phonemic content of the spontaneous speaking samples compared with the standard phonemic content of the sustained vowel task and reading passage did not appear to be a factor in explaining task differences. Group means for CQ and CI for the reading task (which represented standard phonemic content) were similar to other spontaneous speaking tasks. It could be argued that SPL differences accounted for the significant task difference that occurred, as SPL was higher for the sustained vowel task. SPL is correlated with CI, although its change as associated with increasing SPL is in the opposite direction of the change shown in this study (Orlikoff, 1991). However, the present data do not support the notion that SPL was the primary contributor to the task difference in CI seen in this study. SPL and CI were not significantly correlated for the two speaking tasks that showed significant task differences for CI. Comparisons of other continuous speaking tasks that showed greater SPL differences were also not significantly different for CI. An alternative explanation is that the smaller lung volume terminations that were evidenced across participants during conversational speaking may have accounted for the task differences in CI, as smaller lung volumes as assessed in a sentence with progressively decreasing lung volume were associated with more negative CI values.

## ***Respiratory–Laryngeal Interactions***

Respiratory measures differed between the two groups of teachers, but laryngeal measures did not, suggesting that respiratory and laryngeal function were not related. Nevertheless, support for respiratory–laryngeal interaction was found when measures of laryngeal function were examined within breath groups, at least for the sentence representing continuous speech production. Specifically, asymmetry of the contact-closing versus contact-opening phase increased as lung volume decreased during continuous speech production, suggesting that vocal fold tone or tension increased (Orlikoff, 1991). It is uncertain why the same pattern of change was not seen for the maximum phonation time vowel. Perhaps other factors, such as those related to articulatory gestures of the larynx or upper airway, also contribute to this change in vocal fold behavior across the breath group. Due to the contrived nature of the maximum phonation time vowel and its lack of articulatory gestures, assessment of respiratory–laryngeal interactions may be most appropriate in continuous speaking contexts.

For the teachers with voice disorders who consistently used smaller lung volume levels during continuous speaking, contact phase asymmetry may compound

their voice problems by increasing vocal fold tension at the end of breath groups. Previous research has indicated that speaking at smaller lung volume levels may be accompanied by increased laryngeal constriction (Iwarsson et al., 1998; Milstein, 1999). Initiating speech at smaller lung volumes degrades voice quality (Milstein & Watson, 2004) and causes acoustic changes such as a reduction in F1–F2 vowel space (Watson & Ciccio, 2003) and change in voice onset time (Hoit, Solomon, & Hixon, 1993). Thus, speech breathing strategies such as those used by teachers with voice disorders in this study may have respiratory, laryngeal, acoustic, and perceptual consequences.

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**Appendix.** Symptoms in descending frequency for the voice-disordered (VDis) group with the corresponding score for the control (Con) group.

Symptom	Sum score VDis	Sum score Con	Category and subsystem
Throat/voice mechanism feels tired	18	7	Effort/work/fatigue, laryngeal
Throat feels dry	18	7	Pain/discomfort, laryngeal
Need to use more effort for speaking	18	6	Effort/work/fatigue, both
Need to work harder to speak	17	6	Effort/work/fatigue, both
Hoarse/husky voice quality	17	2	Auditory changes, laryngeal
Decreased loudness/power of voice	16	2	Auditory changes, both
Need to cough/clear throat more	15	3	Pain/discomfort, laryngeal
Have to think more about my voice	15	2	Mental effort
Range of loudness (loud or soft voice) is reduced	15	2	Auditory changes, both
Unsteady voice	14	1	Auditory changes, laryngeal
Tightness/constriction in throat	13	3	Tightness/tension, laryngeal
Tension in throat	12	3	Tightness/tension, laryngeal
Difficulty maintaining typical pitch	12	2	Auditory changes, laryngeal
Pitch breaks or changes unpredictably	11	3	Auditory changes, laryngeal
Loss of voice	9	1	Auditory changes, laryngeal
Range of pitch (high and low pitches) is reduced	9	0	Auditory changes, laryngeal
Pain in throat	8	2	Pain/discomfort, laryngeal
Have to think more about what I'm saying	8	5	Mental effort
Tightness in neck/shoulders	7	3	Tightness/tension, both
Breathy voice quality	7	2	Auditory changes, laryngeal
Tension in neck/shoulders	6	4	Tightness/tension, both
Run out of air while talking	6	5	Pain/discomfort, respiratory
Hard to get enough air while talking	6	2	Pain/discomfort, respiratory
Tightness/tension in chest	5	1	Tightness/tension, respiratory
Pain/discomfort in shoulders or neck	4	2	Pain/discomfort, both
Tightness/tension in belly	2	1	Tightness/tension, respiratory
Chest or belly feels tired	2	0	Effort/work, fatigue, respiratory

Note. 0 = never/rarely, 1 = sometimes, 2 = often, 3 = always. The maximum sum score possible is 27 for each symptom, per group.