RESPIRATORY AND LARYNGEAL FUNCTION DURING SPONTANEOUS
SPEAKING IN TEACHERS WITH VOICE DISORDERS

by

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Soren Y. Lowell

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ABSTRACT

Purpose: The purpose of this study was to determine if respiratory and laryngeal function during spontaneous speech production were different for teachers with voice disorders as compared to teachers without voice problems. The basic research questions posed in this study, as assessed during spontaneous speaking were: 1) Do subjects with a voice disorder show differences in lung volume patterns relative to control subjects? 2) Do subjects with a voice disorder show differences in vocal fold approximation as measured by contact quotient and contact index relative to control subjects? 3) Are these between-group differences most pronounced for mock teaching tasks versus a conversational speaking task? 4) Do subjects with a voice disorder rely more on laryngeal versus respiratory-based strategies for increasing loudness level as compared to control subjects?

Method: Nine teachers with and nine teachers without voice problems were included in this study. Respiratory function was measured with magnetometry, and laryngeal function was measured with electroglottography. Respiratory and laryngeal function were measured during three spontaneous speaking tasks: a simulated teaching task at a typical and increased loudness level, and a conversational speaking task. Two structured speaking tasks were included for comparison of electroglottography measures: a paragraph reading task and a sustained vowel.

Results: Lung volume termination level in spontaneous speaking was significantly lower for the teachers with voice disorders relative to teachers without voice problems. Lung volume initiation level was lower for the teachers with versus without voice problems during teaching-related speaking tasks. Laryngeal function as assessed with

electroglottography did not show between-group differences. Across tasks, the measure of contact index was lower (more negative) during the conversational speaking task as compared to the sustained vowel task, indicating greater contact phase asymmetry during vocal fold vibration.

Conclusions: These findings suggest that teachers with a voice disorder use different speech breathing strategies than teachers without voice problems. Management of teachers with voice problems may need to incorporate respiratory training that alters lung volume levels during speaking. Future research is needed to determine whether altering such patterns results in improved voice parameters and self-perceived improvement in vocal symptoms.

INTRODUCTION

Teachers represent an estimated 5.89% of the 2004 U.S. work force¹ (U.S. Bureau of Labor and Statistics), and rely on their voice as a primary tool of trade (Titze, Lemke, & Montequin, 1997). Teachers represent a disproportionately high percentage of the voice-disordered caseload, estimated at 20% or greater. Due to the heavy vocal demands associated with teaching, it is considered an occupation that places individuals at greater risk for voice disorders than other occupations (Roy, Merrill, Thibeault, Gray, & Smith, 2004; Thibeault, Merrill, Roy, Gray, & Smith, 2004; Titze et al., 1997; Verdolini & Ramig, 2001). The prevalence of voice disorders among teachers is significantly higher than for non-teaching occupations (Roy et al., 2004; E. Smith, Lemke, Taylor, Kirchner, & Hoffman, 1998), and voice disorders have a negative impact on job performance, work attendance, emotion, and communication (E. Smith, Gray, Dove, Kirchner, & Heras, 1997; Verdolini & Ramig, 2001; Yiu & Ma, 2002). In a study comparing teachers to other occupations, approximately 20% of teachers versus 0% of non-teachers had missed work days due to their voice problems. The annual cost to the U.S. for lost work time and treatment of teachers' voice problems has been estimated at 2 billion dollars (Verdolini & Ramig, 2001).

Due to the high representation of teachers in the work force and on the clinical caseload, several investigators have studied prevalence rates, vocal symptoms, impact of voice problems, and effective treatment approaches for teachers with voice problems

¹ Number estimated from May, 2004 U.S. Bureau and Labor Statistics, using the general category of Education, Training and Library Occupations and subtracting all non-teaching sub-professions from the overall number.

(Gotaas & Starr, 1993; Kostyk & Rochet, 1998; Roy et al., 2001; Roy et al., 2002; Yiu & Ma, 2002). Interpretation of these study results is complicated by the disparate definitions of voice disorder used across studies (Gotaas & Starr, 1993; Kostyk & Rochet, 1998; Roy et al., 2004; Sapir, Keidar, & Mathers-Schmidt, 1993; E. Smith et al., 1997) and minimal provision of inclusion criteria for the subjects with voice disorders (Roy et al., 2001; Roy, Weinrich et al., 2003). Thus, generalizing study results to specific voice-disordered populations is difficult.

Most researchers reporting on teachers with voice problems have not screened for laryngeal pathology (Gotaas & Starr, 1993; Kostyk & Rochet, 1998; Roy, Weinrich et al., 2003; Sapir et al., 1993; Schmidt, Andrews, & McCutcheon, 1998), and therefore presumably included multiple types of voice disorders in their voice-disordered groups. In many of these studies, non-specific subject inclusion criteria and the lack of operational definitions for voice disorders contribute to the disparity of subjects within the voice-disordered groups. Several researchers have narrowed their focus to teachers and others who experience symptoms of vocal fatigue. Although these researchers have often not incorporated direct laryngeal screening for pathology, the targeted population was individuals with symptoms of vocal fatigue but without laryngeal pathology (Kostyk & Rochet, 1998; Rantala, Paavola, Korkko, & Vilkinan, 1998). Even with this more narrow focus, subject inclusion criteria and definition of voice disorder have varied greatly.

Objectively defining voice disorders that occur in the absence of laryngeal pathology has presented many obstacles to researchers investigating teachers and others

with voice problems. One core characteristic of voice disorders that emerges across most studies is the percept of increased effort associated with speaking. Effort ratings correlate well with several variables that are likely to contribute to physiologic characteristics in people with voice disorders (Cafarelli, 1982; Chang & Karnell, 2004; Colton & Brown Jr., 1973; Gandevia, Killian, & Campbell, 1981; Wright & Colton, 1972b), and effort can be quantified and reliably estimated (Colton & Brown Jr., 1973; Somodi, Robin, & Luschei, 1995; Wright & Colton, 1972b). Therefore, increased speaking effort provides a tool for characterizing teachers with voice disorders whose problems are not associated with laryngeal pathology.

In contrast to the multiple studies on prevalence rates and perceptual and acoustic characteristics of disordered voice in teachers, few studies have objectively documented physiologic characteristics of speech production in teachers with voice disorders. Thus, although increased speaking effort seems to be a core characteristic underlying certain voice problems, the physiologic correlates to this increased effort are largely unknown. Identifying physiologic differences between teachers with and without voice problems would increase our understanding of the etiology of their voice problems and determine appropriate treatment techniques. Assessment of physiologic differences in teachers experiencing voice problems but not exhibiting laryngeal pathology allows for the interpretation of those differences as characteristics of the disorder rather than compensation for an altered structure of the larynx or laryngeal valve.

Voice Disorders in Teachers

Prevalence of voice problems in teachers is estimated between 20 to 50% (Russell, Oates, & Greenwood, 1998; Sapir et al., 1993; E. Smith et al., 1998). Several factors may contribute to these high rates of voice problems in teachers, and their over-representation in the voice clinic caseload relative to other occupations. Teachers frequently have to talk for extended periods, often at increased loudness levels or over background noise (E. Smith et al., 1998). They must also contend with stress or performance factors (Russell, Altmaier, & Van Velzen, 1987) and frequently must use their voice for behavior management issues in the classroom. Titze, Svec and Popolo (2003) have suggested that accumulated dosage of vocal fold vibration may be important to the onset and progression of voice problems, and estimated that safe dosage time may be as low as 17 minutes for continuous phonation, or 35 minutes of continuous talking that includes unvoiced portions and pauses such as when reading aloud. Continuous teaching time for teachers has been estimated at approximately 5 hours a day (E. Smith et al., 1998), with an estimated continuous phonation time of close to 80 minutes (Holbrook, 1977).

When considering the phonation time requirements of teachers, the increased risk for voice disorders seen with this occupation is not surprising. Interestingly, whereas up to 50% of teachers report current problems with their voice (Sapir et al., 1993), an equal percentage of teachers, presumably faced with the same vocal demands, are not experiencing voice problems. Differences in physical constitution of the larynx, as well as differences in the functional use of the respiratory, laryngeal and articulatory

subsystems may explain the predisposition of some teachers versus the invulnerability of others to voice problems. The majority of research has dealt with acoustic characteristics and symptomatology of teachers with voice disorders. Few studies, however, have addressed differences in respiratory and laryngeal function during speech production in teachers.

Acoustic and Perceptual Characteristics of Teachers' Voice

Symptoms of voice problems in teachers have been studied by a number of investigators. One symptom that has been frequently described in teachers is vocal fatigue. Sapir, Keidar and Mathers-Schmidt (1993) distributed a questionnaire regarding multiple symptoms of voice difficulty to 237 teachers. These authors found that 54% of teachers reported three or more current symptoms of voice difficulty, with the most frequent symptoms being dryness in throat, voice fatigue, scratchy sensation, hoarseness and effort to talk. When teachers were queried regarding changes to their voice since they began a teaching career, complaints of voice being more fatigued/fatigable, more throat pain/discomfort, voice being lower in pitch, voice being more hoarse, harsh or breathy, and voice being more effortful to produce were reported most frequently.

Roy, Merrill, Thibeault, Gray and Smith (2004) obtained data from approximately 1200 teachers and 1200 participants from non-teaching occupations. Teachers experienced a significantly higher number of voice symptoms than non-teachers. Specific symptoms that were significantly more frequent for teachers included hoarseness, tiring of the voice, changes to voice quality, difficulty with loudness range, and difficulty projecting the voice. Through a factor analysis, the underlying factors of

difficulty projecting the voice and effort to talk were found to contribute most to the overall category of phonatory signs and symptoms.

Several other studies have measured acoustic and perceptual characteristics of voice in teachers when in their work environment. Rantala, Paavola, Korkko and Vilkman (1998) took acoustic measures from sustained vowel recordings at the beginning, middle and end of the day for 10 teachers. These authors found that when comparing first to last recordings, there was an increase in high frequency spectral energy for the end of the day recordings. This increase in high frequency energy was interpreted as a change associated with hyperfunctional voicing patterns that resulted from vocal loading. Gotaas and Starr (1993) made AM and PM recordings of teachers with and without vocal fatigue symptoms. Subjects rated their own voice symptoms at each session, and listeners later judged voice quality for the AM and PM recordings. Whereas no AM or PM differences were evidenced for the control subjects on listener or self-ratings, subjects with vocal fatigue showed increased reports of difficulty and poorer ratings of voice quality by the end of the day. Schmidt, Andrews and McCutcheon (1998) assessed the correlations between student ratings of teacher effectiveness and acoustic characteristics of teachers' voices recorded during a lecture. Correlations between student ratings and voice characteristics were mostly evidenced for fluency-related variables, but also for fundamental frequency (Fo) range.

Teachers often have to produce voice at increased loudness levels (Holbrook, 1977) to talk over background noise and to traverse increased speaker-to-listener distances. Increased sound pressure level (SPL) is associated with increased maximum

flow declination rate and increased laryngeal resistance, which may result in increased collision forces and strain to the vocal folds (Holmberg, Hillman, & Perkell, 1988). Safe vibration dose as proposed by Titze et al. (2003) is more likely to be exceeded under conditions that increase vocal fold acceleration/deceleration and collision forces (Roy, Weinrich et al., 2003). Several researchers have therefore assessed the effects of amplification on teachers' voices in the classroom in an effort to reduce vocal load. McCormick and Roy (2002) found that when using an amplification device, teachers were able to significantly reduce SPL measured at the mouth while increasing the SPL as measured at the back of the room. Roy, Weinrich et al. (2003) found that after 6 weeks of using a voice amplifier in the classroom, teachers with voice disorders showed improved listener ratings of voice quality. In addition, they showed improved self-ratings of impact of voice problems on the Voice Handicap Index, a measure of self-perceived impact of voice problems. Sapienza, Crandell and Curtis (1999) also found that 9 of 10 teachers significantly reduced their SPL when using an amplification system in the classroom. The benefits of amplification and improved voice clarity extend beyond the teachers themselves. Sound-field amplification in classrooms has been shown to improve listening skills and academic performance in children with and without hearing loss (Crandell, Smaldino, & Flexor, 1995).

Terminology Confusion in Defining Voice Disorders

Many of the studies addressing voice characteristics in teachers have either included both teachers with and without laryngeal pathology (Rantala et al., 1998) or have not directly assessed whether laryngeal pathology was present at the time of testing

(Gotaas & Starr, 1993; Kostyk & Rochet, 1998; Roy, Weinrich et al., 2003; Sapir et al., 1993; Schmidt et al., 1998). Inclusion of subjects with and without laryngeal pathology complicates the interpretation of study results and makes it difficult for clinicians to determine which patients may best benefit from treatment approaches. Voice disorders characterized by vocal complaints in the absence of laryngeal structural pathology may precede laryngeal structural pathology (Morrison & Rammage, 1993). In addition, this group represents an estimated 40% or more of the voice-disordered clinical caseload (Sama, Carding, Price, Kelly, & Wilson, 2001). Many different terms are used to describe these voice disorders, including muscle misuse voice disorders, muscle tension dysphonia, functional voice disorders, and hyperfunctional voice disorders. However, definitions of these terms generally fail to distinguish one diagnosis from another. One common symptom that emerges across all of these disorder diagnoses is that of vocal fatigue, and it is consistently noted to negatively affect multiple domains of life in both teachers and non-teachers experiencing these voice problems (Sapir, 1993; E. Smith et al., 1997; E. Smith et al., 1998).

Whereas vocal fatigue is clearly a significant component of many voice disorders and a problem that impacts many areas of function, operationally defining the term in a manner suitable for controlled, experimental research has proved extremely difficult. There is no currently accepted definition of vocal fatigue (Welham & MacLagan, 2003), and researchers have included a vast array of voice and vocal mechanism symptoms under the umbrella term of vocal fatigue. Lack of an operational definition has resulted in very different inclusion criteria for subjects in studies addressing vocal fatigue, and not

surprisingly, quite disparate results relative to acoustic (Drew & Sapir, 1995; Eustace, Stemple, & Lee, 1996; Neils & Yairi, 1987; Stone & Sharf, 1973), perceptual (Kitch & Oates, 1994; Kostyk & Rochet, 1998) and aerodynamic (Kostyk & Rochet, 1998; Stemple, Stanley, & Lee, 1995) findings. Operationally defining vocal fatigue is challenging because of the complexity of its contributions, including neuromuscular, biomechanical, and material factors (Titze, 1984, 2000; Welham & Maclagan, 2003).

Contributing Factors to Vocal Fatigue

McCabe and Titze (2002) defined vocal fatigue as “a progressive increase in phonatory effort accompanied by a progressive decrease in phonatory capabilities” (p.357). They also presented a hypothetical model for the contributing factors and pathophysiology of vocal fatigue. This model included central and peripheral neuromuscular factors related to the respiratory, phonatory, and resonance/articulatory systems that may influence vocal fatigue. In addition to these neuromuscular factors, biomechanical factors that influence tissue composition and vocal fold stiffness may yield changes to vocal fold vibratory characteristics, and may reduce the efficient transfer of aerodynamic to acoustic energy. These factors include vocal fold viscosity, temperature, depletion or accumulation of metabolic substances, and mechanical stress that may occur during vibration due to repeated acceleration and deceleration of vocal fold tissue. McCabe and Titze (2002) suggested that inappropriate, isometric contractions of antagonistic muscles in the respiratory, laryngeal or articulatory subsystems may trigger further muscle misuse patterns that then lead to the neuromuscular and biochemical changes that characterize vocal fatigue.

Neuromuscular factors that are involved in general muscle fatigue are also thought to contribute to vocal fatigue. Muscle fatigue involves both peripheral components related to changes at the level of the muscle, and central components, related to changes in motor output from the central nervous system (CNS) to the lower motor neurons, or changes to the responsiveness of the lower motor neurons to this output (Cafarelli, 1982, 1988; Enoka & Stuart, 1992; Gandevia, 2001). Changes to the properties of the muscle fibers, depletion of biomechanical substances needed for energy conversion, and depletion of neurotransmitters including acetylcholine at the neuromuscular junction are all factors that may contribute to peripheral muscle fatigue. Titze (2000) has suggested that during vocal fold vibration, blood flow decreases, and this decreased blood flow may lead to decreased reuptake of oxygen and decreased removal of carbon dioxide, potentially impacting vocal muscle function. Synaptic changes to the neuromuscular junction may also result in decreased responsiveness of the muscle fibers. Finally, properties of the muscles themselves are important determinants of the degree of peripheral muscle fatigue. The thyroarytenoid muscle appears to be primarily populated by Type I and Type IIa muscle fibers, which are relatively fatigue resistant (Claassen & Werner, 1992). Less is known about the composition of the other intrinsic and extrinsic laryngeal muscles, however.

Central components to fatigue may include decreased excitatory drive from the motor cortex, as well as decreased responsiveness of the lower motor neuron. Following sustained voluntary contraction, decreased muscle responsiveness to cortically evoked stimulation has been documented, implicating decreased descending drive from the motor

cortex (Fuglevand, 1996). Several mechanisms have been suggested for decreasing the responsiveness of the lower motor neuron itself. Sensory-motor reflex mechanisms may sense accumulation of metabolic substances in the muscle fibers, and send feedback to inhibitory interneurons that synapse on the lower motor neuron (LMN) and subsequently reduce LMN output. Decreased excitatory feedback from pathways such as Ia afferents from the muscle back to the LMN may also reduce LMN drive, and adaptation of the LMN itself to repeated stimulation may reduce its firing frequency (Fuglevand, 1996).

Muscle fatigue has been most extensively studied in physiology, in which direct measures of muscle force are possible to obtain *in vivo*. Muscle fatigue has been defined as “..an acute impairment of performance that includes both an increase in the perceived effort necessary to exert a desired force and an eventual inability to produce this force” (p. 1631) (Enoka & Stuart, 1992). Simultaneous with direct measures of force reduction, physiologists routinely use subjective measures of perceived effort through magnitude estimation techniques to assess muscle fatigue in subjects, as perceived effort reflects both central and peripheral contributions to fatigue (Cafarelli, 1982, 1988; Jones, 1995; Killian, Gandevia, Summers, & Campbell, 1984; Noble, 1982). In these studies, perceived effort systematically increases as increased force or load is applied to the muscle (Cafarelli, 1982, 1988). This increase is not proportional to the increase in force; instead, perception of the magnitude of effort increases at a rate of 1.7 times that of the actual increase in load on the muscle (Cafarelli, 1988; Jones, 1995). As a muscle fatigues with sustained contraction for a static force load, perceived effort systematically increases the longer the force is applied (Jones, 1995). Researchers have suggested that subjects

may preferentially attend to the central fatigue components during muscle fatigue (Cafarelli, 1988; Jones, 1995). Thus, measurement of perceived effort may be critical with muscle fatigue because it will not only increase as output force decreases in a target muscle, but it will increase at a greater rate than what measuring the decline of force alone would suggest.

In addition to neuromuscular contributions, material changes that affect the vocal folds are considered important in vocal fatigue. Titze (1984, 2000) has suggested that one material change which may be important to the vocal fold mucosa is tissue viscosity. Viscosity in the vocal system relates to the property of matter that provides resistance to aerodynamic energy. When viscosity of the mucosa is low, a more optimal transfer of aerodynamic to acoustic energy is achieved, presumably with increased “ease” of phonation. Vocal fold viscosity is best quantified by means of phonation threshold pressure (PTP) (Titze, 1984, 2000) and has been studied extensively under varied conditions of hydration (Roy, Tanner, Gray, Blomgren, & Fisher, 2003; Solomon & DiMattia, 2000; Solomon, Glaze, Arnold, & van Mersbergen, 2003; Verdolini, Titze, & Fennel, 1994). PTP is the minimum amount of tracheal pressure needed to initiate vocal fold oscillation for voice production. Titze (1984, 2000) proposed that increased tissue viscosity could lead to increased PTP. Solomon et al. (2000) described PTP as an indicator of the relative “ease of phonation”. PTP has been used as a physiologic measure for respiratory/phonatory effort (Solomon & DiMattia, 2000; Solomon et al., 2003; Verdolini et al., 1994), with the supposition that lower PTP should correspond to reduced phonatory effort, and increased vocal efficiency. PTP generally increases with

fatigue-inducing speaking tasks that require extended speaking at increased loudness, and is inversely related to hydration, particularly for high-pitched phonation.

Finally, mechanical stress during phonation may alter tissue characteristics in a way that makes the vocal mechanism more susceptible to fatigue or to further laryngeal pathology. Tensile stress due to intrinsic muscle contraction, shearing stress, and vocal fold impact stress are forms of mechanical stress that occur during vibration that may negatively affect the health of the vocal fold tissue (Verdolini, Chan, Titze, Hess, & Bierhals, 1998). Impact stress in hyperphonated canine larynges results in tissue changes to the basement membrane zone, a region that shows cellular changes in vocal nodules (Gray & Titze, 1988).

Sense of Effort as a Core Characteristic of Vocal Fatigue

Because these contributions to vocal fatigue are multifaceted and difficult to measure, investigators have generally defined vocal fatigue on a constellation of symptoms reported by patients. These symptoms include changes to auditory characteristics of voice as well as to the vocal mechanism itself. Specific symptoms reported by patients include perception of increased vocal effort, changes in voice quality with extended talking, and reduced endurance and flexibility of the voice which may impact both pitch and loudness ranges (Kelchner, Lee, & Stemple, 2003; Kitch & Oates, 1994; Scherer et al., 1987; Welham & MacLagan, 2003). Across virtually all of these studies, a symptom that is consistently represented is the report of increased effort associated with speaking (Eustace et al., 1996; Gotaas & Starr, 1993; Kitch & Oates, 1994; Kostyk & Rochet, 1998; McCue, Barkmeier, & Story, 2001; Roy et al., 2004; Sapir

et al., 1993; Scherer et al., 1987; E. Smith et al., 1997; Solomon & DiMattia, 2000; Solomon et al., 2003; Stemple et al., 1995; Welham & MacLagan, 2003). This increased speaking effort is typically characterized by symptoms of the vocal mechanism or voice feeling tired, weak, or effortful such that it presents a functional problem to individuals with voice problems (E. Smith et al., 1997). Speaking effort is positively associated with the neuromuscular (Cafarelli, 1982, 1988; Gandevia et al., 1981), material (Chang & Karnell, 2004; Solomon et al., 2003) and aerodynamic and acoustic factors (Colton & Brown Jr., 1973; Wright & Colton, 1972b) thought to be important in vocal fatigue. Thus, speaking effort may reflect a unifying, core characteristic of vocal fatigue.

As seen in physiology research, sense of effort may provide a more comprehensive measure of muscle fatigue than muscle force alone and is considered critical to the assessment of muscle fatigue. Positive correlations between sense of effort and muscle fatigue have been demonstrated in the respiratory, laryngeal and articulatory subsystems. Researchers have shown that effort ratings may be appropriate indicators of respiratory muscle fatigue (Gandevia et al., 1981; Supinski, Clary, Bark, & Kelsen, 1987), and that perceived effort increases as increased inspiratory pressure load is applied (Killian et al., 1984). Solomon (2000) found that sense of effort progressively increased during successive phases of a task designed to induce fatigue of the tongue muscles. In the laryngeal subsystem, perceived effort has been used as an indicator of vocal fatigue (McCabe & Titze, 2002; Verdolini et al., 1994). Direct measurement of muscle force is not possible in the larynx without causing permanent damage and obstructing the airway. Thus, studies of laryngeal muscle fatigue in voice disorders have relied on estimation of

vocal or speaking effort as an indirect measure that correlates well with factors considered important to fatigue (Chang & Karnell, 2004; McCabe & Titze, 2002; Solomon et al., 2003).

Speaking effort also appears to be positively correlated to some of the material changes to the vocal folds that may contribute to vocal fatigue. Phonation threshold pressure was described as a means of estimating tissue viscosity. Ratings of speaking effort have been consistently incorporated with the aerodynamic measures required for PTP calculation (Chang & Karnell, 2004; Solomon & DiMattia, 2000; Solomon et al., 2003; Verdolini et al., 1994). Self-ratings of speaking effort systematically increase during fatigue-inducing speaking tasks that require subjects to speak at increased loudness levels for prolonged periods (Solomon & DiMattia, 2000; Solomon et al., 2003). Some investigators have found perceptual measures of speaking effort to be positively correlated with PTP (Chang & Karnell, 2004; Solomon et al., 2003).

Finally, speaking effort is positively related to several acoustic and aerodynamic measures that may influence vocal fatigue. Wright and Colton (1972a, 1972b) had subjects produce utterances at three different effort levels, and then rate their effort with magnitude estimation techniques. F_0 and SPL were measured for all utterances, and effort ratings showed a strong, positive relationship with both of these acoustic measures. Using similar methods, Colton and Brown (1973) showed that subjects' effort ratings were strongly related to intraoral air pressure.

Thus, speaking effort appears to be a core characteristic of the global construct of vocal fatigue. It also provides a comprehensive indicator of neuromuscular, material,

aerodynamic and acoustic factors that may be important to vocal fatigue. Speaking effort has been used in the field of speech science as an indicator of or correlate to other physiologic measures associated with vocal fatigue.

Reliability and Validity of Effort Ratings

If increased speaking effort is to be used as a core indicator of a voice disorder, it must be a valid, reliable measure that differentiates individuals with voice disorders from people without voice problems. In addition to the support of its construct validity summarized above, several researchers have shown that speaking effort can be reliably judged. In the studies summarized previously by Wright and Colton (1972a, 1972b), the authors included an assessment of the repeat reliability of subjects' effort ratings. After subjects produced their initial vocalizations at low, mid and high targeted effort levels and gave numeric estimations of their speaking effort, subjects were asked to produce utterances which matched those numbers (magnitude production techniques). Subjects were highly consistent in matching their productions to their previous effort ratings, especially for SPL (Colton & Casper, 1990). Subjects have also been shown to reproduce consistent amounts of measured force with the tongue and hand when asked to match force exertion to a given percentage of effort over repeated trials (Somodi et al., 1995).

Increased speaking effort may differentiate people with voice problems from those who are not experiencing voice difficulties. Verdolini(2004) had 6 individuals with voice disorders and 45 control subjects make retrospective ratings of phonatory effort throughout a 60-minute period for a situation requiring heavy voice use. Whereas all subjects showed an increase in effort ratings over the 60-minute interval, subjects with

voice problems showed a substantially higher growth in vocal effort than did the control subjects, and maintained high effort ratings 24-hours after the heavy voice use task. Thus, in addition to its positive relationship with many variables that could influence respiratory and laryngeal physiology, it appears that speaking effort can be reliably judged by subjects and serves to differentially characterize individuals with voice disorders. Increased speaking effort can therefore be used as a quantifiable and replicable defining characteristic of people with voice disorders in the absence of laryngeal structural pathology.

Physiologic Differences in Voice Disorders

Although this percept of increased speaking effort appears to be a critical component of voice disorders that occur without laryngeal pathology, the physiologic differences that might relate to this increase in effort are not well understood. Differences in functional use of the respiratory and laryngeal subsystems are often assumed to contribute to the onset and progression of multiple voice disorders (Aronson, 1990; Koufman & Blalock, 1988; Morrison & Rammage, 1993). These assumptions include the notions that speaking at lower lung volumes, failing to adequately replenish breath during speech production, and speaking with excessive intrinsic and extrinsic laryngeal muscle tension may be important to the etiology and progression of voice problems. Clinically, when respiratory and phonatory subsystems are targeted in treatment, multiple voice parameters seem to improve (Koufman & Blalock, 1988; Stemple, Glaze, & Klaben, 2000). However, objective assessment of speech breathing behavior in voice disorders is minimal, and has not been studied in teachers.

Laryngeal function has mostly been explored with videoendoscopy in voice disorders, with some studies that explored phonatory function through aerodynamic assessment of airflow or laryngeal resistance. Only one of these studies has used aerodynamics to assess laryngeal function in teachers (Kostyk & Rochet, 1998). Knowledge of physiologic differences in both respiratory and laryngeal function between teachers with and without voice difficulty is critical to understanding the etiology of voice problems and appropriate methods to treat these problems. The study of individuals with voice disorders but without laryngeal pathology may reveal physiologic characteristics that contribute to the disorder versus those characteristics that are likely to result from compensation for laryngeal pathology.

Respiratory Characteristics of People with Voice Disorders

Although there is limited information on teachers, some information regarding respiratory and laryngeal physiologic characteristics in other individuals with voice disorders is available in the literature. Respiratory behavior has been primarily studied in voice-disordered populations with laryngeal structural pathology with only a small number of investigators studying individuals with voice disorders without vocal fold lesions. Most of the information on respiratory characteristics in individuals with voice disorders is for people with vocal fold nodules. Greater lung volume excursion has been documented in adults and children with vocal nodules when compared to control subjects (Sapienza & Stathopoulos, 1994; Sapienza, Stathopoulos, & Brown Jr., 1997). Trends of increased lung volume initiation and decreased lung volume termination likely contributed to the group differences in lung volume excursion. These authors suggested

that individuals with vocal fold nodules exhibit some of these respiratory changes as a compensation for the inadequate valving that occurs at the level of the vocal folds (due to the presence of the lesions, which impede complete closure). Speaking tasks for these studies included string of syllables (Sapienza & Stathopoulos, 1994) and a reading task (Sapienza et al., 1997). Scheffer, Cavallo, Wall, and Diakow (2002) found lower lung volume termination in subjects with mixed vocal fold pathology (vocal polyps, vocal nodules, contact ulcers, edema) as assessed in a reading task with lengthy sentences.

Only one single subject case study has investigated respiratory kinematics in someone with voice problems that were not characterized by laryngeal pathology or neurologic disease. In a presentation of three case studies of subjects with voice abnormalities, Hixon and Putnam (1983) assessed the speech breathing characteristics of a subject with functional misuse of the respiratory apparatus, apparently without laryngeal lesion. They found that this subject showed lower lung volume initiations, lower lung volume terminations, greater lung volume excursions, and reduced frequency of inspiratory replenishment when compared to a control subject. Therefore, although changes to respiratory kinematics have been documented in voice problems related to organic lesions, the respiratory characteristics of individuals who present with voice difficulty without organic lesions have been minimally explored. To better understand the contribution of respiratory behavioral changes to voice problems, it is critical to study a system that is not complicated by a laryngeal leak that may result in compensatory versus pre-existing respiratory differences.

Support for respiratory differences in individuals with voice disorders without laryngeal pathology as compared to control subjects was also provided by a pilot study that led to the current dissertation project (Lowell, Hoit, & Barkmeier, 2004). Speech breathing was assessed for three subjects with muscle tension dysphonia (MTD) and three control subjects without voice problems who were matched by age and sex. MTD is typically defined as a voice disorder characterized by increased muscle tension in and around the laryngeal area. Subjects with MTD had no laryngeal structural pathology, reported frequent vocal complaints, and showed signs of laryngeal constriction on videostroboscopy exam. Respiratory patterns were assessed with magnetometry. Three speaking tasks were used: a reading task with lengthy sentences to elicit a range of breathing patterns, a spontaneous “casual” speaking task, and a spontaneous “mock” voice difficulty task. Results showed task-specific differences in respiratory patterns for the subjects with MTD versus the control subjects. Whereas reading and “casual” speaking tasks did not show clear lung volume differences between the two groups, marked differences in lung volume initiation, lung volume termination, and lung volume excursion were seen for the MTD versus control subjects on the “mock” voice difficulty task. For all three lung volume measures, subjects with MTD showed smaller values than their matched control subject. Average lung volume expenditure (%vital capacity/syllable) showed differences between the MTD and control subjects, with smaller values for subjects with MTD on both spontaneous speaking tasks, particularly for the “mock” voice difficulty task, indicating possible constriction at the laryngeal level to make maximal use of a reduced lung volume reserve during speech production.

Laryngeal Function in Voice Disorders

As opposed to the available literature on respiratory behavior in speech, laryngeal function has been assessed in voice-disordered populations without laryngeal pathology, predominantly for subjects with muscle misuse voice disorders or symptoms of vocal fatigue. Differences to laryngeal configuration, both at the level of the vocal folds and the supraglottis, have been demonstrated in these individuals. Videostroboscopic assessment has shown that both individuals who are experiencing vocal fatigue and individuals without voice complaints in whom vocal fatigue is induced show an increased frequency of anterior gap between the vocal folds (Eustace et al., 1996; Stemple et al., 1995). Supraglottic constriction has been consistently documented in individuals with voice disorders related to muscle misuse (Behrman, Dahl, Abramson, & Schutte, 2003; Stager et al., 2001; Stager, Bielamowicz, Regnell, Gupta, & Barkmeier, 2000). Different patterns of laryngeal muscle use, such as increased activation of the thyroarytenoid muscle (Eustace et al., 1996; McCue et al., 2001; Stemple et al., 1995) and increased extrinsic laryngeal muscle tension (Angsuwarangsee & Morrison, 2002; Morrison, 1997) have also been implicated in these voice disorders.

The study of aerodynamics has yielded mixed results for people with voice disorders that are not associated with laryngeal pathology. Several researchers have studied the aerodynamic effects of inducing vocal fatigue in healthy subjects or subjects with voice disorders. Most investigators have found no significant change to airflow when comparing pre- to post-fatigue inducing task performance (Neils & Yairi, 1987; Stemple et al., 1995). However, in a study of 16 teachers with and without symptoms of

vocal fatigue (Kostyk & Rochet, 1998), teachers with vocal fatigue showed changes to airflow on repeat measures across the work week. Kostyk and Rochet (1998) studied laryngeal resistance characteristics of teachers with vocal fatigue in comparison to teachers without voice complaints and conducted multiple measures over one week to obtain comparisons of voice before and after occupation-induced fatigue. Laryngeal resistance differences were not evidenced between groups. However, differential changes to airflow and pressure were demonstrated by each group across time; airflow decreased over the week-long course of measurement in subjects with complaints of vocal fatigue, whereas estimated tracheal pressure showed an increasing trend over the week for control subjects. Kostyk and Rochet (1998) suggested that changes in airflow may have indicated a laryngeal adjustment strategy in the teachers with vocal fatigue, whereas changes in pressure may have indicated a respiratory-based strategy for the control subjects. Predominant use of a laryngeal adjustment strategy rather than a combined respiratory and laryngeal adjustment strategy to maintain laryngeal resistance during speech production would be less efficient and could contribute to symptoms of vocal fatigue due to the increased stress placed on the laryngeal musculature (Kostyk & Rochet, 1998).

In addition to the studies summarized above, other researchers have highlighted differences in laryngeal adduction characteristics for individuals with muscle misuse voice disorders. Hillman, Holmberg, Perkell, Walsh and Vaughan (1989) have suggested a theoretical framework for the etiology of voice disorders related to vocal hyperfunction. Hillman et al. (1989) suggested that two states may result from increased laryngeal

muscle tension. The first state is “adducted hyperfunction”, 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. These factors would all contribute to an increased risk of vocal fold pathology, such as vocal nodules. The second state is “non-adducted hyperfunction”, characterized by increased stiffness and tension of the vocal folds, but incomplete vocal fold adduction. The authors suggested that this second state might contribute to symptoms of vocal fatigue, but would be less likely to result in vocal fold pathology. To test this theoretical framework, Hillman et al. (1989) studied several subgroups of subjects with voice disorders, including 4 subjects with functional dysphonia, but without laryngeal lesions. Aerodynamic measures showed increased transglottal pressure and average glottal flow in 3 of the 4 subjects, which the authors interpreted as support for increased vocal fold stiffness and incomplete vocal fold adduction, characteristics of a non-adducted hyperfunctional voicing pattern. In a follow-up study (Hillman, Holmberg, Perkell, Walsh, & Vaughan, 1990), abnormally high values for transglottal pressure and maximum flow declination rate were found in subjects with vocal fold pathology (vocal nodules and vocal polyps). The authors interpreted these results as support for their construct of adducted hyperfunction which characterizes individuals with laryngeal pathology related to vocal hyperfunction.

Tools to Assess 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. These images are usually obtained during extended vowels rather than during continuous speech production to provide a consistent and steady-state context from which to make ratings. Nasoendoscopy has been used to make subjective ratings of laryngeal closure characteristics during connected speaking; however, this technique has been limited by the reduced illumination of the endoscope resulting in compromised image clarity. Researchers have shown that it is difficult to obtain reliable subjective ratings, and that signs of laryngeal constriction may not differentiate subjects with and without voice disorders (Sama et al., 2001).

Electroglottography as an Assessment Tool for Vocal Fold Adduction

Electroglottography (EGG) is a non-invasive tool that has been used to assess laryngeal adduction characteristics. EGG shows the progression of vocal fold contact during the glottal cycle, and researchers have shown that EGG may be useful in characterizing vocal pathology. Several studies have shown that the contact quotient measure, 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 and Bierhals (1998) showed that EGG contact quotient had a high, positive correlation with measures of vocal fold impact stress in excised canine larynges. Normative values for contact quotient are similar between males and females (Orlikoff, 1991; Orlikoff, Baken, & Kraus, 1997). 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).

The advantage of EGG over endoscopy is that it is non-invasive, can be used for extended periods, and does not interfere with articulation. EGG can therefore be used in continuous speech production. Dr. Adrian Fourcin, who developed the Laryngograph, has discussed the clinical utility of EGG for assessing mode of vocal fold vibration during continuous speaking (Fourcin, 2004). However, to date, the use of EGG in continuous speaking has been limited to frequency tracking (Pederson, Moller, Krabbe, & Bennett, 1986; Pederson, Moller, Krabbe, Bennett, & Svenstrup, 1990) or assessment of isolated consonants within a stimuli set of nonsense syllables (Hong & Kim, 1997). Application of EGG to continuous speaking in individuals with voice disorders might reveal more regarding differential patterns of vocal fold adduction than EGG during extended vowels. However, there are several limitations to EGG, including procedural concerns of electrode placement and skin contact for obtaining an optimal signal, effects of laryngeal movement on the EGG waveform, and need for caution in interpreting EGG waveforms (Colton & Conture, 1990). Many of these limitations can be addressed with appropriate filtering techniques. EGG measures such as contact quotient and contact index are affected by SPL, whereas its relationship to F_0 is less clear and may vary from women to men (Baken & Orlikoff, 2000; Murty, Carding, Kelly, & Lancaster, 1990).

Summary of Physiologic Characteristics of People with Voice Disorders

To summarize, speech breathing behavior has been implicated in the onset and progression of many voice disorders, and differences in speech breathing for individuals with voice disorders with laryngeal pathology compared to normal controls have been demonstrated (Sapienza & Stathopoulos, 1994; Schaeffer et al., 2002). Whereas respiratory behavior has been minimally studied in individuals with voice disorders but without laryngeal pathology, some data on laryngeal behavior in these individuals is available in the literature. Subjects with muscle misuse voice disorders and symptoms of vocal fatigue have shown differences in laryngeal configuration, vocal fold adduction patterns, and aerodynamic characteristics.

Respiratory-Laryngeal Interaction in Speech Production

Given the respiratory and laryngeal findings summarized above, and the functional and biologic coupling of these two subsystems, understanding the functional relationship between these two subsystems is critical to research in voice disorders. Several investigators have demonstrated the interactive nature of these two subsystems in individuals without voice problems or other disorders (Hoit, Solomon, & Hixon, 1993; Iwarsson, Thomasson, & Sundberg, 1998; Milstein, 1999). By manipulating the lung volume levels at which subjects produced speech, changes to laryngeal configuration, both at the level of the vocal folds and the supraglottis, could be observed. Hoit, Solomon and Hixon (1993) found that voice onset time (VOT) was related to lung volume level, with longer VOT associated with high lung volumes and shorter VOT associated with low lung volumes. The authors suggested that the increased VOT at high

lung volumes may be attributed to a downward pull of the trachea due to its mechanical link to the diaphragm, generating an abductory force on the vocal folds. At low lung volumes, the shorter VOT may reflect a behavioral strategy to conserve air due to the depleted lung volume levels that the subjects were speaking with.

Other investigators have also found that lung volume levels are associated with varied laryngeal configuration and aerodynamics during speech production. Iwarsson, Thomasson and Sundberg (1998) and Milstein (1999) have investigated the relation between lung volume and laryngeal configuration and aerodynamics. Higher lung volumes were associated with a more open laryngeal configuration, increased tracheal pressure, increased airflow, more abducted vocal fold configuration, and lower closed quotient values on EGG. Lower lung volumes were associated with greater closed quotients, increased degree of vocal fold approximation as judged by raters, decreased airflow, and a more elevated vertical position of the larynx.

Milstein and Watson (2004) found that lung volume initiation level may affect voice quality during speech production. These researchers manipulated the lung volume level at which speech was produced in normal subjects, and had listeners rate the voice quality of the resulting speech productions. Phrases produced at lower lung volumes were judged as more deviant than those produced at typical or high lung volume levels. Voice quality during speech initiated at a lower lung volume was judged as pressed, effortful, and strained.

Watson and Ciccia (2003) investigated the relation of lung volume initiation to selected acoustic measures. When speech was produced at increased lung volume

initiation levels, acoustic measures such as SPL and average F_0 increased. The authors also found that a plot of the first and second formant frequencies for each of the English language vowels (i.e., vowel space) was more compressed at low lung volume initiation levels in comparison to high or typical initiation levels. The authors interpreted this change to the vowel space as indicative of interactions between lung volume levels and the articulatory subsystem. As a whole, these studies support the notion that lung volume affects vocal fold adduction, voice quality, and the speech articulators. Thus, continued simultaneous study of the respiratory and laryngeal systems may offer further information regarding the physiologic differences between people with and without voice problems.

Although simultaneous assessment of respiratory and laryngeal function is lacking in subjects with voice disorders, several researchers have investigated these subsystems simultaneously in normal subjects under conditions of varied intensity or loudness levels. Stathopoulos and Sapienza (1993) simultaneously measured respiratory kinematics with magnetometry and laryngeal function with aerodynamic measures. The authors found that subjects varied in the strategies that they employed for increasing voice intensity, with three different patterns demonstrated. In the first pattern, subjects altered both laryngeal configuration and respiratory function as they increased loudness level. That is, subjects demonstrated increased laryngeal resistance, a decrease in open quotient, faster vocal fold closing time, and an increase in lung volume initiation and lung volume excursion. This pattern was characteristic of the group mean values, and suggested corresponding increases in both respiratory and laryngeal contribution to

increase intensity. The second pattern showed predominant use of the respiratory system for increasing intensity, with atypical laryngeal changes. In these subjects, lung volume initiation and lung volume excursion increased as with the other subjects, but open quotient values increased rather than decreased. The third pattern was characterized by subjects who showed predominant use of the laryngeal system for intensity control, with atypical respiratory changes. These subjects showed typical laryngeal patterns, with decreased open quotient, faster vocal fold closure, and increased laryngeal resistance, but decreases to lung volume initiation and lung volume excursion. Thus, in these subjects the respiratory system did not appear to contribute to the same degree in achieving the necessary tracheal pressure increase for increased intensity. All subjects showed increased tracheal pressure (estimated from oral pressure) when producing increased voice intensity.

Finnegan, Luschei and Hoffman (2000) also simultaneously measured respiratory and laryngeal changes associated with increasing voice intensity. In contrast to the results of Stathopoulos and Sapienza (1993), who found that the majority of their subjects produced adjustments to the laryngeal and respiratory system of comparable degree, Finnegan and colleagues concluded that their subjects primarily used respiratory versus laryngeal control strategies in the control of voice intensity (Finnegan, Luschei, & Hoffman, 2000). Discrepancies between these results and the Stathopoulos and Sapienza (1993) study might be due in part to the much smaller subject sample size used by Finnegan et al. (2000) ($N = 6$ versus $N = 20$) as well as substantial methodology differences. Stathopoulos and Sapienza (1993) estimated tracheal pressure and laryngeal

resistance through the use of pressure transducers and a pneumotachograph, with methods outlined by Smitheran and Hixon (1981). In contrast, Finnegan et al. (2000) used tracheal puncture to directly measure tracheal pressure and calculate laryngeal resistance. These authors then derived a measure of alveolar pressure which was argued to reflect respiratory drive without the influence of laryngeal activity. Non-invasive versus invasive techniques could therefore have contributed to the differing results of these studies. However, it appears that different subjects may rely on the respiratory or laryngeal subsystem to varying degrees when increasing their loudness level.

Huber, Chandrasekaran, and Wolstencroft (2004) have shown that subjects may employ different respiratory mechanisms to increase loudness level as a function of the type of loudness cue presented. This study assessed differences in respiratory mechanisms only, versus assessing respiratory and laryngeal mechanisms simultaneously, but adds to the body of literature demonstrating that subjects may employ different kinds of strategies when increasing loudness level. When asked to produce speech at 10 dB above their comfortable loudness level (monitored by subjects on a sound level meter), subjects primarily relied on increased lung volume initiation levels. When asked to produce speech at twice their comfortable loudness level, subjects seemed to rely on increased expiratory (abdominal) muscle pressure rather than changes to lung volume initiation, as evidenced by significantly lower abdomen volume initiations and terminations as compared to a comfortable loudness task. Finally, in a background noise condition, there was a non-significant trend toward increased abdominal volume initiations and terminations, with no significant increase in lung volume initiations and

terminations. Therefore, depending on the type of cue provided, subjects showed variable reliance on mechanisms that capitalized more on expiratory recoil forces (by initiating speech at high lung volume levels) or strategies that involved greater reliance on expiratory muscle pressure (demonstrated by changes to abdominal volumes).

Overall Summary

In summary, teachers represent a significant percentage of the U.S. workforce and represent a large proportion of the clinical caseload. There is a paucity of research on the physiologic characteristics of the respiratory and laryngeal subsystems of teachers with voice problems that are not associated with laryngeal pathology, and this knowledge is critical to the effective treatment of this population. A variety of symptoms are reported in people with voice disorders not associated with laryngeal pathology, but a perceived increase in speaking effort is a core characteristic which is consistently reported by these individuals. Speaking effort can be reliably judged by subjects and is positively related to many variables that could contribute to physiologic differences in the respiratory and laryngeal subsystems. The physiologic differences underlying this increase in effort are not well understood. Changes to respiratory behavior are often assumed but generally not objectively tested in those with voice disorders lacking laryngeal pathology. Respiratory behavior has been shown to influence laryngeal behavior in normal subjects. Therefore, studying respiratory and laryngeal behavior simultaneously in individuals with voice disorders characterized by complaint of increased speaking effort, without laryngeal structural pathology, is critical for understanding more about the physiologic differences in these individuals.

Study Purpose and Hypotheses

The purpose of this study was to determine if respiratory and laryngeal characteristics during spontaneous speech production were different for teachers with voice disorders in the absence of laryngeal pathology as compared to teachers without voice problems. Specific hypotheses were as follows: 1) Subjects with a voice disorder would show decreased mean values for lung volume (LV) initiation, decreased LV termination, decreased LV excursion, and decreased LV expenditure per syllable relative to control subjects 2) Subjects with a voice disorder would show differences in vocal fold approximation as measured by contact quotient and contact index relative to control subjects 3) Group differences in respiratory kinematics and laryngeal constriction between groups would be most pronounced for mock teaching tasks versus conversational speaking task 4) Subjects with a voice disorder would rely more on laryngeal versus respiratory-based strategies for increasing loudness level, as demonstrated by less change to lung volume initiation levels and greater change to vocal fold approximation as measured by contact quotient when comparing the normal to increased loudness tasks for each group.

METHOD

Subjects

Eighteen teachers, nine with voice problems (voice-disordered group) and nine without (control group), served as subjects. The voice-disordered group included two men and seven women, ranging in age from 31 to 56 years. The control group also included two men and seven women who ranged in age from 22 to 53 years. Kindergarten through 12th grade and university level teachers were included in this study. Table 1 summarizes subject sex, 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.

Table 1. Teacher characteristics for subjects with voice disorders (VDis) and control (Con) subjects. Elementary school=ES, Middle school =MS, High school=HS.

Subject	Sex	Age	Level of Teaching	Class size	% Talking Time When Teaching	# 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

Permission for research and recruitment was obtained from four local school districts and the Institutional Review Board (IRB) at the University of Arizona. Subjects signed consent forms approved by the University IRB, and were paid for their participation. In addition, subjects with voice problems were offered free voice therapy services at the completion of the study; eight subjects participated in treatment. Subjects were recruited from the Tucson, AZ area through distribution of flyers (K-12 schools) and an email recruitment script (University of Arizona).

Subject selection criteria were chosen due to their potential influence on respiratory or laryngeal measures in this study, and to assure appropriate differentiation between the voice-disordered versus non-voice disordered groups. Characteristics of subjects are summarized below based on those that pertained to all subjects, those that pertained to subjects with voice disorders only, and those that pertained to control subjects only.

General Subject Characteristics

All subjects reported good general health with no history of neurologic, cardiovascular, or pulmonary disease. Subjects also denied a history of vocal fold pathology, laryngeal trauma or surgery, and were non-smokers for at least 5 years prior to their participation. In addition, participants denied symptoms of cold or allergies on the day of testing. Based on their reported weight and height, subjects were required to have a body mass index (BMI) below the obese range (BMI=30 or greater). The BMIs for participants in this study ranged from 18 to 28, inclusively. Subjects reported no history of previous voice therapy, or professional singing or voice training. All participants reported English as their primary language.

All subjects demonstrated adequate hearing skills as determined by passing a hearing screening bilaterally at 40 dB HL at 1000, 2000, and 4000 Hz. Subjects showed no evidence of laryngeal pathology as determined by videostroboscopic evaluation and review of videostroboscopy recordings by an otolaryngologist. Speech (including articulation, intelligibility and fluency) and language skills were normal for all participants 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 subjects' group designation. Judgments were based on recordings of six standard sentences read aloud and two spontaneous speech samples for each subject. See Appendix A for the rationale underlying each of these criteria.

Subject Characteristics of the Voice-Disordered Group

Subjects in the voice-disordered group had to meet several additional criteria. They reported current problems with their voice or vocal mechanism, including vocal symptoms that related to the general symptom category of effort/work to speak or weak/tired voice. Vocal symptoms were reported to occur frequently, defined as once or more weekly. Onset of these symptoms was required to occur 3 or more months prior to testing, with actual onset ranging from 1 to 20 years; 5 of the 9 subjects with voice disorders reported an onset ≥ 5 years prior to testing. See Appendix B for the rationale for these criteria.

Subjects with voice disorders reported an increase in speaking effort during teaching. Speaking effort during teaching was measured on a 100 millimeter (mm) visual analog scale (VAS) bounded by the descriptors of “no effort” (representing 0 mm) and “extreme effort” (representing 100 mm). Increased speaking effort during teaching was indicated when subjects reported a 15 mm or greater difference between their comfortable level of effort (CL) and their actual level of effort (AL) during teaching. The validity of this difference value was determined from a pilot survey, described in the Procedures section. The average CL – AL difference for the subjects with voice disorders in this study was 33.61 mm, with a range of 23.5 to 49 mm.

Table 2 summarizes voice characteristics for the voice-disordered group. The characteristics include the duration of voice problems, CL – AL VAS speaking effort rating differences, average Fo during a conversational sample, Fo range in a pitch glide, average SPL (obtained using a calibrated sound level meter) during a conversational speaking task, noise-to-harmonics ratios (N:H) during sustained phonation of /a/, and Voice Activity Participation Profile (VAPP) scores (i.e., subject perception of the impact of their voice problems) (Ma & Yiu, 2001). Higher scores on the VAPP are indicative of greater negative impact of a voice problem.

Table 2. Voice characteristics for the teachers in the voice-disordered group. Voice-disordered=VDis.

Subject	Years Post Onset of Voice Problems	Effort Rating Difference (mm)	Average Fo (Hz)	Fo Range (Hz)	Average SPL (dB)	N:H Ratio (dB)	VAPP Score (cm)
VDis1	10	23.5	109.2	403	55.6	0.16	9.65
VDis2	>20	28	153.9	604.7	58.8	0.15	51.5
VDis3	1	41	194.8	936.8	55.1	0.13	61.5
VDis4	8 to 10	36	175.9	839.9	64.9	0.12	13.15
VDis5	8	30	176.1	506.4	52.1	0.1	142.45
VDis6	8	49	161.2	419.7	64.7	0.13	13.45
VDis7	4 to 5	25.5	156.3	1157	59.3	0.12	29.6
VDis8	3 to 4	26	172.9	426.4	51.7	0.13	32.1
VDis9	2	43.5	89.7	834.2	59.8	0.14	46.3

Subject Characteristics of the Control Group

Subjects in the control group (without voice problems) also met additional criteria. Subjects who qualified for the control group reported no problems with the voice or vocal mechanism while teaching, and indicated minimal or no VAS CL – AL speaking effort score difference (i.e., less than 15 mm difference). The mean VAS CL – AL speaking effort difference for control subjects was -2.39 mm, with a range of -35 to 13.5 mm. In other words, the mean rating for AL of speaking effort was less than that for CL of speaking effort. Control subjects were unanimously judged to have normal voice characteristics by two certified speech-language pathologists with expertise in voice and voice disorders who were blind to subjects' group designation. Judgments were determined from ratings of six sentences and two spontaneous speech sample recordings (one recorded during screening procedures and one recorded during experimental procedures) for each subject. See Appendix C for the rationale for these criteria. Table 3 summarizes teacher characteristics for the control group. These characteristics include CL – AL VAS speaking effort rating differences, average F_0 during a conversational sample, F_0 range in a pitch glide, average SPL (obtained using a calibrated sound level meter) during a conversational speaking task, N:H ratios during sustained phonation of /a/, and VAPP scores.

Table 3. Voice characteristics for the teachers in the control group. Control=Con.

Subject	Effort Rating Difference (mm)	Average Fo (Hz)	Fo Range (Hz)	Average SPL (dB)	N:H Ratio (dB)	VAPP Score (cm)
Con1	-7.5	220.6	465.5	59	0.16	1.45
Con2	0	140.6	697.5	61.4	0.12	0.02
Con3	13.5	180.9	754.9	60	0.13	1.4
Con4	5	222.4	704.2	68.6	0.11	3.35
Con5	-35	186.1	401.5	62.4	0.14	0.06
Con6	4.5	101.6	581.66	58	0.14	2.9
Con7	-2	103.2	729.2	54.1	0.21	1.25
Con8	0	159.2	572.7	67.4	0.12	0.25
Con9	0	160.8	793	64.2	0.14	1.15

Equipment

Respiratory Equipment

Respiratory kinematics were assessed by measurement of the 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 applied to speech breathing assessment by Hixon, Goldman and Mead (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, Ellis, & Adams, 1994). Linearized magnetometers (GMG Scientific Inc., 1980) were used to assess anterior-posterior changes to the rib cage and abdomen for kinematic respiratory measures. These incorporate two generator-sensor coil pairs, one for the rib cage and one for the abdomen. One member of the rib cage coil pair was

attached to the rib cage at the level of the sternum, with the other member of the rib cage pair attached posteriorly at the same level. One member of the abdomen coil pair was attached to the abdomen at the level just above the umbilicus, with the other member of the abdomen pair attached posteriorly at the same level. An oscilloscope was used to monitor the respiratory signals on an X - Y display. A 9.0-liter respirometer (Warren E. Collins Inc.) was used to calibrate to absolute lung volume quantities. Calibration was monitored every 2 weeks during testing with a 3.0-liter calibration syringe (CDX Corporation).

Electroglottograph Equipment

A Kay Elemetrics model 4338 electroglottograph (Laryngograph) (Kay Elemetrics Corp., 1995a) was used to assess changes in vocal fold contact area over time during phonation. The Laryngograph hardware unit included components that acted to high-pass filter the signal, resulting in a display of what is called the Lx waveform. The term “Lx waveform” is used to describe the high-pass filtered version of the EGG signal, in contrast to the “Gx waveform” which is used to describe the raw EGG signal (Baken & Orlikoff, 2000). The only output generated by the Laryngograph is the Lx signal; this is the standard output signal of most electroglottograph hardware units, and the signal that has been used in most studies reporting on EGG (Baken & Orlikoff, 2000; Motta et al., 1990; Orlikoff, 1991; Orlikoff et al., 1997; Peterson et al., 1994). The audio signal was recorded with an omnidirectional, electret condenser lapel microphone (Radio Shack, model 33-3013).

Acoustic and Physiologic Recording Equipment

All four data channels were recorded on two data acquisition systems: an eight channel Digital Audio Tape (DAT) recorder, SONY model # PC208Ax, and a computer-based multi-channel acquisition system, DATAQ, DI-720 Series (DATAQ Instruments, 2000). Respiratory signals were analyzed from the DAT recordings and electroglottography (EGG) signals were analyzed from the DATAQ recordings. A Panasonic VHS camcorder (model AG-195), mounted on a tripod, was used to videotape subjects throughout the respiratory and EGG procedures. These videotapes were used for speech transcription and to note any movements that might be associated with signal artifacts.

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 SPL during all speaking tasks (Larson Davis Inc.). The microphone was mounted on a microphone stand at the approximate height of the subject's lips. The SLM was calibrated weekly during testing using a pure-tone generator (114 dB SPL) with procedures outlined in the operation manual.

Screening Equipment

A 70-degree rigid oral endoscope and stroboscopy equipment, model RLS 9100 (Kay Elemetrics Corp., 1995b) was used to obtain laryngeal images during voicing tasks and rest breathing. The Multidimensional Voice Program, or MDVP, model 4305 (Kay Elemetrics Corp., 1993a) and VisiPitch II, or VP II (Kay Elemetrics Corp., 1993b), were used for acoustic recordings and analysis. The MDVP and VP II are two of several

software packages contained within the CSL hardware/software unit. Recordings were made with a table-mounted, dynamic microphone. Hearing was screened using a Beltone audiometer (model 119).

Figure 1 demonstrates the general equipment set-up used during recording. The figure displays functional connections only; not all channels on multi-channel equipment are represented. The magnetometer signal generator and receiver box, the EGG signal generator and receiver box (EGG), the DAT, the audio amplifier (Audio Amp.), the oscilloscope (OSC), the videocamcorder, the SLM and attached microphone (Mic), the DATAQ analog-to-digital converter box (DATAQ converter) and the DATAQ signal acquisition software used on a laptop (DATAQ recorder) are all displayed.

Magnetometer coil connectors and EGG electrodes are displayed as attached to a subject. A lapel microphone is also displayed as clipped to the subject and connected to the audio amplifier.

Figure 1. Equipment set up and connection for experimental recordings from subjects.

Procedures

Physiologic and perceptual testing involved an initial battery of screening tasks followed by all experimental respiratory and laryngeal assessment. Testing was conducted in one visit over approximately a 2 hour and 45-minute period. The battery of initial screening tasks occupied the first 75 minutes of testing, and the respiratory and laryngeal physiologic measurement occupied the second 90 minutes of testing time. One subject was scheduled for the experimental assessment session one week after the initial screening session due to her schedule requirements.

Screening Procedures

An initial telephone screening was conducted prior to all testing to determine general eligibility criteria. Those subjects who passed the telephone screening were scheduled for the experiment.

Questionnaires

Several questionnaires were administered by the experimenter at the beginning of the screening task battery. All questionnaires were used to determine initial eligibility or to obtain descriptive information regarding the subjects in each group. The questionnaires used in this study included:

- 1) *A vocal complaint index.* This index was administered to each subject by the investigator to determine whether subjects met the criteria for the voice-disordered or control group (see Appendix D). The vocal complaint index was developed specifically for this study. Open-ended questions were included in this index so as to avoid biased responses to closed-set questions about voice problems. This index also included a visual analog scale (VAS) of speaking effort. This scale displayed a 100-mm line bounded on the left by the descriptor “no effort”, representing 0 mm, and bounded on the right by the descriptor “extreme effort”, representing 100 mm. The VAS was used to determine the difference in what subjects perceived as a comfortable level of speaking effort during teaching compared to actual effort levels during teaching. A minimal difference score of 15 mm was used to differentiate participation in the voice-disordered and control groups. Subjects were instructed to indicate with a red X

on the VAS how much effort, on average, they felt when teaching a typical class, and then to mark with a green X what a comfortable level of effort would be when teaching a typical class. The validity of this difference value was determined from a pilot survey distributed to approximately 100 University of Arizona instructors across three different departments. Based on results from the completed surveys (N = 41), a mean VAS CL - AL score difference of 14.75 mm occurred for instructors replying “yes” to sometimes having voice problems when teaching. Higher score differences occurred for subjects reporting frequent voice problems (mean of 21.71 mm). In contrast, the mean score for those denying voice problems was 1.17 mm. Therefore, a difference score of 15 mm was chosen as a boundary for differentiating subjects with voice disorders from control subjects. See Appendix E for the pilot survey form and specific findings.

- 2) *A vocal use questionnaire.* This questionnaire was completed by subjects to assess medical history and vocal habits, and was adapted from a previously developed questionnaire (McCue et al., 2001). See Appendix F for the vocal use questionnaire.
- 3) *The Voice Activity Participation Profile (VAPP).* The VAPP was completed by subjects to determine their perception of the impact of voice difficulties on various areas of their life (Ma & Yiu, 2001). Good validity and reliability have been demonstrated with this measure, and significant group differences between people with and without voice disorders were found (Ma & Yiu, 2001). See Appendix G for the VAPP questionnaire.

Hearing Screening

A pure tone hearing screening was administered. Passing status was defined as 40 dB HL at 1000, 2000 and 4000 Hz in at least one ear (Morrell, Gordon-Salant, Pearson, Brant, & Fozard, 1996).

Voice Screening

Each subject's voice was recorded during different voice and speech tasks performed in a sound-proof booth using the Kay Elemetrics CSL MDVP as well as VisiPitch II. Recordings were obtained using a table mounted dynamic microphone positioned 5 inches in front of the speaker's lips. Subjects performed each of four tasks that included:

- a) sustained phonation of /a/ for approximately 5 seconds,
- b) one pitch glide from low to high pitch using the vowel /a/,
- c) reading six sentences aloud, and
- d) speaking continuously for 15 seconds to provide a spontaneous speaking sample.

Acoustic recordings were performed using a sampling rate of 50 kHz. The voice screening recordings were used primarily for the purposes of obtaining perceptual judgments of voice quality to determine whether subjects met inclusion criteria. However, acoustic measures were also performed for subject descriptive purposes. The acoustic measures performed consisted of:

- a) Average Fo measured from the spontaneous speaking sample,
- b) Fo range measured from the pitch glide task, and
- c) N:H ratios measured from the sustained /a/.

The average Fo and Fo range measures were obtained from the entire recorded sample.

N:H ratios were obtained from the middle 3 seconds of the recorded vowel.

Laryngeal Screening

Videostroboscopy using a 70-degree rigid oral scope was performed to rule out laryngeal pathology. During this exam, the subject was seated comfortably while leaning slightly forward. A stethoscope microphone was secured over the thyroid cartilage with a Velcro collar. The subject was asked to sustain /a/ prior to performing stroboscopic recordings to confirm adequate tracking of Fo by the throat microphone so that the strobe light properly illuminated the vocal folds during voicing. During this exam, the subject's tongue was held by the examiner and the scope was inserted midway into the oral cavity. At this point, the subject was asked to perform sustained phonation of /i/ at comfortable pitch until the vocal folds were visualized. Next, the subject was asked to perform a pitch glide from low to high pitch and vice versa, and to breathe quietly while viewing the vocal folds. Videostroboscopy recordings were subsequently reviewed by an otolaryngologist to confirm absence of laryngeal pathology.

Experimental Procedures

Respiratory and laryngeal characteristics were assessed in the experimental portion of the study. All experimental procedures were conducted with subjects in a seated position.

Respiratory Calibration Maneuvers

Maneuvers similar to those described by Hixon, Goldman and Mead (Hixon et al., 1973) were used for calibrating respiratory signals. Calibration maneuvers included

assessment of vital capacity (VC) to measure the subject's largest manipulable range of lung volume and to normalize lung volume across subjects (Hoit & Hixon, 1987). In the VC maneuver, subjects inspired maximally from resting expiratory level (REL) and then expired fully. During this procedure, the subject was coupled to the spirometer by a respiratory mask secured over their mouth while wearing a nose clip to prevent air leakage through the nasal passageways. The VC maneuver was performed three times, and the maneuver that was performed most accurately and represented the largest volume was selected for analysis.

Calibration of voltage range to absolute lung volumes was also performed at lung volume levels of 1 liter above and below each subject's measured REL. During this maneuver, subjects were instructed to slowly inspire or expire from REL to the target volume as monitored on the spirometer. After reaching the target level, subjects were instructed to maintain that lung volume for several seconds. This was done to calibrate for lung volume measures within the expected lung volume ranges for speech.

Isovolume maneuvers were performed 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. During this maneuver, subjects were instructed to hold their breath at REL (holding lung volume constant) and slowly displace the volume between their abdomen and rib cage. At least three isovolume maneuvers were recorded throughout the entire session. The maneuver that represented the straightest line on the X – Y oscilloscope display, optimum amount of displacement, and the most consistent slope was used for analysis.

Electroglottography Procedures

Two electrodes were placed over each thyroid cartilage lamina and secured with a Velcro collar. Prior to electrode placement the skin was cleaned with alcohol to achieve optimal contact. EGG electrodes were secured in the position that resulted in the greatest amplitude of signal. EGG electrodes were positioned and secured upon completion of the respiratory calibration maneuvers. EGG recordings were obtained simultaneously with respiratory signal recordings during all speaking tasks.

Speaking Tasks

Subjects were given specific instructions for producing three different speaking tasks and a subsequent structured speaking sample (see below). Speaking tasks included a conversational speaking task, a mock teaching task, and a mock teaching task at increased loudness level, and a conversational speaking task. Mock teaching tasks were included based on findings from the pilot study (Lowell et al., 2004), which showed the greatest group differences on speaking tasks designed to elicit voice difficulty. The mock teaching tasks provided a simulated speaking context in which voice problems were reported to occur. The mock teaching sample at an increased loudness level was performed to help determine whether subjects in each group used different strategies for achieving increased loudness. A conversational speaking task was included as a contrast to the job-related speaking tasks, and to allow for comparisons to other respiratory studies that have included a similar task (Hoit & Hixon, 1987; Hoit et al., 1989; Winkworth, Davis, Adams, & Ellis, 1995).

The following instructions were provided for the three spontaneous speaking tasks:

- 1) Conversational speaking task (CONV) - a spontaneous “casual” sample: The subject was asked to describe a favorite vacation while speaking at a comfortable pitch and loudness level as if talking to a friend. The subject was asked to provide details regarding the trip to assure a 3 minute speaking sample. One research assistant (RA) served as a listening partner to make the situation more natural, sitting 5 feet away from the subject. Another RA sat at a 10-foot distance from the subject and monitored and recorded (via writing) SPL values from the SLM at 30-second intervals throughout the speaking task.
- 2) Mock task (MOCK) - a spontaneous “mock” teaching sample: The subject was instructed to speak as if teaching to a small graduate class of approximately 20 students, and to target a regular pitch and loudness level that they would use when teaching a class of this size. An RA sat at a 10-foot distance from the subject, and acted as a student in the class, taking notes throughout the mock lesson. The subject was asked to speak to that RA as they would to a student in the class. A second RA sat at a 10-foot distance from the subject and monitored and recorded SPL as described earlier. Prior to recording this speaking task, the subject performed a 45-second practice, in which SPL was recorded three times, every 15 seconds, to derive a target dB level for the subsequent mock loud task (see below).

- 3) Mock Loud task (ML) - a spontaneous “mock, loud” teaching sample: The subject was instructed to speak as if teaching to a large class of 100 students or more, projecting to an audience 20 feet or further away. An RA sat at a 20-foot distance from the subject and acted as a student in the class, taking notes throughout the lesson. The subject was asked to speak and project to that RA as they would to a student in the class. A second RA sat at a 10-foot distance from the subject, and monitored and recorded SPL as described earlier. The subject was told to target an increased loudness level. A target range was calculated for each subject based on the mock practice obtained earlier; the target was 10 dB greater than the mean SPL recorded during the mock practice sample. The subjects were informed that loudness level would be monitored, and if it fell below a certain target level, the RA provided cues to the subject as needed to increase loudness level (Kelchner et al., 2003; Stemple et al., 1995). Prior to recording the actual speaking task, a 45-second mock loud practice was performed in which the subject was cued regarding loudness level, to familiarize the subject with the target loudness level. The RA therefore provided cues as needed to the subject to increase loudness level if SPL dropped below the target. This task was designed to observe respiratory and laryngeal behavior that might be involved in a functional activity requiring increased loudness. Initial pilot work indicated that having subjects increase their loudness level in the ML task by 10 dB relative to their individual SPL levels, rather than instructing subjects to increase to a level that was standard for all speakers, resulted in more natural and accurate performance.

To better simulate the teaching environment, subjects were told that they were being videotaped so that a group of students could later rate them on factors such as information organization, content, clarity, and interest level of the material. This deception component was included in an attempt to approximate some of the realistic situational stressors that occur during teaching. Subjects were debriefed at the end of the experiment, and were re-consented with a second Subject Informed Consent that described the actual purpose of the video recordings, in accordance with IRB specifications.

For all speaking tasks, subjects were instructed to start speaking when the experimenter cued them to begin. Subjects then continued speaking for 3 minutes until the experimenter cued them to stop. Subjects were instructed to minimize body movements in order to avoid signal artifacts. The microphone that was coupled to the SLM was placed at a 45 degree angle and 18 inches from the speaker's mouth (weighting scale A) during all speaking tasks. Speaking tasks were video-recorded to determine whether any extraneous movement resulted in respiratory signal artifacts.

The order of the spontaneous speaking tasks was counterbalanced across subjects. Prior to recording any of the speaking tasks (regardless of order), the 45-second MOCK practice described above was conducted to obtain a target SPL level for the ML task. Prior to the ML task, the 45-second ML practice was conducted.

After completion of all spontaneous speaking tasks, an additional structured speaking sample was collected to serve as a comparison to the spontaneous speaking tasks. The application of EGG to continuous speech is a novel method. Thus, a more

standard voicing task for measuring EGG was also included for comparison. The structured speech sample included a prolonged /a/ vowel (at comfortable pitch and loudness, 8 seconds), and a prolonged maximum duration /a/ vowel. For the latter task, subjects were cued to start with a maximal inspiration and continue phonating until they ran out of breath. This maximum phonation time (MPT) vowel was included to determine whether EGG measures changed over time as lung volume progressively decreased during a controlled utterance. Finally, subjects were asked to read a written passage aloud to elicit an approximate one-minute sample. This passage contained a predominantly voiced phoneme paragraph (DeFeo, 2005) that was repeated to increase its length. See Appendix H for the reading paragraph used. For all structured speaking tasks, subjects were instructed to speak at a comfortable pitch and loudness level as if talking to a friend.

Perceived Speaking Effort Procedures

After subjects completed each spontaneous speaking task, they were asked to rate the amount of speaking effort they experienced with that task on a 100 mm VAS. This was the same VAS as used in the vocal complaint index described earlier. See Appendix I for the speaking effort rating sheet. The experimenter gave instructions and administered each of these ratings, with the subject marking the VAS lines as appropriate. Previous markings were available for view to help subjects make comparative judgments of effort, and markings were made on the same VAS (in different colors) for the three speaking tasks.

Symptoms Checklist Procedures

To gather additional information on specific symptoms of vocal fatigue that subjects may experience during teaching, a checklist of symptoms was given to each subject upon completion of the experiment, in which he or she indicated the symptoms experienced during teaching and the frequency of those symptoms (see Appendix J). 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: 1) pain/discomfort, 2) tightness/tension, 3) work/effort/weakness/fatigue, 4) mental fatigue, and 5) auditory changes to voice. This checklist was given after the study was completed to avoid biasing subjects during open-ended questions posed to subjects in the experiment. An ordinal scale was used to compute scores on this measure, with a score of 0 representing “never/rarely”, 1 representing “sometimes”, 2 representing “often” and 3 representing “always”.

Measures and Data Analysis

Respiratory Measures and Analysis

Resting expiratory level (REL) for each subject was determined from the VC maneuver. 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:

- 1) lung volume initiation (LVI, in %VC)

- 2) lung volume termination (LVT, in %VC)
- 3) lung volume excursion (LVE, in %VC)
- 4) lung volume expenditure per syllable (in %VC/syllable)

All speaking tasks were transcribed at the word level from the videotaped recordings. The middle 2 minutes of each speaking task were then analyzed. Utterances with one or two syllables were excluded from the analysis, as atypical lung volume patterns and lung volume expenditure were often seen with these utterances that would skew average measures. This resulted in 112 out of 1693, or 6.6%, discarded breath groups for all subjects across the three spontaneous speaking tasks, with 5.9% in the voice disordered group and 7.3% in the control group. LVI and LVT were calculated from each utterance, measured at the start and end of each breath group so as to compare to available normative data (Hoit & Hixon, 1987; Hoit et al., 1989). For the structured speaking tasks, the full reading sample was analyzed (representing approximately 1 minute of speech), with any one to two syllable breath groups deleted. For the extended /a/ and MPT /a/, LVT was assessed at 7 seconds post onset of vocalization for the /a/ and 3 seconds prior to the end of the MPT utterance. When a subject produced the MPT /a/ for longer than 30 seconds, LVT was assessed at 30 seconds post-onset of vocalization. These procedures were used in order to approximately match the portions of these samples being analyzed for the EGG data.

Respiratory data were analyzed using a custom software function (Watson, 1994) with LabView (3.0.1). Means for each subject, 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.

Electroglottography Signal Processing and Measures

Tracking the contact quotient (CQ) and contact index (CI) over the time course of an EGG signal required the following operations to be applied. The digitized signal was first low-pass filtered (300 tap, FIR) with a cutoff frequency of 1000 Hz. The fundamental frequency (F_0) was estimated from differences between the harmonic frequencies detected in an FFT-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 based on the methods described by Orlikoff (1991). Figure 2 exemplifies the process by which the low frequency variation (a) was subtracted from the EGG signal (b) to obtain the detrended signal (c) which is normalized to a 0.0 to 1.0 range.

Figure 2. Procedures to obtain the detrended EGG signal.

Using procedures delineated by Orlikoff (1991), 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, the following dependent variables were assessed, as exemplified in Figure 3:

1) contact quotient (CQ) =

$$100 * \text{contact phase} / \text{period}$$

2) contact index (CI) =

$$(\text{contact closing phase} - \text{contact opening phase}) / \text{total contact phase}$$

$$((\text{ccp}) - (\text{cop})) / (\text{ccp} + \text{cop})$$

Figure 3. Derivation of contact quotient (CQ) and contact index (CI) from EGG signal.

Vocal fold contact area=VFCA, contact opening phase=cop, contact closing phase=ccp, contact phase =CP, period = t .

Sensitivity of Electroglottography Measures

To assess whether EGG CQ and CI measures would be sensitive enough to detect changes in vocal fold adduction, a pilot speech sample with presumed maximal change in vocal fold adduction was collected. Two adductory glides were produced on a sustained /a/ vowel, moving from a highly breathy quality to a highly pressed quality. These samples were then analyzed to obtain a contour of the change in CQ and CI over the course of the adductory glide. Substantial changes in CQ and CI values over the course

of the adductory glide were demonstrated on both trials. For CQ, values started at approximately 25% (for breathy quality) and increased to approximately 60% (for pressed quality) over the course of the utterance. For CI, values started at approximately 0.05 (for breathy quality) and decreased to approximately -0.60 (for pressed quality) over the course of the utterance.

Electroglottography (EGG) Data Analysis

To date, no previously published papers were found on the use of EGG for measuring CQ or CI across phonemes in continuous speech. Therefore, analysis procedures were developed through pilot work on EGG signals. The emphasis was on capturing each subject's characteristic EGG pattern. Therefore, variations that occurred at the onset and offset of voicing were mostly excluded, as these portions would increase variability of the signal and make interpretation of mean values difficult. Criteria used for segmenting individual voiced files from the original continuous speech file were developed so that accurate calculations from the MatLab read-in functions were possible.

Analysis of the Overall Signal

For EGG analysis, the same middle 2-minute 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 MatLab function (Story, 2005). WAV files were then hand-analyzed within Praat (Boersma & Weenink, 2005) to isolate all voiced segments into sequential files from the initial, 120-second sample of continuous speech. Three 15-second samples were analyzed from the total 120-second sample for spontaneous speaking tasks: portions 0 to 15 seconds, 60 to 75

seconds, and 105 to 120 seconds. This analysis procedure was determined to adequately represent the entire sample with minimal error. That is, pilot analysis showed mean CQ and CI levels to be within a 0.2 range for a 45-second subset (derived as described above) as compared to means generated from analysis of the entire 120 seconds of EGG data for the speaking task.

Segmenting the Signal Into Individual Voiced Files

Several analysis procedures were followed for obtaining segmented voiced-phoneme files from the initial continuous speech file. Procedures were developed so that segmented files represented the characteristic pattern of vocal fold adduction for each subject, and to assure accurate read-in of these files by MatLab functions.

Simultaneous display of the EGG signal, the acoustic signal, and the narrow band spectrogram were used during analysis. Voiced segments were selected for analysis 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 seconds of analysis time was added to the end of that 15-second analysis segment.

Deriving Measures of CQ and CI

Sequential files were obtained for the voiced segments of each analyzed portion of the continuous speaking tasks, typically 90-100 files per subject per task. These

sequential files were then read by a custom software function (Story, 2005) under MatLab, which also performed the filtering function described above. Means and standard deviations for each subject per task were then calculated with this MatLab function. Individual standard deviations were calculated as an indicator of intra-subject variability for CQ and CI. Group means and mean standard deviations were then calculated and compared.

EGG Analysis for Structured Speaking Tasks

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 subjects. Initial pilot work indicated that phonemic content may affect EGG measures such as CQ. Although it was expected that phonemic content would be balanced across the length of speech analysis that was used for the spontaneous speaking tasks, comparison of a sample in which phonemic content was controlled provided a method to test this assumption. For the paragraph reading task, analysis of approximately 20 seconds of the second repeated paragraph (which fell midway into the reading passage, as shown in Appendix H) was performed. Analysis began at the start of the second paragraph and ended after the phrase “many do not” of that paragraph (see Appendix H), which represented approximately 20 to 25 seconds of speech for most subjects. Therefore, phonemic content for this analysis was the same for all subjects. To assess the interaction of lung volume and EGG measures during continuous speech, an utterance that was produced on one breath group for most subjects 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 speech.

Finally, for analysis of the sustained vowels, procedures were adopted using Orlikoff (1991) guidelines. For the 8-second sustained vowel, the first and last second of the sample was excluded from the /a/, resulting in 6 seconds 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 high 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. To avoid distortion of the EGG signal, analysis was ended 3 seconds prior to the completion of each subjects' MPT voicing, due to the fact that voicing and the EGG signal often became intermittent or irregular in the final portion of the MPT vowel. When a subject produced a MPT /a/ for longer than 30 seconds, analysis was ended at 30 seconds post onset of vocalization. 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 (Story, 2005) 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.

As an additional analysis of change in CQ and CI over time as lung volume decreased, a single utterance was chosen from the paragraph reading. In contrast to the MPT vowel analysis, this analysis represented the change in CQ and CI that occurred during continuous speech, as lung volume progressively decreased. The segmented, voiced files that represented this utterance were analyzed sequentially using another MatLab function (Story, 2005). This represented between 5 and 11 segmented files for each subject (median=8 files). As with the MPT analysis, graphs of CQ and CI as a changing contour across time, along with mean values of CQ and CI for the first and last 5% of the total sentence duration, were generated. The sentence “Every day you drive over the bridge is a grand day” was selected because it represented an utterance that the majority of subjects produced on one breath group. Thirteen subjects initiated and terminated the breath group at the start at end of this sentence. Three subjects initiated the breath group at the start of this sentence but had additional words on the breath group; sequential analysis in this case was terminated at the end of the target sentence. One subject produced the target sentence in the middle of a breath group, sequential analysis in this case was initiated and terminated at the start and end of the target sentence. Finally, one subject initiated the breath group at the start of the target sentence, but ended her breath group early on the word “bridge” of the target sentence; sequential analysis in this case was terminated after “bridge” so that only one breath group was represented.

Assessing EGG Signal Quality

Due to differences in laryngeal prominence and adipose tissue in the neck, EGG signal quality varied across subjects. To characterize the relative differences in signal

quality across subjects, harmonics-to-noise (H:N) ratios were calculated for six segmented files for each subject in each speaking tasks. Two segmented files from each of the three 15-second subsets were chosen for H:N ratios, with files selected that were 0.3 seconds or longer to provide a sufficient amount of signal for analysis. Means of these six H:N ratios were then calculated for each subject, for each of the speaking tasks.

Effort Ratings Analysis

Quantification of effort ratings was made by measuring the number of millimeters on the VAS, with the left boundary representing 0 mm and the right boundary representing 100 mm. Means and standard deviations across groups were then calculated for each spontaneous speaking task.

Inferential Statistical Analysis

Due to the multivariate nature of this study, repeated measure multivariate analysis of variance (MANOVA) was used for statistical analysis of respiratory and laryngeal data to make comparisons across groups and across tasks. A separate MANOVA was used for respiratory and laryngeal data (two MANOVAS total) because theoretical guidelines for the use of MANOVA suggest that only those dependent variables that represent one underlying construct (e.g. respiratory behavior versus laryngeal behavior) should be included in a given MANOVA. An alpha level of .05 was used to define statistical significance. When the omnibus MANOVA was significant, follow-up repeated measure ANOVAs were performed to determine which variables were significant, for between-subject (group) effects, within-subject (task) effects, and task by group interaction effects. When task effects or task by group interaction effects

occurred, follow-up post-hoc tests using Tukey's Honestly Significant Difference (HSD) were implemented to determine the contrasting conditions that were significant. SPSS 13.0 was used for all statistical analyses.

To assess group differences in speaker characteristics, including SPL, speaking rate, effort ratings, symptoms of voice difficulty, and impact of voice difficulty, repeated measure ANOVAs with follow-up posthocs using Tukey's HSD were used. To assess group differences for the vocal symptoms checklist, a Mann-Whitney U test was used due to the ordinal nature of this data. Finally, to assess changes in EGG measures that occurred over the course of an utterance, paired-sample t-tests with a Bonferroni adjustment were used.

Reliability Measures

To assess inter-rater reliability of respiratory measurements, two subjects from each group (representing 21% of the total subjects) were randomly selected and analyzed by a different experimenter than the primary analyzer. This experimenter was trained in all respiratory analysis techniques prior to conducting her reliability assessment. Means across breath groups for the dependent measures of LVI-R, LVT-R, LVE and %VC/syl were calculated for each of the four subjects across the three spontaneous speaking tasks. Pearson product-moment correlation coefficients were then computed for each dependent variable. Mean difference scores and standard error of measurement (SEM) were also assessed for each of the four subjects by comparing mean values assessed by the primary analyzer to those values assessed by the reliability analyzer.

Inter-rater reliability was also assessed for the VAS effort ratings on the three spontaneous speaking tasks and VAS measurements from the VAPP for the same 21% of randomly selected subjects. Pearson product-moment correlation coefficients with mean difference scores and SEM were then computed for these measurements. Because EGG analysis essentially involved developing an algorithm for segmenting the overall file into individual voiced files, and then running those files through an automated analysis program under MatLab, reliability measures were not undertaken for the EGG data.

RESULTS

Reliability

The respiratory variables (LVI-R, LVT-R, LVE, and %VC/syl) showed reliability coefficients ranging from .980 to .998, indicating good inter-rater reliability. Mean difference scores were all less than 1.0 %VC. The three measures that involved calculation of millimeters on a VAS showed reliability coefficients of 1.0, also indicating good inter-rater reliability. Mean difference scores were 0.25 mm or less for the effort ratings, and .06 centimeters (cm) for the VAPP. Table 4 summarizes the correlation coefficients, significance levels (*p*), mean difference scores, and standard error of measurement (SEM) for the four respiratory variables and three VAS measures (AL– TL effort difference on the vocal index, VAPP, and task effort ratings).

Table 4. Reliability coefficients (Pearson r), significance levels (p), mean difference scores, and standard error of measurement (SEM) for respiratory and visual analog scale (VAS) measures (* indicates significant results). Lung volume initiation-reference REL=LVI-R, Lung volume termination-reference REL=LVT-R, lung volume excursion=LVE, percent vital capacity/syllable=%VC/syl.

Variables	Pearson r	p	Mean Difference	SEM
Respiratory measures				
LVI-R	.988	<.001*	0.74 %VC	0.19
LVT-R	.980	<.001*	0.67 %VC	0.15
LVE	.998	<.001*	0.49 %VC	0.09
%VC/syl	.996	<.001*	0.02 %VC/syl	0.01
VAS measures				
Effort Difference	1.00	<.001*	0.13 mm	0.13
VAPP	1.00	<.001*	0.06 cm	0.03
Task Effort	1.00	<.001*	0.25 mm	0.10

Respiratory Measurements

Measures of lung volume initiation (LVI) and lung volume termination (LVT) were referenced to each subject's resting expiratory level (REL), such that REL represented 0%. Appendix K presents individual subject characteristics that are pertinent to respiratory measures, including VC, REL in %VC, height, weight, and BMI for each subject. Group means and individual subject data for respiratory measures across all speaking tasks are presented in Appendix L.

Figure 4 displays mean LVI-R, LVT-R, and lung volume excursion (LVE) for each group across the three spontaneous speaking tasks. The zero line represents REL for all subjects, with all other measures referenced to REL.

Figure 4. LVI-R, LVT-R, and LVE for the voice-disordered (VDis) and control (Con) groups across the three spontaneous speaking tasks. CONV=conversational speaking task, MOCK=mock teaching task, ML=mock loud teaching task.

This figure displays group and task differences. The measure of LVI-R (indicated by the top of each bar) was lower for the voice-disordered group across all tasks, with the control subjects showing mean LVI-R levels that were nearly double that of the voice-disordered group for the MOCK and ML tasks. LVT R values (indicated by the bottom of each bar) were lower for the voice-disordered group across all tasks. It is also evident from this figure that LVE (indicated by the vertical length of the bars) showed minimal differences between groups.

Statistical tests showed that respiratory characteristics during spontaneous speaking tasks were different for the voice-disordered versus control group. An overall repeated measures multivariate analysis of variance (MANOVA) for the four respiratory

dependent variables revealed a significant, omnibus between-subject difference for group ($p=.029$), within subject difference for task ($p=.038$) and a significant interaction between group and task ($p=.041$). Follow-up repeated measure (univariate) ANOVAs were then performed to determine which dependent variables were significantly different. When considered between groups, measures of LVI-R and LVT-R were significantly different for the voice-disordered versus control group. LVE and %VC/syl were not significantly different between groups. Table 5 summarizes the ANOVA findings for each variable, including degrees of freedom (df), F statistic, significance level (p), and power. A power of .80 is generally accepted as an appropriate level in behavioral sciences (Cohen, 1965, 1977; Keppel, 1991).

Table 5. Univariate repeated measure ANOVA results for respiratory measures. Lung volume initiation-reference REL=LVI-R, Lung volume termination-reference REL=LVT-R, lung volume excursion=LVE, percent vital capacity/syllable=%VC/syl.

Variables	df	<i>F</i>	<i>p</i>	Power
Between subjects (group)				
LVI-R	1	9.08	.008*	.81
LVT-R	1	11.86	.003*	.90
LVE	1	.07	.794	.06
%VC/syl	1	1.94	.182	.26
Within subjects (task)				
LVI-R	2	.66	.524	.15
LVT-R	2	3.46	.044*	.61
LVE	2	2.93	.068	.53
%VC/syl	2	7.78	.002*	.93
Interaction (task x group)				
LVI-R	2	4.58	.018*	.74
LVT-R	2	1.44	.252	.29
LVE	2	6.04	.006*	.85
%VC/syl	2	1.72	.196	.33

Follow-up posthoc tests using Tukey's HSD were then performed to assess the significant main effects for task (LVT-R, %VC/syl) and the task by group interaction effects for LVI-R and LVE. For LVT-R, significant within-subject differences were found between the CONV and MOCK tasks ($p=.036$), with LVT-R being significantly lower for the CONV task than for the MOCK task. For %VC/syl, significant within-subject differences were found between the CONV and ML tasks ($p=.001$), with %VC/syl being significantly higher for the ML task than for the CONV task.

Assessment of interaction effects between group and task for LVI-R with Tukey's HSD revealed significant between-group differences for the MOCK ($p=.025$) and ML

($p < .001$) tasks, but not the CONV task ($p = .275$). LVI-R was significantly lower for the voice-disordered versus control group on the MOCK and ML teaching tasks. Although LVI-R was also lower during the CONV task for the voice-disordered versus control group, these differences did not reach statistical significance. Post-hoc tests using Tukey's HSD revealed no significant comparisons for the measure of LVE. See Appendix M for all posthoc test results.

Electroglottography (EGG) Measurements

Signal Quality

EGG signal quality was variable across all subjects. In general, EGG signal amplitude was highest and signal noise lowest in males. Females with ample adipose tissue in the neck showed lower signal amplitude and higher signal noise. Harmonics-to-noise (H:N) ratios were computed for all subjects to provide a representation of EGG signal quality. The H:N ratios are summarized in Table 6, for all subjects across all speaking tasks. Mean H:N ratios ranged from 18.41 dB (SD=3.04 dB) to 22.90 dB (SD=4.72 dB), with the highest values demonstrated during the sustained /a/ vowel and MPT /a/ vowel.

Table 6. Harmonics-to-noise ratios, in dB, for all subjects across all speaking tasks.

Voice-disordered-VDis, Control=Con. CONV=conversational speaking task,

MOCK=mock teaching task, ML=mock loud teaching task, READ=paragraph reading

task, /a/=sustained /a/ vowel, MPT /a/=maximum phonation time sustained /a/ vowel.

Subject	CONV	MOCK	ML	READ	/a/	MPT /a/
VDis1	19.38	16.59	17.73	17.68	26.03	23.41
VDis2	13.70	12.61	14.30	15.67	16.95	15.16
VDis3	20.04	17.35	22.19	19.30	22.36	24.75
VDis4	21.72	21.81	20.59	22.65	26.05	24.97
VDis5	15.76	15.89	16.50	15.92	17.37	17.90
VDis6	14.30	14.91	14.79	14.44	16.15	16.17
VDis7	23.55	23.43	23.02	25.02	24.78	25.14
VDis8	22.99	20.94	22.00	22.48	28.41	26.92
VDis9	17.44	17.35	20.72	20.88	21.36	22.35
Con1	18.86	17.93	16.02	17.31	23.85	26.12
Con2	19.53	21.00	20.26	22.46	22.92	24.32
Con3	17.60	17.35	17.48	17.70	18.24	18.15
Con4	17.15	20.19	20.14	18.28	24.69	23.81
Con5	20.78	22.79	23.09	24.65	27.07	29.28
Con6	15.90	13.83	15.70	14.83	14.58	13.92
Con7	20.01	19.34	19.62	21.24	21.63	22.71
Con8	18.95	20.23	19.93	19.63	29.22	27.19
Con9	20.58	17.92	21.29	20.07	30.47	28.28
Mean	18.79	18.41	19.19	19.46	22.90	22.81
St. Dev.	(2.76)	(3.04)	(2.83)	(3.23)	(4.72)	(4.63)

A repeated measures ANOVA was performed to determine whether any differences in signal quality were evidenced between subject groups. The ANOVA showed no significant between-subjects (group) effects ($p=.607$), significant task effects ($p<.001$ with Greenhouse-Geisser adjustment), and no significant interaction effects. Follow-up posthocs with Tukey's HSD revealed significant task effects for the sustained /a/ vowel and MPT /a/ when compared to all other speaking tasks (significance levels

ranging from $p=.001$ to $p=.017$). Mean H:N ratios for the two sustained /a/ tasks were higher than the four continuous speech tasks. See Appendix M for posthoc test results.

Laryngeal Measurements: CQ and CI

Group means and individual subject data for EGG measures across the five speaking tasks are presented in Appendix N. Figure 5 displays mean contact quotient (CQ) values for each group across the five speaking tasks (three spontaneous tasks, paragraph reading, and /a/).

Figure 5. Mean contact quotient (CQ), reported as a percent, across five speaking tasks for the voice-disordered (VDis) and control (Con) groups. CONV=conversational speaking task, MOCK=mock teaching task, ML=mock loud teaching task, READ=paragraph reading, /a/=a/ vowel.

This figure demonstrates a trend toward lower CQ means in the voice-disordered versus control group.

Figure 6 displays mean contact index (CI) values for each group across the five speaking tasks (three spontaneous tasks, paragraph reading, and /a/). There was a trend toward more negative CI means in the voice-disordered versus control group.

Figure 6. Mean contact index (CI) across five speaking tasks for the voice-disordered (VDis) and control (Con) groups. CONV=conversational speaking task, MOCK=mock teaching task, ML=mock loud teaching task, READ=paragraph reading, /a/=a/ vowel.

Task differences in CI are also demonstrated in Figure 6; the CI values for both groups are lower, or more negative, on the CONV task in comparison to the /a/ vowel.

With statistical testing, EGG measures did not show differences between the voice-disordered and control groups, but did show differences within subjects, across

speaking tasks. An overall repeated measures multivariate analysis of variance (MANOVA) for the two laryngeal dependent variables revealed a non-significant, omnibus between-subject difference for group ($p=.258$), a significant within-subject difference for task ($p=.001$), and a non-significant interaction between group and task ($p=.488$). Follow-up repeated measure (univariate) ANOVAs were then performed to determine which dependent variables were significantly different. Table 7 summarizes the ANOVA findings for each variable, including degrees of freedom (df), F statistic, significance level (p), and power. CI was significantly different across speaking tasks ($p=.002$ with Greenhouse-Geisser adjustment).

Table 7. Univariate repeated measure ANOVA results for electroglottography measures.

Contact quotient (reported as a percent)=CQ, contact index=CI.

Variables	df	F	p	Power
Within subjects (task)				
CQ	1.70	2.16	.140	.38
CI	2.49	6.75	.002*	.94

Follow-up posthoc tests using Tukey's HSD were then performed to determine which tasks resulted in significant within-group differences for CI. 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 to the /a/ vowel. A lower CI value reflects a shorter contact-closing phase and/or a longer contact-opening phase during vocal fold vibration. See Appendix M for all posthoc test results.

To characterize the within-subject variability throughout each speaking task, individual standard deviation (SD) values were calculated for CQ and CI, which are also

presented in Appendix N. Means of these SD values were similar across groups for CQ and CI, ranging from approximately 2.4 to 4.2% for CQ and 0.04 to 0.08 for CI.

Two repeated measure ANOVAs were conducted to assess whether differences between groups or across tasks were evidenced in the individual standard deviation values for CQ and CI. Results of the ANOVA for CQ showed no significant between-subject differences, but significant within-subject (task) differences ($p=.001$). Interaction effects were non-significant ($p=.515$). Follow-up posthocs using Tukey's HSD were performed to reveal which task comparisons for CQ SD were significant. These posthoc comparisons showed that comparisons of the ML task to the CONV ($p=.005$), READ ($p=.013$) and /a/ ($p=.003$) tasks were significant.

Results for the ANOVA for CI showed no significant between-subject differences, but significant within-subject (task) differences ($p=.003$ with Greenhouse-Geisser adjustment). Interaction effects were non-significant ($p=.362$). Follow-up posthocs using Tukey's HSD were performed to reveal which task comparisons for CI SD were significant. As with the results for CQ SD, these posthoc comparisons showed that comparisons of the ML task to the CONV ($p=.001$), READ ($p=.005$) and /a/ ($p<.001$) tasks were significant. The error terms for "sphericity assumed" were used for calculating these post-hoc results, because calculation using Greenhouse-Geisser error terms resulted in over-inflation of Type II errors with no significant task comparisons. See Appendix M for all posthoc test results.

Interaction of the Respiratory and Laryngeal Subsystems

Significant between-group differences occurred for selected respiratory variables but not for EGG variables. Thus, an overall correspondence of between-group differences in respiratory patterns to between-group differences in laryngeal patterns as assessed through EGG was not demonstrated. To further explore the possible interaction between lung volume and EGG measures, the MPT vowel and paragraph reading task were analyzed for change in CQ and CI over time. The MPT vowel represented a standard, sustained vowel utterance in which lung volume was initiated at a high level and terminated at a low level. For the voice-disordered group, mean LVI-R was 36.03 (SD=16.02) and mean LVT-R was -24.27 (SD=7.99). For the control group, mean LVI-R was 38.77 (SD=10.14) and mean LVT-R was -16.32 (SD=9.8). Table 8 summarizes the mean CQ and CI values for each group, computed for the first and last 5% of the total analyzed duration of the MPT. Table 9 presents the individual CQ and CI data for each subject.

Table 8. Group means and standard deviations (SD) for contact quotient (CQ), reported as a percent, and contact index (CI) at time points of 0 to 5% and 95 to 100% of the MPT vowel.

Subject Group	CQ 5% Mean (SD)	CQ 95% Mean (SD)	CI 5% Mean (SD)	CI 95% Mean (SD)
Voice-Disordered	50.31 (5.56)	52.82 (5.85)	-0.40 (0.08)	-0.43 (0.10)
Control	57.59 (6.30)	57.51 (10.03)	-0.47 (0.07)	-0.46 (0.12)

Table 9. Individual subject data for contact quotient (CQ), reported as a percent, and CI at time points of 0 to 5% and 95 to 100% of the MPT vowel.

Subject	CQ 5%	CQ 95%	CI 5%	CI 95%
VDis1	48.22	52.07	-0.54	-0.61
VDis2	44.60	47.26	-0.31	-0.36
VDis3	47.00	50.62	-0.34	-0.36
VDis4	41.63	50.66	-0.38	-0.50
VDis5	50.55	42.49	-0.40	-0.30
VDis6	53.47	55.48	-0.50	-0.47
VDis7	52.60	60.29	-0.38	-0.46
VDis8	55.16	59.65	-0.45	-0.48
VDis9	59.56	56.90	-0.34	-0.36
Con1	63.27	51.78	-0.51	-0.39
Con2	45.24	51.37	-0.41	-0.49
Con3	62.44	52.11	-0.48	-0.37
Con4	53.37	47.83	-0.32	-0.24
Con5	59.25	62.15	-0.49	-0.50
Con6	52.67	50.91	-0.54	-0.65
Con7	62.66	59.13	-0.43	-0.43
Con8	63.57	80.40	-0.51	-0.55
Con9	55.84	61.95	-0.54	-0.54

Figures 7 and 8 display an example of the CQ and CI contour that occurred over the course of the MPT utterance for one subject.

Figure 7. Example of change in contact quotient (CQ), reported as a percent, over the course of the MPT vowel for one subject.

Figure 8. Example of change in contact index (CI) over the course of the MPT vowel for one subject.

Comparison of the 5% to 95% mean CQ and CI values using a paired samples t-test with Bonferroni adjustment for four tests revealed no significant differences (range of $p=.184$ to $.980$). Closer inspection of the individual data suggested that there were two different patterns for CQ change over the course of the MPT vowel: (1) a pattern of increasing CQ over time, and (2) a pattern of decreasing CQ over time. Dividing subjects into these two pattern sub-categories revealed substantial change in CQ over the course of the MPT vowel.

For the control subjects, approximately half ($N=4$) of the group increased CQ over the course of the MPT vowel from approximately 56 to 64%. The other half of the group ($N=5$) decreased their CQ value from approximately 59 to 52%. Therefore, individual subjects were showing change in CQ over time, but the two opposing patterns cancelled each other out when examining the group mean. Changes in CI were less clear, but generally were slightly more negative when CQ increased during the MPT vowel. Table 10 shows the means and SDs for the sub-grouping of the control subjects based on increasing or decreasing CQ.

Table 10. Changes in contact quotient (CQ), reported as a percent, during MPT vowel for the control group, subdivided by pattern.

Pattern of Change	CQ 5% Mean (SD)	CQ 95% Mean (SD)	CI 5% Mean (SD)	CI 95% Mean (SD)
Con subjects with increasing CQ pattern ($N=4$)	55.98 7.82	63.97 12.06	-0.49 0.05	-0.52 0.03
Con subjects with decreasing CQ pattern ($N=5$)	58.88 (5.37)	52.35 (4.15)	-0.45 (0.09)	-0.41 (0.15)

For the voice-disordered group, the majority of subjects (N=7) showed an increase in CQ, which was generally accompanied by a change to a more negative CI value. Mean values for CQ for this voice-disordered subgroup went from approximately 49 to 54% over the course of the MPT vowel. For the 2 subjects who showed a decreasing pattern, CQ values changed from approximately 55 to 50%. Table 11 shows the means and SDs for the sub-grouping of subjects with voice disorders based on increasing or decreasing CQ.

Table 11. Changes in contact quotient (CQ), reported as a percent, during MPT vowel for the voice-disordered group, subdivided by pattern.

Pattern of Change	CQ 5% Mean (SD)	CQ 95% Mean (SD)	CI 5% Mean (SD)	CI 95% Mean (SD)
VDis subjects with increasing CQ pattern (N=7)	48.95 (4.99)	53.72 (4.91)	-0.41 (0.09)	-0.46 (0.09)
VDis subjects with decreasing CQ pattern (N=2)	55.05 (6.37)	49.69 (10.19)	-0.37 (0.04)	-0.33 0.04

Change in CQ and CI that occurred during continuous speech over the course of a breath group was assessed with a sentence selected from the EGG-analyzed portion of the paragraph reading. This represented a standard, continuous speech utterance in which lung volume progressively decreased. For the voice-disordered group, mean LVI-R was 15.24 (SD=10.57) and mean LVT-R was -0.45 (SD=6.90). For the control group, mean LVI-R was 26.41 (SD=10.12) and mean LVT-R was 12.65 (SD=10.74). Table 12 summarizes the mean CQ and CI values for each group, computed for the first and last

5% of the total analyzed duration of the sentence. Individual data are presented in Appendix O.

Table 12. Contact quotient (CQ), reported as a percent, and contact index (CI) values for the voice-disordered group at time points of 0 to 5% and 95 to 100% of the standard sentence.

Subject Group	CQ 5% Mean (SD)	CQ 95% Mean (SD)	CI 5% Mean (SD)	CI 95% Mean (SD)
Voice-Disordered	53.96 (7.09)	57.65 (7.22)	-0.46 (0.09)	-0.57 (0.10)
Control	54.62 (5.78)	56.30 (4.75)	-0.43 (0.09)	-0.57 (0.09)

Similar individual and group means trends were demonstrated by both groups; mean CQ increased slightly over the course of the utterance and mean CI became substantially more negative. Figures 9 and 10 display examples of the changes in CQ and CI over the course of the utterance for one subject.

Figure 9. Example of change in contact quotient (CQ), reported as a percent, over the course of an utterance for one subject.

Figure 10. Example of change in contact index (CI) over the course of an utterance for one subject.

Because trends were similar for both groups, data were combined and a paired-samples t-test was performed to assess change in CQ and CI from the first to last 5% of the total duration of the utterance. A Bonferroni adjustment was applied (.05 divided by two, $\alpha=.025$). The decrease in CQ that occurred over the course of the utterance was non-significant ($p=.165$). The change in CI that occurred over the course of the utterance

was significant ($p < .001$). As the utterance progressed in time (decreasing lung volume), mean CI became significantly more negative. That is, there was greater asymmetry between the contact-closing and contact-opening phases of vocal fold vibration.

Effort Ratings

Mean scores for effort ratings were somewhat higher for the voice-disordered group on each of the spontaneous speaking tasks in comparison to the control group. Table 13 summarizes mean effort ratings for the three spontaneous speaking tasks.

Table 13. Group means for effort ratings. CONV=conversational speaking task, MOCK=mock teaching task, ML=mock loud teaching task.

Task	Voice-Disordered		Control	
	Mean	(SD)	Mean	(SD)
CONV	20.61	15.08	11.17	9.99
MOCK	28.44	18.55	13.78	11.10
ML	48.50	14.36	39.11	24.07

Figure 11 shows that effort ratings were higher for all three tasks for the voice disordered teachers as compared to the control group.

Figure 11. Group means for effort ratings across the three spontaneous speaking tasks.

CONV=conversational speaking task, MOCK=mock teaching task, ML=mock loud teaching task, voice-disordered=VDis, control=Con.

A repeated measures ANOVA showed no significant between-subject, group differences or interaction effects for the three speaking tasks ($p=.070$), but did show significant within-subject, task differences ($p<.001$). Follow-up posthocs using Tukey's HSD showed that the comparisons of the CONV to ML task and MOCK to ML task were significant ($p<.001$), with higher effort ratings for the ML task as compared to the other two tasks.

Speech Characteristics

Some differences in speech characteristics were noted between groups. Table 14 summarizes the average SPL (db HL, weighting scale A, 18 inch mouth-to-mic distance) and speaking rate for both groups over the five speaking tasks.

Table 14. SPL mean (SD) and speaking rate mean (SD) for the five speaking tasks.

CONV=conversational speaking task, MOCK=mock teaching task, ML=mock loud teaching task, READ=paragraph reading, /a/=a/ vowel.

Task	Voice-Disordered		Control	
	SPL	Speaking Rate (syl/min)	SPL	Speaking Rate (syl/min)
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)
ML	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

For SPL, a repeated measures ANOVA showed significant between-subject, group differences ($p=.040$), and significant within-subject, task differences ($p<.001$), with non-significant interaction effects ($p=.083$). Between groups, SPL was significantly lower for the voice-disordered group. Follow-up posthocs using Tukey's HSD were performed to assess which task comparisons were significant. These follow-up tests showed that comparisons of the CONV to ML task ($p<.001$), CONV to READ task ($p=.013$), CONV to /a/ task ($p<.001$), MOCK to ML task ($p<.001$), MOCK to /a/ task ($p=.011$), ML to READ task ($p<.001$), and ML to /a/ task ($p<.001$) were significant. Within groups, SPL for the CONV task was significantly lower than for the READ, /a/ and ML tasks. SPL for the MOCK task was significantly lower than for the ML and /a/ tasks. SPL for the READ and /a/ tasks was significantly lower than for the ML task.

Due to the significant between-group 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 non-significant for the CONV and MOCK tasks. For the ML 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 non-significant for the CONV and MOCK tasks. For the ML task, SPL was significantly, positively correlated to CI ($p=.024$). See Appendix P for the Pearson product-moment correlation coefficients for all respiratory and laryngeal dependent variables.

A repeated measures ANOVA for speaking rate revealed no significant between-subject ($p=.138$) or within-subject ($p=.280$) differences.

Symptoms of Voice/Vocal Mechanism Problems and Their Impact

A checklist of vocal symptoms was given to all subjects to assess the frequency of different symptoms and the representation of those symptoms across different categories and across the respiratory and laryngeal subsystems. The sum score for the voice-disordered group was nearly four times higher than the sum score for the control group (290 versus 76).

Group differences, assessed with a Mann-Whitney U test, revealed a significant between-group difference ($p<.001$). Table 15 lists symptoms for the voice-disordered group in order of descending frequency, with the sum score for each symptom and the category that each symptom represented on the right. The probable subsystem involved

(laryngeal, respiratory, or both) is also listed on the right. Although the articulatory subsystem may also contribute to these symptoms, only the laryngeal and respiratory subsystems were considered here.

Table 15. Symptoms in descending frequency for the voice-disordered group.

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

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 subjects with voice disorders. Interestingly, rankings of symptoms were the same for the first four most frequently occurring symptoms in the control group, although actual scores for these symptoms were much lower. Table 16 summarizes symptoms for the control group in descending frequency, with the sum score for each symptom, category, and subsystem listed to the right.

Table 16. Symptoms in descending frequency for the control group.

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

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 12, which presents the sum score for each category as a percent of the total possible score for that category (TPCS). Abbreviations of categories are as follows: effort/work/fatigue=EFW, auditory changes=AC, mental effort=ME, pain/discomfort=PD, tightness/tension=TT.

Figure 12. Sum symptom scores by category as a % of total possible score for each category (TPCS) for the voice-disordered and control groups.

This figure shows that the category of effort/work/fatigue is most highly represented by both groups. In the voice-disordered group, scores for this category represented approximately 51% of the TPCS, whereas in the control group, scores represented approximately 18% of the TPCS. For the voice-disordered group, auditory changes to voice were also reported frequently; scores for this category represented approximately 45% of the TPCS. In contrast, this was the least represented category for

the control group, with a sum score of approximately 6% of the TPCS. Mental effort was also indicated frequently by the voice-disordered group, with a score of approximately 43% of the TPCS. Thinking about voice versus thinking about what to say contributed most to this elevated score (28% versus 15% of TPCS). Mental effort was also the third most represented category for the control group (13% of TPCS), but thinking about what to say versus thinking about voice contributed most to the category score in this case (9% versus 4% of TPCS). Pain/discomfort and tightness/tension were the two least represented categories for the voice-disordered group, with scores of approximately 35% and 28% of TPCS, respectively. In contrast, pain/discomfort and tightness tension were the second and fourth most frequently occurring categories for the control group, with scores of approximately 13% and 8% of the TPCS.

The VAPP provided an additional measure of impact of voice problems for each group. To determine whether group differences were evidenced on the VAPP, an independent samples t-test was performed. Significant group differences occurred ($p=.014$, equal variances not assumed); the mean overall VAPP score was significantly higher for the subjects with voice disorders (mean=44.4, SD=41.0) as compared to the control subjects (mean=1.3, SD=1.2).

DISCUSSION

This was the first study to investigate respiratory and laryngeal function simultaneously in teachers with voice disorders. The purpose of this study was to determine if respiratory and laryngeal characteristics during spontaneous speech production were different for teachers with voice problems as compared to teachers without voice problems. Respiratory function during spontaneous speech production was different for teachers with voice problems when compared to teachers without voice problems. Laryngeal function as assessed with electroglottography did not show differences between groups. The following discussion focuses on the major respiratory and laryngeal findings, clinical implications of these findings, the interaction between the respiratory and laryngeal subsystems, a critique of the method, and directions for future research.

Respiratory Function in Teachers

Teachers with voice problems exhibited different respiratory behavior than teachers without voice problems during spontaneous speaking. Teachers with voice problems started and ended their breath groups at significantly lower lung volume levels than control teachers. These differences were most pronounced during simulated teaching tasks produced at typical and increased loudness levels. In contrast, the task in which teachers spoke as they would in a conversation to a friend showed less pronounced between group differences. Speaking rate differences did not account for the lower lung volume termination levels of teachers with voice disorders, as between-group comparisons were not significant. Instead, low initiations and terminations to breath

groups seemed to be a true difference in speech breathing behavior for the teachers with voice problems.

When required to speak at an increased loudness level, teachers with voice problems initiated their breath groups at slightly lower levels than they did for a speaking task requiring a conversational loudness level. Teachers without voice problems exhibited different speech breathing patterns when increasing their loudness level. These teachers initiated their breath groups at a level close to 10% vital capacity higher than they did for speech requiring a conversational loudness level.

Researchers who have studied speech breathing in healthy individuals have found that during spontaneous speaking, utterances are usually initiated 10 to 25% above an individual's resting expiratory level, and terminated at or near resting expiratory level (Hixon et al., 1973; Hoit & Hixon, 1987; Hoit et al., 1989; Winkworth et al., 1995). In this study, subjects with voice disorders initiated and terminated their breath groups at the low end of previously reported ranges (Hoit et al., 1989; Winkworth et al., 1995). In contrast to the teachers with voice disorders, teachers without voice problems started and ended their breath groups at the high end of previously reported ranges (Hixon et al., 1973; Hoit & Hixon, 1987; Hoit et al., 1989; Winkworth et al., 1995).

Previous research findings for healthy subjects show that when voice intensity is increased, most subjects initiate speech at higher lung volume levels (Hixon et al., 1973; Hixon, Mead, & Goldman, 1976; Huber et al., 2004; Stathopoulos & Sapienza, 1993). Hixon et al. (1973) noted that for speech produced at an increased loudness level as compared to speech at a conversational loudness level, "...breathing phrases

characteristically were started from substantially higher lung volumes...typically between 10 – 20% [vital capacity] higher” (p.110). Teachers with voice disorders in this study did not start their breath groups at higher levels when they spoke at an increased loudness level. In contrast, teachers without voice problems demonstrated patterns of lung volume change similar to those previously reported in healthy subjects (Hixon et al., 1973; Huber et al., 2004) when increasing their loudness level.

The differences in lung volume patterns evidenced between groups suggest that teachers with voice problems adopted different breathing strategies for speaking. Teachers with voice problems produced speech in a lower lung volume range, and consistently ended their breath groups below resting expiratory level. Therefore, these teachers did not capitalize on increased recoil forces that are available at higher lung volume levels. In addition, speaking below resting expiratory level requires increased muscular pressure to counteract the inspiratory recoil forces that are presented by the chest wall unit. Speaking at lower lung volumes has been described as costly relative to muscle expenditure (Forner & Hixon, 1977). This is due to the need for increased muscular pressure to produce speech at lower lung volumes and the muscular work required to counteract inspiratory recoil forces that are present below resting expiratory level. Use of strategies that increase expiratory muscle expenditure may be costly to individuals who are faced with an occupation that is highly vocally demanding. Strategies that differentially increase muscular work on the expiratory side might be more costly during speech production than those that increase muscular work on the inspiratory side. This is due to the fact that expiratory time during speech production is much greater

than inspiratory time; in this study, average expiratory time was approximately eight times greater than inspiratory time across speaking tasks. Furthermore, teachers with voice disorders showed similar breathing patterns during teaching tasks as they did for conversational speaking. Thus, these teachers did not adopt differential speech breathing strategies for teaching.

In contrast, the strategies adopted by teachers without voice problems appeared to minimize muscle expenditure. At higher lung volume initiation levels, greater respiratory recoil forces are available for expiration (Hixon et al., 1973). By starting their breath groups at higher levels, teachers without voice problems capitalized on these expiratory recoil forces. By ending their breath groups at higher levels, teachers without voice problems avoided the additional muscle expenditure required for speech produced below resting expiratory level. Teachers without voice problems also seemed to adopt differential strategies when teaching versus when speaking conversationally. That is, when speaking for teaching, teachers initiated their breath groups at significantly higher levels than the teachers with voice disorders, but did not start their breath groups at significantly higher levels for the conversational speaking task. Finally, teachers without voice problems also took advantage of higher expiratory recoil forces by increasing lung volume initiation for the loud teaching task by approximately 10% vital capacity. This strategy would increase lung pressure through passive forces, an efficient way to increase sound pressure level. These combined strategies might serve to minimize the need for excessive muscular expenditure during speech production, which could help prevent the

onset of voice problems in a job that requires potentially damaging vocal fold vibration doses (Titze et al., 2003).

Teachers frequently have to speak at increased loudness levels when teaching. Differential use of strategies for increasing loudness has been demonstrated by several researchers (Huber et al., 2004; Stathopoulos & Sapienza, 1993). The increase in sound pressure level that results from respiratory adjustments is greater than that resulting from laryngeal adjustments (Finnegan et al., 2000; Titze, 1988; Titze & Sundberg, 1992). Respiratory adjustments to achieve increased loudness include initiating breath groups at a higher lung volume level and increasing expiratory muscle pressure, which both result in increased lung pressure. Healthy subjects demonstrate increased expiratory muscle activity as well as increased lung volume initiation levels when increasing loudness, thus taking advantage of muscular pressure and expiratory recoil forces for achieving the necessary increase in tracheal pressure (Hoit, Plassman, Lansing, & Hixon, 1988). By not capitalizing on a strategy of increased lung volume initiation, teachers with voice disorders must rely on increased expiratory muscle pressure for any respiratory-based increase in loudness. Reliance on strategies that utilize active (muscle) forces only may be less efficient than strategies that combine passive and active forces when increasing loudness.

Huber et al. (2004) demonstrated that the type of cue provided to subjects influenced the respiratory mechanisms that subjects employed to increase their loudness level. These authors suggested that background noise was the most natural elicitation method for increasing loudness level. In this study, the majority of teachers in the voice-

disordered and control groups reported low levels of background noise in their classrooms. Therefore, although background noise is certainly one factor that influences teachers' need for increased loudness level when teaching, it seems that other factors such as need to project the voice over longer distances, desire for an authoritative voice, and behavior management, may also be important. In a survey completed by 554 kindergarten through 12th grade teachers, E. Smith et al. (1998) noted that although 83% of teachers reported the need to speak louder in the classroom than they would in conversational speaking, only 48% reported the need to speak over background noise in the classroom. Thus, multiple factors may contribute to the increased loudness level needed by teachers in their classroom instruction.

The use of respiratory strategies that relied on low lung volume levels may have carried an additional acoustic cost to teachers with voice disorders. Sound pressure level was significantly lower for the voice-disordered group relative to the control group. Lower lung volume initiation levels might have influenced these differences in sound pressure levels between groups. The reliance on expiratory muscle pressure alone versus combined increases to muscular pressure and lung volume initiation levels might have been less effective for generating the increased tracheal pressures needed for louder speech. The reduced sound pressure level for the teachers with voice disorders also provides objective support for the symptoms of decreased loudness and restricted loudness range; teachers with voice disorders in this study reported frequent occurrence of these symptoms in the vocal symptoms checklist.

The results of the present study show that decreased levels of lung volume initiation and termination are associated with voice problems in teachers. Sapienza and colleagues (Sapienza & Stathopoulos, 1994; Sapienza et al., 1997) have found that people with vocal nodules have increased lung volume excursion as compared to control subjects. These authors noted that the increased lung volume excursion is contributed to by trends of increased lung volume initiation and decreased lung volume termination in subjects with vocal nodules, 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. Whether these speech breathing differences contribute to the onset or progression of voice problems in teachers is unknown. However, the increased cost of speaking at low 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.

In summary, the respiratory strategies adopted by teachers with voice problems were less efficient and potentially more costly in muscle expenditure relative to strategies used by teachers without voice problems. Furthermore, speaking at lower lung volume levels may influence laryngeal behavior. The influence of respiratory behavior on laryngeal behavior will be discussed in a later section.

Laryngeal Function in Teachers

Laryngeal function as assessed with electroglottography did not show differences for teachers with voice problems as compared to teachers without voice problems. 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, 1990). Mean values for both electroglottography measures fell within normative ranges (Orlikoff, 1991; Orlikoff et al., 1997) for the voice-disordered and control groups across all speaking tasks.

There were tendencies (although non-significant) toward a reduced degree of vocal fold contact as assessed by contact quotient for teachers with voice problems as compared to teachers without voice problems across all speaking tasks. Therefore, teachers with voice problems may have exhibited decreased vocal fold adduction relative to controls. Symmetry of the vocal fold contact phase as assessed with contact index was also somewhat lower, or more negative, in teachers with voice disorders versus control teachers. Increased contact phase asymmetry during vocal fold vibration may be indicative of increased vocal fold tension. As discussed earlier, Hillman et al. (1989) have proposed two different patterns of vocal fold adduction for people with hyperfunctional voice disorders. In non-adducted hyperfunction, increased vocal fold stiffness with decreased vocal fold adduction is expected, in the absence of laryngeal pathology. It is possible that the teachers with voice disorders in the present study exhibited this non-adducted vocal fold vibration pattern, although no conclusions can be drawn as between-group comparisons were not significant.

Further support for this non-adducted vocal fold vibration pattern is provided by the lung volume expenditure values evidenced by the teachers with voice disorders. Lung volume expenditure as reflected by percent vital capacity per syllable may provide another indicator of laryngeal valving economy. With increased laryngeal valving, amount of lung volume expended per syllable would presumably decrease, and with decreased laryngeal valving, expended lung volume would increase. Lung volume expenditure was slightly greater for the teachers with voice disorders relative to the control group across tasks, but this trend was not statistically significant. Based on the related pilot study (Lowell et al., 2004), it was hypothesized that lung volume expenditure would be decreased in the voice-disordered group, indicating a possible increase in laryngeal constriction. The trend in this study was in the opposite direction. However, this trend toward increased lung volume expenditure provides additional support for the notion that teachers with voice disorders in this study may have exhibited a non-adducted pattern of vocal fold vibration.

There are several possible reasons for the lack of between-group differences in laryngeal function as assessed with electroglottography. Most simply, laryngeal function may not have been different for the teachers with voice problems in this study as compared to the control teachers. Alternatively, it is possible that the measurements made from the electroglottography signal are not sensitive enough to identify potential differences in laryngeal function. An initial pilot test using an adductory glide indicated that both contact quotient and contact index would register change for variations in voice quality, and investigators have shown that contact quotient is higher for a pressed versus

breathy voice quality (Peterson et al., 1994). However, both the pilot test and previous electroglottography studies were conducted with sustained vowel utterances versus analysis of continuous speech. Analysis of continuous speech, which includes a great deal of intra and inter subject variation, may cancel out any specific differences when means are assessed over the course of a speaking task and across subjects. This study was the first to investigate the use of electroglottography in continuous speech to assess differential patterns of vocal fold adduction in teachers with voice disorders. Laryngeal function in previous studies has primarily been assessed with oral or nasal endoscopy (Behrman et al., 2003; Eustace et al., 1996; Morrison & Rammage, 1993; Stager et al., 2001; Stemple et al., 1995), and mostly during sustained vowel utterances. Therefore, the sensitivity of electroglottography analysis for continuous speech still needs to be determined.

Differences in Laryngeal Function Across Tasks

Differences in laryngeal function were evidenced across speaking tasks, as assessed with electroglottography. The measure reflecting symmetry of vocal fold contact (contact index) was lower (more negative) during a conversational speaking task than during the sustained vowel. Thus, greater asymmetry between the contact-closing and contact-opening phase was demonstrated during conversational, continuous speech as compared to the sustained vowel. This may reflect a greater degree of vocal fold tension during the continuous speaking task. During continuous speech production, the vocal folds must continuously 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.

Support for task differences in voice characteristics is also evidenced in previous research. Incidence of supraglottic activity varies across speaking tasks, and is lower during a sustained /i/ vowel than during several continuous speaking contexts (Stager et al., 2000). Several acoustic characteristics such as fundamental frequency and voice intensity are affected by speaking context, and often differ for sustained vowels as compared to continuous speech (Brown Jr., Morris, & Murry, 1996; Fitch, 1990; Nittrouer, McGowan, Milenkovic, & Beehler, 1990). The task differences in this study suggest that in addition to acoustic parameters and supraglottic activity, patterns of vocal fold vibration may differ for sustained vowels versus continuous speech. The patterns of vocal fold asymmetry that characterized the conversational speaking task may be more indicative of the patterns typically evidenced during every day speaking.

It is not clear why the only significant difference that occurred when comparing tasks was for the sustained vowel relative to the conversational speaking task. It could be argued that sound pressure level differences accounted for the significant task difference that occurred, as sound pressure level was higher for the sustained vowel task. Sound pressure level is correlated with contact index, although its change as associated with increasing sound pressure level is in the opposite direction of the change shown in this study (Orlikoff, 1991). However, the data do not support the notion that sound pressure level was the primary contributor to the task difference seen in this study. Sound pressure level and contact index were not significantly correlated for either the

conversational speaking task or the sustained vowel task, even though these two tasks showed significant within-subjects differences. Differences in sound pressure level were also much greater for comparisons between the four continuous speaking tasks, and yet these comparisons did not show significant task effects.

Measures that reflected degree of vocal fold contact and symmetry of the contact phase of vibration did not show significant changes when comparing any of the typical loudness level tasks to the mock teaching task at an increased loudness level. In previous studies, an increase in contact quotient and a decrease (more negative change) in contact index was correlated to sound pressure level increase (Orlikoff, 1991). In this study, there was a non-significant trend toward increasing contact quotient as sound pressure level increased between tasks. This trend was therefore in agreement with previously published data. Teachers in this study showed a trend toward less asymmetry of vocal fold vibration as sound pressure level increased (evidenced by an increasing, or less negative, contact index value). This trend was therefore in the opposite direction of previously published data. Furthermore, sound pressure level was significantly, positively correlated to contact index during the simulated teaching task at an increased loudness level in this study.

Sex differences for the measure reflecting symmetry of vocal fold contact may partially account for the discrepancy between the contact index trend in this study and the results reported by Orlikoff (1991) relative to sound pressure level changes. Published data on correlations between contact index and sound pressure level are on male subjects only (Orlikoff, 1991). In this study, the majority of subjects were female (78%).

Interestingly, inspection of individual data showed that three of the four male subjects had a decreasing (more negative) change in contact index as sound pressure level increased between the conversational task and the mock teaching task at increased loudness. This change for the three male subjects was in the opposite direction of the overall group trend, but in the same direction as previously published normative values for males (Orlikoff, 1991). Although the subject numbers are too small to draw conclusions, these trends indicate that there may be male/female differences in correlation of contact index to sound pressure level. The fact that normative values for contact index show overall sex differences whereas those for contact quotient do not (Orlikoff, 1991; Orlikoff et al., 1997) supports the possibility of additional sex differences in contact index change associated with sound pressure level.

Respiratory-Laryngeal Interactions

An overall relationship between respiratory and laryngeal function was not supported in this study, in that respiratory function differed for teachers with voice disorders as compared to the control group, but laryngeal function did not. Within breath-group changes to vocal fold contact and contact symmetry as a function of decreasing lung volume were assessed with the sustained, maximum phonation time vowel and the continuous speaking (sentence) utterance. Subject subgroups showed opposing trends for changes in contact quotient over the course of the sustained maximum phonation time vowel, although in assessment of group means, these trends cancelled each other out. Although small numbers of subjects limit any conclusive statements, it appears that teachers without voice problems exhibited more variation in

the types of strategies used, whereas teachers with voice problems relied predominantly on one strategy – increasing vocal fold contact as lung volume decreased. Restricted use of strategies for vocal fold adduction patterns might correspond to other areas of restriction reported by these teachers with voice problems, such as reduced pitch and loudness range.

Changes to laryngeal function as a function of decreasing lung volume were more pronounced when assessed during continuous speaking rather than during a sustained vowel utterance. Significant change in contact symmetry was demonstrated over the course of the sentence. Asymmetry of the contact-closing versus contact-opening phase increased as lung volume decreased and as a continuous speech utterance progressed from start to end. This may reflect an increase in vocal fold tone or tension. Changes in contact phase symmetry were non-significant in the maximum phonation time utterance, whereas in the continuous speech utterance, mean change was significantly different from beginning to end of the utterance. Therefore, change in lung volume itself cannot explain the symmetry change. If lung volume alone accounted for the change in vocal fold contacting symmetry, results for the maximum phonation time utterance and the continuous speech utterance would be the same. Instead, it appears that both decreasing lung volume and articulatory effects may influence contact phase symmetry over the course of an utterance.

For the teachers with voice disorders who consistently used lower lung volume levels during continuous speaking, contact phase asymmetry may compound their voice problems by increasing vocal fold tension at the end of every utterance. Previous

research has indicated that speaking at lower lung volume levels may carry physiologic and acoustic repercussions. Speech produced at lower lung volume levels has been associated with increased laryngeal constriction (Iwarsson et al., 1998; Milstein, 1999) and aerodynamic changes such as decreased AC flow (Milstein, 1999). Initiating speech at lower lung volume levels results in negative consequences to voice quality (Milstein & Watson, 2004), and some changes to acoustic parameters such as a reduction in F1-F2 vowel space (Watson & Ciccia, 2003) and change in voice onset time (Hoit et al., 1993). In the present study, analysis of utterances that represented decreasing lung volume yielded mixed results relative to change in laryngeal function. Degree of vocal fold contact as assessed with electroglottography did not reflect significant change as lung volume decreased, whereas contact phase symmetry during vocal fold vibration did significantly change during continuous speech. Greater contact phase asymmetry may indicate increased vocal fold tension at the end of each breath group. Therefore, the changes evidenced during continuous speech may add to the body of literature supporting negative sequelae associated with producing speech at lower lung volume levels.

Use of Effort Ratings to Operationally Define Voice Disorders

Use of effort ratings as an inclusion criterion for subjects with and without voice disorders in this study helped to differentiate these two populations. The criterion level for increased effort during teaching relative to comfortable level of effort was selected based on a pilot survey which supported this as a cut-off level between groups. The inclusion of the Voice Activity Participation Profile, the vocal symptoms checklist, and effort ratings after each speaking task provided additional measures to validate that the

two groups in this study were distinct. Mean overall scores for the measure that assessed impact of voice problems were significantly higher for the teachers with voice disorders than the control teachers, supporting the notion that these two groups were different. Mean voice-impact scores for subjects in this study were lower than the normative scores reported by Ma and Yiu (2001). Scores for the control teachers were within one standard deviation of those reported by Ma and Yiu (2001), whereas scores for the teachers with voice disorders were within two standard deviations of the Ma and Yiu (2001) voice-disordered group. The differences in scores for the voice-disordered groups between studies were likely due to the inclusion of all severity levels and multiple types of laryngeal pathology in the validation study conducted by Ma and Yiu (2001). In the present study, people with laryngeal pathology were excluded.

In addition to assessing impact of voice problems, assessment of voice and vocal mechanism symptoms differentiated the two teacher groups; the voice-disordered group reported a significantly greater frequency of symptoms as compared to the control group. Thus, it seems that the use of a pre-determined, differential effort criterion for difference in comfortable versus actual level of speaking effort, in combination with the other subject inclusion criteria used in this study, resulted in two distinct subject populations. This study incorporated multiple inclusion/exclusion criteria and multiple descriptive measures of voice problems in an effort to maximally differentiate groups with and without voice problems, and to increase the likelihood that other researchers and clinicians could generalize findings to patients with similar characteristics.

Ratings of effort directly after each of the spontaneous speaking tasks were also included in this study as an additional assessment of the percept of effort. Although effort ratings 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. There are several possible reasons for this lack of statistical difference in effort ratings for speaking tasks. High degrees of within-group, inter-subject variability likely contributed to the non-significant findings. It is also likely that the 3 minute speaking tasks used in this study did not evoke the same symptoms that an entire teaching day or a one-hour lecture would invoke. Therefore, when teachers with voice problems reported on frequency of vocal symptoms during teaching, they showed significantly higher scores than teachers without voice problems, but did not show these significant differences for ratings of task effort. Another possibility is that on-line ratings of effort, for example at 30-second intervals throughout the speaking tasks, might have better reflected effort differences between groups than ratings directly after the task, which involved a retrospective memory component.

Overall, it appears that the percept of increased speaking effort is a critical aspect of defining voice disorders. Use of differences between comfortable and actual teaching effort ratings helped differentiate teachers with voice problems from teachers without voice problems. Comparison to other measures of degree of voice difficulty validated the distinctness of these two groups. Previous research in voice disorders has shown that effort ratings correlate well to certain physiologic variables and effort ratings change over the course of a fatigue-inducing speaking task (Solomon, 2000; Solomon & DiMattia,

2000; Stemple et al., 1995). In this study, additional inclusion/exclusion criteria likely contributed to the group differentiation as well, such as self-definition of voice as a problem and report of frequently occurring symptoms for the voice-disordered group, and the exclusion of control subjects based on these criteria.

Symptoms of Voice/Vocal Mechanism Problems

Teachers with voice problems reported symptoms of voice and vocal mechanism difficulty while teaching at a significantly higher frequency than teachers without voice problems. The sum score of vocal symptoms was nearly four times higher for the teachers with voice disorders as compared to the control group. The nature of these symptoms was somewhat different for each group. The most highly represented category for teachers with voice disorders was that representing symptoms of effort, work and fatigue associated with talking. Therefore, for teachers with voice disorders in this study, symptoms related to increased effort, weakness, and fatigue were the most salient aspect of their disorder. The category of auditory changes to the voice was the second most frequently represented for the voice-disordered group, followed by mental effort associated with speaking. The relative prominence of this category in teachers with voice disorders is not surprising, since the salient features of voice disorders to both patients and observers are often those that are auditory.

Teachers without voice problems also reported symptoms related to effort, work and fatigue most frequently, although their category score was nearly three times lower than that of the voice-disordered group. Therefore, teachers without a voice disorder also experienced a low level of effort, work, and fatigue symptoms as a component of their

teaching experience. This makes intuitive sense given the heavy vocal demands that teachers are faced with. Unlike with the teachers in the voice-disordered group, symptoms related to auditory voice changes were reported least frequently by teachers without voice problems, with a frequency of symptoms more than seven times lower than for the control group. Therefore, report of auditory changes to voice might be minimally expected in teachers who are not experiencing voice problems.

Across all symptom categories, those symptoms that primarily affected the laryngeal region were more frequently represented than those affecting the respiratory system for the voice-disordered group. Thus, although teachers with voice disorders showed abnormal respiratory patterns during speech, symptoms of difficulty in this subsystem were not as prominent to these teachers. Teachers without voice difficulty reported respiratory symptoms at a somewhat greater frequency than teachers with voice problems. For example, the symptom of running out of air while talking was the 5th most frequently reported for the control group, versus the 22nd most frequently reported for teachers in the voice-disordered group. The symptom of difficulty getting enough air while talking was the 15th most frequently reported symptom for the control group, versus the 23rd most frequently reported for teachers in the voice-disordered group. Objective assessment showed significantly higher lung volume levels during speech production in the teachers without voice difficulty. Perhaps the increased awareness of low lung volume levels aided these teachers in achieving higher lung volume levels. Conversely, it is possible that if teachers had rated symptoms on-line during speaking

tasks, respiratory symptoms may have been more salient for teachers with voice problems.

Critique of the Method

The strengths of this study included novel findings relative to respiratory function in teachers, novel methods for the use of electroglottography in continuous speech, support for the use of speaking effort as a criterion for subjects with voice disorders, and assessment of the physiologic characteristics of teachers with voice disorders in speaking contexts that were applicable to the context associated with their voice difficulty. The following critique will focus on these study strengths, and will also address study limitations.

Study Strengths

This was the first study of respiratory function in teachers. Due to the overrepresentation of teachers in voice clinics (Titze et al., 1997), the occupational risk that teaching carries for having a voice disorder (Roy et al., 2004; Thibeault et al., 2004), and the negative impact of voice problems in teachers (E. Smith et al., 1997; Verdolini & Ramig, 2001), many investigators have studied symptomatology, prevalence rates, acoustic characteristics, and treatment approaches for teachers with voice disorders (Gotaas & Starr, 1993; Kostyk & Rochet, 1998; Roy et al., 2001; Roy et al., 2002; Yiu & Ma, 2002). However, few researchers have reported on the physiologic characteristics that might underlie symptoms and acoustic characteristics of voice problems.

Determination of physiologic differences between teachers with and without voice

problems is critical to understanding etiology of and appropriate treatment for those voice problems.

This was the first group study to investigate speech breathing behavior in people with voice problems that are not associated with laryngeal pathology. Previous research has demonstrated speech breathing differences for individuals with voice disorders characterized by laryngeal lesions (Sapienza & Stathopoulos, 1994; Sapienza et al., 1997; Schaeffer et al., 2002). However, respiratory differences in speech breathing for people with laryngeal pathology may be a compensation for the inadequate closure at the level of the vocal folds, rather than a characteristic of their disorder (Sapienza et al., 1997). In this study, laryngeal pathology was ruled-out, and therefore did not contribute to respiratory differences between groups.

This study was the first to objectively measure respiratory and laryngeal function simultaneously during spontaneous, continuous speaking. Simultaneous assessment of respiratory and laryngeal behavior may be important to understanding the physiology of teachers with voice disorders. Previous research has shown that lung volume level may influence laryngeal and articulatory characteristics during speech production (Iwarsson et al., 1998; Milstein & Watson, 2004; Watson & Ciccio, 2003).

A novel method for the use of electroglottography to track contact quotient and contact index during continuous speech was introduced in this study. Consistency in electroglottography measures was noted across all spontaneous speaking tasks, supporting the idea that the method set forth was a reliable way to track these variables during continuous speech. The inclusion of a sustained vowel allowed for comparison

between the novel and standard methods of electroglottography measurement. The inclusion of a paragraph reading task allowed for comparison of electroglottography measures derived from a speech sample in which phonemic content was the same for all speakers to electroglottography measures derived from spontaneous speech, in which phonemic content varied across speakers. Electroglottography measures were not significantly different for the reading task as compared to any of the spontaneous speaking tasks. This indicates that the varying phonemic content during spontaneous speech did not differentially affect electroglottography measures for those tasks. In all likelihood, phonemic content would be balanced across speakers for the length of analyzed speech that was included in this study.

In this study, a rationale was provided for using the percept of effort as a core characteristic of vocal fatigue. Operationally defining voice disorders that occur in the absence of laryngeal structural pathology has presented great challenges to researchers in voice and voice disorders. The symptom of vocal fatigue has emerged as a common feature of these voice disorders in teachers and the voice-disordered population as a whole. However, vocal fatigue presents a constellation of composite symptoms itself, and researchers who have studied vocal fatigue have used quite disparate inclusion criteria for subjects (Eustace et al., 1996; Gotaas & Starr, 1993; Kostyk & Rochet, 1998). Results of this study supported the notion that use of effort ratings that indicate a difference between comfortable and actual effort levels appropriately differentiated teachers with voice problems from teachers without voice problems. Symptoms related to effort, weakness and fatigue were also the most frequently occurring for teachers with

a voice disorder, at a rate nearly three times higher than for teachers without voice problems.

This study included several components to more closely approximate the teaching situation in which teachers were reporting voice problems. Research assistants acted as “student listeners” or conversational partners to present a more natural speaking context for all speaking tasks. Speaking tasks included simulated teaching lectures that were personally relevant to each subject. Teachers were told that the videotapes of their teaching tasks would be rated by a group of students for aspects of teacher efficacy. Subjects reported after completion of the study that they believed the videotapes would be rated, and therefore “tried harder” to make their mock lectures realistic. Therefore it seemed that the methods employed to better approximate a realistic teaching situation were effective.

Finally, this study is one of the few to assess laryngeal behavior during continuous speaking. Due to instrument limitations, previous research assessing laryngeal function has mostly measured that function during a sustained vowel versus during continuous speech production (Eustace et al., 1996; Morrison, Nichol, & Rammage, 1986; Orlikoff, 1991; Orlikoff et al., 1997; Sama et al., 2001; Stemple et al., 1995). The results of this study indicated that laryngeal function may be different during continuous speaking than during a sustained vowel. Results of previous research on acoustic differences (Brown Jr. et al., 1996; Fitch, 1990; Nitttrouer et al., 1990) and differences in supraglottic activity (Stager et al., 2000) that are evidenced across speaking tasks support the task differences seen in this study.

Study Limitations

There are several limitations to this study. Limitations of the measurement environment and restrictions to subject movement will be discussed first. Lack of sound pressure level control and its influence on electroglottography measures will be discussed next. Finally, because the method of electroglottography analysis presented in this study is novel, more detailed discussion of the variability associated with these measures will be discussed, with reference to statistical testing of differences in relative signal quality and signal variability.

Data in this study were not collected in a natural environment. A common problem that researchers are faced with is that of measuring subject behavior in an artificial environment with the hope that these behaviors represent those typically demonstrated by the subject in their natural environment. Measurement of any behavior also increases a subject's awareness of that behavior. The goal in this study was to assess the respiratory and laryngeal physiologic differences of teachers with and without voice problems. As such, the effects of the measurement environment, which was an artificial lab rather than the natural classroom environment, were presumably the same for both groups and should not have affected group differences. Nevertheless, if it were feasible to operate all the necessary equipment in the classroom, actual classroom measurement of these behaviors would have been ideal. Teachers in this study were tested in the seated position, and were instructed to minimize any body movements as these could result in signal artifacts. Most teachers reported that they typically teach in a standing position,

and usually move a great deal when teaching. These constraints were necessary to achieve appropriate signals, but made the testing situation less realistic.

In an effort to measure physiologic behavior that was representative of each teacher's true patterns, sound pressure level was allowed to vary within and across subjects. The only constraint placed on sound pressure level was during the teaching task that required subjects to teach at increased loudness level. A 10 dB increase was targeted in this task, but individual targeted levels were each different. Previous research has shown that sound pressure level is correlated to the two electroglottography measures used in this study: contact quotient and contact index (Orlikoff, 1991). The optimal experimental control for assessing electroglottography measures would therefore be under conditions in which sound pressure level is controlled at a standard level for all speakers across all speaking tasks. However, this control of sound pressure level would have resulted in speech production that was atypical to each subject's individual patterns. Therefore, sound pressure levels were recorded so that its influence could be assessed, but allowed to vary so that natural respiratory and laryngeal function could be demonstrated. As discussed earlier, electroglottography measures did not show task differences for the task comparisons that represented the greatest differences in sound pressure level. Furthermore, sound pressure level was not correlated to contact index for either of the tasks that showed a significant task difference (sound pressure level only showed a significant correlation to contact index for the loud simulated teaching task). These results therefore indicate that sound pressure alone did not account for the task difference in contact phase symmetry.

The relative signal quality and degree of intra-subject variability differed across speaking tasks, but did not differ between groups. Harmonics-to-noise ratios, which provided an indicator of relative signal quality, were higher for the two sustained vowel tasks (sustained /a/ and maximum phonation time /a/) in comparison to all other speaking tasks. Thus, analyzing electroglottography measures during continuous speech resulted in lower signal quality as compared to analysis during sustained vowels. This is not surprising, as the continuous speech analysis covers a much longer time period, thus allowing for more noise and variability. In addition, continuous speech analysis will include portions of the signal that approach devoiced consonants, and thus will introduce more noise into the signal. This being said, mean difference scores between the sustained vowel tasks as compared to the continuous speaking tasks were relatively small (approximately 4 dB or less). Overall mean values for harmonics to noise ratios also indicated good signal quality. Furthermore, none of the continuous speaking tasks showed significant differences in relation to each other. Therefore, although signal quality was lower for continuous speech analysis, mean differences were relatively small, and signal quality was consistent and good across different continuous speaking contexts.

Some signal variability within subjects, across speaking tasks was also evidenced. Individual standard deviations for the electroglottography measures of contact quotient and contact index were calculated to assess this intra-subject variability. Comparisons of these values showed task differences, but not group differences. The task differences seemed to be explained by increased variability during the mock teaching task at an increased loudness level as compared to several of the other speaking tasks. It seems that

when increasing loudness level, subjects showed increased variability in their patterns of vocal fold contact and symmetry of the contact phase. Overall, however, the variability evidenced for electroglottography measures both within and across subjects was less than the variability evidenced for respiratory measures and effort ratings, indicating that the analysis of electroglottography during continuous speech introduces acceptable amounts of signal variation. Previous research has shown a great deal of intra-subject and inter-subject variability in both respiratory behavior (Winkworth et al., 1995; Winkworth et al., 1994) and laryngeal behavior (Sama et al., 2001), so some degree of variability in electroglottography analysis as a tool for measuring laryngeal function would be expected.

Future Directions

The results of this study suggest several interesting directions for future research in respiratory behavior, respiratory-laryngeal interactions, and the use of electroglottography for assessing dynamic laryngeal function. Research is needed to determine whether altering patterns of lung volume use in individuals with voice disorders would improve their voice quality, ratings of speaking effort, and self-perceived vocal symptoms. Based on the results of 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 to document the effects of respiratory training are generally limited to voice disorders with neurologic origin (Huber, Stathopoulos, Ramig, & Lancaster, 2003; L. O. Ramig & Countryman, 1995;

Thompson-Ward, Murdoch, & Stokes, 1997) or have focused on inspiratory or expiratory muscle training (Cerny, Panzarella, & Stathopoulos, 1997; Roy, Weinrich et al., 2003; Ruddy et al., 2004) rather than lung volume levels during speech production.

Assessing differences in abdominal versus rib cage contribution during speech production for subjects with voice disorders may also be of value. Huber et al. (2004) have shown that healthy subjects may employ different strategies for increasing loudness level. These researchers assessed abdomen contribution as an indicator of expiratory muscle use. It is possible that people with voice problems will employ different patterns of rib cage and abdomen contribution during speech production than those demonstrated by healthy subjects. Many clinicians promote the use of abdominal breathing techniques during therapy. However, studies to determine whether abdominal contribution varies for individuals with voice disorders relative to control subjects are limited to subjects with laryngeal pathology (Sapienza et al., 1997).

Further simultaneous study of the respiratory and laryngeal subsystems during speech production is also needed. Studies to date have investigated changes that occur to externally rated voice quality (Milstein & Watson, 2004) and acoustic characteristics of speech (Watson & Ciccio, 2003) as lung volume initiation levels are altered.

Determining the self-perceived changes to vocal parameters, including speaking effort, would be an important contribution to the existing literature on respiratory-laryngeal interactions. Furthermore, use of electromyography to directly study muscle activation might provide insight into the possible contributions of intrinsic and extrinsic laryngeal muscle activity to voice disorders. If conducted simultaneously with measures of lung

volume use during phonation, the interaction between lung volume levels and laryngeal muscle activation could be directly assessed.

Finally, this was the first study to investigate a method for using electroglottography to assess dynamic laryngeal changes during continuous speech. Future studies are needed to validate this analysis method. In addition, studies to document the use of electroglottography in continuous speech in the normal population would be helpful for establishing normative values and comparing those norms to the teacher populations in this study. In this study, a 25% cutoff level was used to define the minimum level of the contact phase (Orlikoff, 1991). This level was used so that data from this study could be compared to other normative data. It is possible that use of a different cutoff criterion could reveal greater differences in electroglottography measures when assessing the continuous speech signal. Future studies to compare electroglottography measures derived with differing minimum cutoff levels would be useful to determine the effect of this criterion on contact quotient and contact index. Furthermore, investigation of the changes that occur to vocal fold contact and symmetry of contact as a function of varying voice quality during continuous speaking would provide a comparison to previous studies that have investigated electroglottography change with voice quality in extended vowel utterances (Motta et al., 1990; Peterson et al., 1994).

APPENDIX A
GENERAL SUBJECT CRITERIA

General Subject Criterion	Determinant	Rationale
Good general and respiratory health	Self-report (medical history)	Respiratory, cardiovascular, or neurologic disease may affect multiple speech subsystems (Darley, Aronson, & Brown, 1975; Lee, Loudon, Jacobson, & Stuebing, 1993). Infection may affect the respiratory and laryngeal subsystems (Boone & McFarlane, 2000; I. M. Smith, 1985)
Non-smoking for at least 5 years	Self-report	Respiratory disease is associated with smoking and affects respiratory function (US Department of Health and Human Services, 2004). Laryngeal disease is associated with smoking and affects laryngeal function (Boone & McFarlane, 2000; Case, 2002). The criterion of non-smoking for at least 5 years has been used in previous speech breathing studies (Hoit & Hixon, 1987; Hoit et al., 1989).
Adequate hearing so as not to affect speech breathing or voice	Hearing screening 40 dB HL at 1000, 2000, & 4000 Hz	Profound hearing impairment (HI) and total deafness have been associated with speech breathing differences (Forner & Hixon, 1977; Lane, Perkell, Svirsky, & Webster, 1991). A less stringent screening level, based on threshold shifts considered normal for subjects 50 years or older (Morrell et al., 1996), was used to reduce the likelihood of severe to profound HI in subjects. Current standards for hearing screening assess the frequencies of 1000, 2000, and 4000 Hz (ASHA, 1997).
English as the primary language	Self-report	Spoken language characteristics may affect speech breathing (Hixon, 1991)
Normal speech and language skills	Binary, unanimous judgment of normal for three speaking tasks	Reduce the influence of disordered speech or language skills on voice or breathing characteristics

General Subject Criterion Continued	Determinant	Rationale
No body mass index that falls in the obese range	Self-report of height and weight, calculation of body mass index	Obesity may influence respiratory function, and adequate EGG signals are difficult to obtain in necks with increased adipose tissue (Baken & Orlikoff, 2000). Influence of height and body size differences was minimized by presenting all dependent measures as a normalized percent of vital capacity.
Age range of 22 to 56 years	Self-report	Minimal differences in speech breathing have been noted for subjects in the 25 to 50 year age ranges, whereas some differences have been noted when comparing 25 year-old to 75 year-old subjects (Hoit & Hixon, 1987; Hoit et al., 1989). Changes to laryngeal structure have been described in the 5 th decade, but are most pronounced in the 6 th decade and beyond (Colton & Casper, 1996; Hirano, Kurita, & Nakashima, 1983; Kahane, 1983). Changes to laryngeal function in older subjects appear to be associated with disease processes or degree of physical health versus age itself (L. A. Ramig & Ringel, 1983; Woo, Casper, Colton, & Brewer, 1992).
Inclusion of both males and females	General recruitment procedures	Studies comparing EGG data for males and females indicate that CQ does not show a sex effect (Orlikoff, 1991). Sex effects related to torso size differences for respiratory measures were minimized by presenting all measures as a percent vital capacity. To further minimize group differences relative to sex, equal ratios of females to males were included in each group.

General Subject Criterion Continued	Determinant	Rationale
No history of voice therapy	Self-report	Voice treatment often includes respiratory and laryngeal components (Stemple et al., 2000) which may alter speech breathing and laryngeal function
No history of professional voice training	Self-report	Professional acting or singing training may influence speech breathing (Hixon, 1991)
No history of vocal fold pathology or surgery to the larynx	Self-report	Laryngeal tissue changes may be evidenced after laryngeal surgery and may affect voice characteristics
No evidence of laryngeal pathology at time of testing	Videostroboscopy examination with review of videotaped images by otolaryngologist	Speech breathing differences have been described for subjects with laryngeal pathology (Sapienza & Stathopoulos, 1994; Sapienza et al., 1997)

APPENDIX B
SUBJECT CRITERIA FOR THE VOICE-DISORDERED GROUP

Voice-Disordered Subject Criterion	Determinant	Rationale
Current problem with the voice or vocal mechanism	Self-report (vocal index questionnaire)	Voice disorder is typically defined by patient report of a problem or disruption in function (Verdolini & Ramig, 2001)
Increased sense of effort when using voice for teaching	Psychophysical visual analog scale which measured actual effort during teaching versus comfortable level of effort in mm. A difference of 15 mm or more between comfortable and actual used as criterion for voice disordered inclusion.	Increased speaking effort has been consistently reported in voice disordered subjects (Eustace et al., 1996; Gotaas & Starr, 1993; Kostyk & Rochet, 1998) and has been shown to differentiate voice disordered subjects from controls (Verdolini, 2004). See Appendix E for pilot survey determining the 15 mm criterion.
Frequent voice problems	Self-report (vocal index questionnaire) of symptoms occurring at a frequency of once or more weekly	Include voice disordered subjects with a relatively consistent voice problem. Once or more weekly has been used to define frequent voice problems in previous voice studies (Kostyk & Rochet, 1998; McCue et al., 2001)
Onset of voice problems 3 or more months prior to testing	Self-report (vocal index questionnaire)	Include voice disordered subjects with a relatively persistent voice problem

APPENDIX C
SUBJECT CRITERIA FOR THE CONTROL GROUP

Control Subject Criterion	Determinant	Rationale
No current problem with the voice or vocal mechanism	Self-report (vocal index questionnaire)	Include subjects in the control group who are not defining voice as a problem
No percept of increased effort when using voice for teaching	Visual analog scale which measured actual effort during teaching versus comfortable level of effort in mm. A difference of less than 15 mm between comfortable and actual speaking effort was used as the criterion for control subject inclusion.	Increased speaking effort has been consistently reported in voice disordered subjects (Eustace et al., 1996; Gotaas & Starr, 1993; Kostyk & Rochet, 1998) and has been shown to differentiate voice disordered subjects from controls (Verdolini, 2004). A lack of speaking effort would therefore be important in selecting control subjects who are not having voice problems. In a pilot survey (see Appendix E), a mean difference score of 15 mm appeared to be an appropriate compromise value for ruling out control subjects with voice problems while including voice disordered subjects with increased speaking effort.
Normal voice and resonance	Unanimous judgment of normal on a binary scale (normal/abnormal) as assessed during standard sentences and two spontaneous speech samples	Reduce the likelihood of including subjects in the control group who have abnormal voice characteristics that are not self-perceived. Studies in voice and speech breathing have incorporated external ratings of normal speech or voice as a criterion for normal subjects (Hoit & Hixon, 1987; Kostyk & Rochet, 1998; Sapienza et al., 1999; Sapienza et al., 1997).

APPENDIX D
VOCAL COMPLAINT INDEX

Subject Code _____

Date _____

When you are teaching, do you have problems with how your voice sounds or feels?
Yes / No

Please describe the problems with how your voice sounds:

Please describe the problems with how your voice feels:

(If response does not include statements re: increased effort/work/exertion or weak/tired voice)

Do these problems include an increased sense of effort while using your voice for teaching?
Yes / No

How often do you experience these problems when you are teaching:
____ **Never/Rarely** (not at all, or 1-2 times a year only, associated with illness)
____ **Sometimes** (approximately once a month or less)
____ **Often** (once a week or more)
____ **Always** (almost every time I teach)

When did these problems begin?

Are you experiencing these problems with your current teaching duties?
Yes / No

Describe your typical teaching situation relative to:
class size:

length of talking time:

background noise:

sitting or standing position while teaching:

How much speaking effort, on average, do you feel when teaching a typical class? (mark "x" on the line with RED)

Now indicate what a comfortable level of speaking effort would be when teaching a typical class (mark "x" on the line above with GREEN)

Do you find that the problems you experience with how your voice sounds change from the beginning to the end of your teaching day or within a lecture?

Do you find that the problems you experience with how your voice feels change from the beginning to the end of your teaching day or within a lecture?

Do you experience these problems with how your voice sounds or feels in any other situations besides teaching?
Yes / No

Please describe those situations:

APPENDIX E

PILOT SURVEY AND SURVEY RESULTS

When you are teaching, do you have problems with how your voice sounds or feels?
(Yes / No)

Please describe these problems:

How often do you experience these problems when you are teaching:

_____ **Never/Rarely** (not at all, or 1-2 times a year only, associated with illness)

_____ **Sometimes** (approximately once a month or less)

_____ **Often** (once a week or more)

_____ **Always** (almost every time I teach)

How much speaking effort, on average, do you feel when teaching a typical class? (mark on the line with an x)

<div style="position: absolute; left: -5px; top: 50%; bottom: 50%; border-left: 1px solid black; width: 5px;"></div>	<div style="position: absolute; right: -5px; top: 50%; bottom: 50%; border-right: 1px solid black; width: 5px;"></div>
No effort	Extreme effort

Now indicate what a comfortable level of speaking effort would be when teaching a typical class (mark on the line above with a vertical line)

N = 41 surveys returned

Survey results for those instructors reporting “no” to having voice problems

N = 26

Mean = 1.17 mm

Median = 0.0 mm

St.Dev. = 13.55 mm

Range = -34 to 34 mm

Survey results for those instructors reporting “yes” to having voice problems

N = 15

Mean = 18.23 mm

Median = 13.0 mm

St.Dev. = 15.99 mm

Range = 0 to 49 mm

Symptom frequency of “sometimes”

N = 7

Mean = 14.75 mm

Median = 8.0 mm

St.Dev. = 15.98 mm

Range = 0 to 47 mm

Symptom frequency of “often”

N = 8

Mean = 21.71 mm

Median = 22.0 mm

St.Dev. = 16.38 mm

Range = 1 to 49 mm

APPENDIX F VOCAL USE QUESTIONNAIRE

VOCAL QUESTIONNAIRE

Subject Code: _____ Date of Birth: _____ Age: _____

Sex: _____

Height: _____ Weight: _____

Street Address: _____

City: _____ State: _____ Zip code: _____ Phone: (____) _____ Today's Date: _____

School where you teach: _____ Subject taught: _____ Grade level taught: _____

Primary, Dominant Language: _____

SECTION I

CURRENT EXPERIENCE (TODAY) OF THE FOLLOWING: (circle yes or no; y/n)

Allergy or cold symptoms: y / n; type _____

Flu, respiratory infection, or other illness symptoms: y / n; type _____

CURRENT EXPERIENCE OR HISTORY OF THE FOLLOWING: (circle yes or no; y/n)

Laryngeal/throat surgery: y / n; type _____ when _____

Traumatic injury to the larynx/throat: y / n; type _____ when _____

Medically diagnosed:

Neurological disorder: y / n; type _____

Neuromuscular disorder: y / n; type _____

Cardiovascular disorder: y / n; type _____

Pulmonary disorder, including asthma: y / n; type _____

Allergies: y / n; type _____

Congenital (from birth) laryngeal/voice disorder: y / n; type _____

Organic voice (e.g., polyps, nodules, etc.) disorder: y / n; type_____ when_____

Psychological disorder requiring treatment: y / n; type_____ when_____

Swallowing disorder: y / n; when_____ type_____

Gastro-esophageal reflux disease: y / n; when_____ current/previous medication_____

Hormone imbalance/disorder: y / n; when_____ current/previous medication_____

Underwent/undergoing:

Menopause: y / n; pre-menopausal_____ post-menopausal_____

Hormone therapy: y / n; when_____ what kind_____ how long_____

Voice therapy: y / n; when_____ where_____ how long_____

University/college or professional vocal/theatrical training: y / n

If yes, nature of training:

*Current prescription or over-the-counter medication:*___ type(s) _____

Tobacco Use: y / n; If yes, How many years_____ Current packs/wk_____ If < 1 pack,
cigarettes/wk_____

If you have quit how many years since you have last smoked_____

Water intake: How many 8 oz. Glasses/day_____

Miscellaneous: (Check all that occur at least 4/7 days per week)

Eat before bed_____ Eat spicy food_____ Use a humidifier_____

SECTION II

OCCUPATION(S):

Amount of voice use for occupation:

mild (0 to 3 hrs.)____ moderate (3+ to 6 hrs.)____ heavy (6+ hrs.) ____

Hours/day at work____ Percentage of time using voice____

All other voice use: (voice use outside of work- remainder of your day)

mild (0 to 3 hrs.)____ moderate (3+ to 6 hrs.)____ heavy (6+ hrs.) ____

Hours/day outside of work____ Percentage of time using voice____

Speaking over background noise (e.g., music, customers, machines, children, etc.):

yes____ no____ if yes, describe_____

SECTION III

RECREATIONAL/ADDITIONAL ACTIVITIES: (check all that apply and list hours per week)

<u>Activity</u>	<u>Hours per week on average</u>
Sports participant[list sport(s)]_____	_____
Sports spectator [list sport(s)]_____	_____
Sports coach [list sport(s)]_____	_____
Choir____ professionally trained: yes____ no____ where_____	_____
Primary caretaker for child(ren)____ How many children_____	_____
Supervise children (e.g., babysitting, scouts, etc) How many children_____	_____
Attendance at bars, clubs/discos, pool halls, house parties, etc.____	_____
Other activities (please list) with moderate (3+ to 6 hrs.) to heavy (6+ hrs.) voice use:	
Activity_____	_____
Activity_____	_____
Activity_____	_____

APPENDIX G
VOICE ACTIVITY PARTICIPATION PROFILE, OR VAPP

Voice Activity and Participation Profile

1. How severe is your voice problem now?

Normal	<div style="position: absolute; left: -5px; top: 50%; transform: translateY(-50%); border-left: 1px solid black; height: 20px;"></div> <div style="position: absolute; right: -5px; top: 50%; transform: translateY(-50%); border-right: 1px solid black; height: 20px;"></div>	Severe
--------	---	--------

Please answer the following questions by putting a cross (“x”) on the line which best represents your answer. A cross towards the left side means you are never affected while a cross towards the right side means you are always affected.

Effect on job

2. Is your job affected by your voice problem?

Never	<div style="position: absolute; left: -5px; top: 50%; transform: translateY(-50%); border-left: 1px solid black; height: 20px;"></div> <div style="position: absolute; right: -5px; top: 50%; transform: translateY(-50%); border-right: 1px solid black; height: 20px;"></div>	Always
-------	---	--------

3. In the last 6 months, have you thought of changing your job because of your voice problem?

Never	<div style="position: absolute; left: -5px; top: 50%; transform: translateY(-50%); border-left: 1px solid black; height: 20px;"></div> <div style="position: absolute; right: -5px; top: 50%; transform: translateY(-50%); border-right: 1px solid black; height: 20px;"></div>	Always
-------	---	--------

4. Has your voice problem created any pressure on your job?

Never	<div style="position: absolute; left: -5px; top: 50%; transform: translateY(-50%); border-left: 1px solid black; height: 20px;"></div> <div style="position: absolute; right: -5px; top: 50%; transform: translateY(-50%); border-right: 1px solid black; height: 20px;"></div>	Always
-------	---	--------

5. In the last 6 months, has your voice problem affected your decisions for your future career?

Never	<div style="position: absolute; left: -5px; top: 50%; transform: translateY(-50%); border-left: 1px solid black; height: 20px;"></div> <div style="position: absolute; right: -5px; top: 50%; transform: translateY(-50%); border-right: 1px solid black; height: 20px;"></div>	Always
-------	---	--------

Effect on daily communication

6. Do people ask you to repeat what you have just said because of your voice problem?

Never		Always
-------	--	--------

7. In the last 6 months, have you ever avoided talking to people because of your voice problem?

Never		Always
-------	--	--------

8. Do people have difficulty understanding you on the phone because of your voice problem?

Never		Always
-------	--	--------

9. In the last 6 months, have you reduced the use of the telephone because of your voice problem?

Never		Always
-------	--	--------

10. Does your voice problem affect your communication in quiet environments?

Never		Always
-------	--	--------

11. In the last 6 months, have you ever avoided conversations in quiet environments because of your voice problem?

Never		Always
-------	--	--------

12. Does your voice problem affect your communication in noisy environments?

19. In the last 6 months, have you ever avoided social activities because of your voice problem?

Never		Always
-------	--	--------

20. Are your family, friends, or co-workers annoyed by your voice problem?

Never		Always
-------	--	--------

21. In the last 6 months, have you ever avoided communicating with your family, friends, or co-workers because of your voice problem?

Never		Always
-------	--	--------

Effect on your emotion

22. Do you feel upset about your voice problem?

Never		Always
-------	--	--------

23. Are you embarrassed by your voice problem?

Never		Always
-------	--	--------

24. Do you have low self-esteem because of your voice problem?

Never		Always
-------	--	--------

25. Are you worried about your voice problem?

Never		Always
-------	--	--------

26. Do you feel dissatisfied because of your voice problem?

Never			Always
-------	--	--	--------

27. Does your voice problem affect your personality?

Never			Always
-------	--	--	--------

28. Does your voice problem affect your self image?

Never			Always
-------	--	--	--------

From Ma and Yiu (2001), *Journal of Speech, Language, and Hearing Research*, 44, 511-524.

APPENDIX H
PREDOMINANTLY VOICED PARAGRAPH

Every day you drive over the bridge is a grand day. Under the big, bold iron beam lies an undeniably wide river - broadly running down the gorge, dividing and diverging over a boulder, raging along the wall, winding miles and miles. Everyone is moved by the river. Me? I love the loud roar, I really do. Many do not. They avoid the water although they enjoy the bridge while never going near the river's edge. Either way, all are drawn by the river's unbelievably gurgling energy. Every day you drive over the bridge is a grand day. Under the big, bold iron beam lies an undeniably wide river - broadly running down the gorge, dividing and diverging over a boulder, raging along the wall, winding miles and miles. Everyone is moved by the river. Me? I love the loud roar, I really do. Many do not. They avoid the water although they enjoy the bridge while never going near the river's edge. Either way, all are drawn by the river's unbelievably gurgling energy.

(DeFeo, 2005)

APPENDIX I
SPEAKING TASK EFFORT RATINGS

SPEAKING TASKS

Green = conversational spontaneous

Blue = mock teaching

Red = mock teaching loud

Subject code: _____

How much speaking effort did you feel during that talking task?

<div style="position: absolute; left: -5px; top: 50%; bottom: 50%; border-left: 1px solid black; width: 5px;"></div>	<div style="position: absolute; right: -5px; top: 50%; bottom: 50%; border-right: 1px solid black; width: 5px;"></div>
No effort	Extreme effort

Where did you feel the effort?

Task 1:

Task 2:

Task 3:

Did you feel any other sensations besides effort?

Task 1:

Task 2:

Task 3:

APPENDIX J VOCAL SYMPTOMS CHECKLIST

Vocal Symptoms Checklist

Subject Code:_____ **Date:**_____

Relative to **how you feel when using your voice for teaching**, please circle the frequency at which you experience any of the following sensations:

Frequency definitions:

Never/Rarely: not at all, or 1-2 times a year only, associated with illness

Sometimes: approximately once a month or less

Often: once a week or more

Always: almost every time I teach

Tension in neck/shoulders	Never/Rarely	Sometimes	Often	Always
Tightness in neck/shoulders	Never/Rarely	Sometimes	Often	Always
Pain/discomfort in shoulders or neck	Never/Rarely	Sometimes	Often	Always
Pain in throat	Never/Rarely	Sometimes	Often	Always
Tightness/constriction in throat	Never/Rarely	Sometimes	Often	Always
Tension in throat	Never/Rarely	Sometimes	Often	Always
Throat/voice mechanism feels tired	Never/Rarely	Sometimes	Often	Always
Throat feels dry	Never/Rarely	Sometimes	Often	Always
Need to use more effort for speaking	Never/Rarely	Sometimes	Often	Always
Need to work harder to speak	Never/Rarely	Sometimes	Often	Always
Need to cough/throat clear more	Never/Rarely	Sometimes	Often	Always
Tightness/tension in chest	Never/Rarely	Sometimes	Often	Always
Tightness/tension in belly	Never/Rarely	Sometimes	Often	Always
Chest or belly feels tired	Never/Rarely	Sometimes	Often	Always
Run out of air while talking	Never/Rarely	Sometimes	Often	Always
Hard to get enough air while talking	Never/Rarely	Sometimes	Often	Always
Have to think more about what I'm saying	Never/Rarely	Sometimes	Often	Always
Have to think more about my voice	Never/Rarely	Sometimes	Often	Always

Other; please describe:

Relative to **how your voice sounds when teaching**, please circle the frequency at which you experience any of the following sensations:

Frequency definitions:

Never/Rarely: not at all, or 1-2 times a year only, associated with illness

Sometimes: approximately once a month or less

Often: once a week or more

Always: almost every time I teach

Hoarse/husky voice quality	Never/Rarely	Sometimes	Often	Always
Unsteady voice	Never/Rarely	Sometimes	Often	Always
Breathy voice quality	Never/Rarely	Sometimes	Often	Always
Loss of voice	Never/Rarely	Sometimes	Often	Always
Difficulty maintaining typical pitch	Never/Rarely	Sometimes	Often	Always
Pitch breaks or changes unpredictably	Never/Rarely	Sometimes	Often	Always
Range of pitch (high and low pitches) is reduced	Never/Rarely	Sometimes	Often	Always
Range of loudness (loud or soft voice) is reduced	Never/Rarely	Sometimes	Often	Always
Decreased loudness / power of voice	Never/Rarely	Sometimes	Often	Always

Other; please describe:

Are you experiencing any of these symptoms today? Yes No

APPENDIX K
SUBJECT CHARACTERISTICS PERTINENT TO RESPIRATORY MEASURES

Key: Voice-disordered=VDis, Control=Con. Resting expiratory level=REL, vital capacity=VC, feet=ft., inches=in., pounds=lbs., body mass index=BMI.

Subject	VC (L)	REL (%VC)	Height (ft, in)	Weight (lbs.)	BMI
VDis1	3.4	32.0	5'5"	150	25
VDis2	3.3	33.3	5'10"	146	21
VDis3	3.6	31.9	5'4"	135	23
VDis4	3.0	46.7	5'5"	125	20
VDis5	3.03	43.8	5'7"	115	18
VDis6	2.85	35.1	5'3"	125	22
VDis7	3.85	46.8	5'5"	155	25
VDis8	3.88	38.1	6'2"	166	21
VDis9	4.82	33.2	5'6"	150	24
Con1	3.8	34.2	5'3"	155	27
Con2	3.7	35.1	5'7"	145	22
Con3	3.7	36.5	5'4"	150	25
Con4	3.8	43.4	5'6"	155	25
Con5	3.85	33.8	5'4"	127	21
Con6	6.3	30.2	6'0"	185	25
Con7	5.63	34.7	6'1"	170	22
Con8	3.75	37.3	5'4"	120	20
Con9	3.5	35.7	5'9"	190	28

APPENDIX L
GROUP MEANS AND INDIVIDUAL DATA FOR RESPIRATORY MEASURES

Key: Lung volume initiation-reference REL=LVI-R, Lung volume termination-reference REL=LVT-R, lung volume excursion=LVE, percent vital capacity/syllable=%VC/syl. CONV=conversational speaking task, MOCK=mock teaching task, ML=mock loud teaching task. Standard deviation=SD.

Group Means for Respiratory Measures				
Variables	Voice-Disordered		Control	
	Mean (%VC)	(SD, %VC)	Mean (%VC)	(SD, %VC)
LVI-R CONV	13.70	8.71	21.46	12.55
LVI-R MOCK	13.55	7.87	26.01	12.38
LVI-R ML	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 ML	-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 ML	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 ML	1.36	0.44	1.22	0.36

Key: Voice-disordered=VDis, Control=Con. Lung volume initiation-reference REL=LVI-R, Lung volume termination-reference REL=LVT-R, lung volume excursion=LVE, percent vital capacity/syllable=%VC/syl. CONV=conversational speaking task, MOCK=mock teaching task, ML=mock loud teaching task. Standard deviation=SD.

Individual Subject Data for Respiratory Measures												
Subject	LVI-R CONV	LVT-R CONV	LVE CONV	%VC/syl CONV	LVI-R MOCK	LVT-R MOCK	LVE MOCK	%VC/syl MOCK	LVI-R ML	LVT-R ML	LVE ML	%VC/syl ML
VDis1	20.95	-10.79	31.74	1.92	24.73	-3.28	28.01	2.41	6.61	-15.23	21.84	2.28
VDis2	11.48	-6.88	18.36	1.28	11.97	-2.83	14.80	1.18	16.38	2.50	13.88	1.22
VDis3	8.35	-10.35	18.70	1.12	7.81	-6.68	14.49	1.09	5.27	-10.98	16.25	1.20
VDis4	25.27	2.89	22.38	1.31	14.90	-2.56	17.46	1.10	12.43	-3.80	16.22	1.23
VDis5	21.30	3.56	17.74	0.71	15.69	0.49	15.21	0.65	18.12	2.01	16.11	0.69
VDis6	3.01	-15.61	18.63	1.64	11.63	-8.48	20.11	1.92	-4.23	-20.75	16.52	1.70
VDis7	21.06	-8.65	29.71	1.35	25.14	-1.69	26.83	1.48	25.69	-0.59	26.28	1.50
VDis8	10.48	-8.38	18.86	1.03	9.87	-9.56	19.44	1.13	7.63	-7.85	15.48	1.25
VDis9	1.43	-17.42	18.85	0.85	0.23	-11.79	12.01	1.00	-3.49	-17.69	14.20	1.16
Con1	28.63	13.64	14.99	1.49	24.85	10.52	14.33	1.35	20.87	-1.28	22.15	1.45
Con2	40.00	13.80	26.20	1.16	47.82	25.04	22.77	1.28	47.02	26.22	20.80	1.31
Con3	30.74	11.75	18.99	0.95	35.29	18.69	16.60	0.86	44.89	19.90	24.99	1.25
Con4	1.84	-12.97	14.81	0.84	30.73	9.43	21.30	1.35	30.34	8.66	21.68	1.85
Con5	16.93	5.48	11.45	0.81	8.66	-2.70	11.36	0.79	16.29	3.07	13.22	0.95
Con6	6.38	-6.49	12.87	0.56	13.41	-1.45	14.86	0.76	14.38	-2.89	17.27	0.77
Con7	19.18	1.27	17.91	0.62	32.30	14.51	17.80	0.71	35.39	17.70	17.68	0.70
Con8	16.97	-5.65	22.62	0.79	14.11	-5.06	19.17	0.74	29.08	0.25	28.83	1.23
Con9	32.46	-5.71	38.18	1.19	26.95	2.20	24.76	1.49	25.44	-4.50	29.94	1.46

Key: Voice-disordered=VDis, Control=Con. Lung volume initiation-reference REL=LVI-R, Lung volume termination-reference REL=LVT-R, lung volume excursion=LVE, percent vital capacity/syllable=%VC/syl. READ=paragraph reading task, /a/=sustained /a/ vowel, MPT /a/=maximum phonation time /a/ vowel.

Individual Subject Data for Respiratory Measures										
Subject	LVI-R READ	LVT-R READ	LVE READ	%VC/syl READ	LVI-R /a/	LVT-R /a/	LVE /a/	LVI-R MPT /a/	LVT-R MPT /a/	LVE MPT /a/
VDis1	31.17	10.67	20.50	2.30	39.09	-3.57	42.66	33.91	-21.00	54.91
VDis2	10.92	2.50	8.42	0.74	15.05	-29.55	44.60	12.31	-26.02	38.33
VDis3	7.71	-8.74	16.46	1.01	21.15	-12.14	33.29	53.25	-17.37	70.62
VDis4	17.33	3.23	14.10	1.37	14.42	-35.53	49.95	16.54	-39.73	56.27
VDis5	22.24	7.74	14.50	0.50	14.06	-11.24	25.30	20.75	-28.09	48.84
VDis6	12.03	-7.13	19.15	1.78	20.67	-20.61	41.28	45.96	-17.54	63.50
VDis7	18.09	-4.34	22.43	1.10	44.49	-11.45	55.94	55.09	-32.21	87.30
VDis8	10.77	-6.10	16.88	1.37	13.98	-18.45	32.43	40.85	-20.87	61.72
VDis9	11.32	-1.34	12.66	0.83	23.93	0.40	23.53	45.59	-15.58	61.17
Con1	33.58	18.77	14.81	1.55	41.65	2.72	38.93	52.56	-14.92	67.48
Con2	27.87	15.01	12.86	0.77	17.74	-10.33	28.07	50.73	-18.25	68.98
Con3	35.79	25.09	10.70	0.48	30.82	15.43	15.39	31.56	-16.10	47.66
Con4	13.82	1.97	11.85	0.79	22.16	-7.54	29.70	27.69	-26.87	54.56
Con5	14.03	4.18	9.86	0.61	15.38	-11.71	27.09	45.53	-15.03	60.56
Con6	5.91	-1.70	7.61	0.52	11.70	-1.54	13.24	26.02	-27.80	53.82
Con7	19.21	8.91	10.31	0.55	27.99	19.09	8.90	43.73	6.26	37.47
Con8	18.33	4.70	13.63	0.68	14.74	-12.84	27.58	30.05	-15.85	45.90
Con9	31.07	12.79	18.28	1.33	20.99	-14.17	35.16	41.06	-18.34	59.40

APPENDIX M
FOLLOW-UP POSTHOC TESTS FOR ALL DATA

Key for all tables: Voice-disordered=VDis, Control=Con. Lung volume initiation-reference REL=LVI-R, lung volume termination-reference REL=LVT-R, lung volume excursion=LVE, percent vital capacity/syllable=%VC/syl. CONV=conversational speaking task, MOCK=mock teaching task, ML=mock loud teaching task, READ=paragraph reading, /a/=sustained /a/ vowel, MPT=maximum phonation time /a/ vowel. Standard error of measurement=SEM, decibels=dB, Tukey's HSD=Tukey's Honestly Significant Difference, p=significance levels, *denotes a significant effect

Tukey's HSD for Task x Group Interaction Effects with LVI-R Between-Subject Differences with Same-Task Comparisons			
Task Comparison	Mean Difference (%VC)	SEM (%VC)	<i>p</i>
VDisCONV to ConCONV	-7.76	3.47	.275
VDisMOCK to ConMOCK	-12.46	3.47	.025*
VDisML to ConML	-19.92	3.47	<.001*

Tukey's HSD for Task x Group Interaction Effects with LVE Between-Subject Differences with Same-Task Comparisons			
Group and Task Comparison	Mean Difference (%VC)	SEM (%VC)	<i>p</i>
VDisCONV to ConCONV	1.88	1.79	.894
VDisMOCK to ConMOCK	0.60	1.79	.999
VDisML to ConML	-4.42	1.79	.191

Tukey's HSD for Task Effects with LVT-R			
Task Comparison	Mean Difference (%VC)	SEM (%VC)	<i>p</i>
CONV to MOCK	-4.52	1.74	.036*
CONV to ML	-2.85	1.74	.243
MOCK to ML	1.67	1.74	.606

Tukey's HSD for Task Effects with VC/syl			
Task Comparison	Mean Difference (VC/syl)	SEM (VC/syl)	<i>p</i>
CONV to MOCK	-0.09	0.05	.152
CONV to ML	-0.20	0.05	.001*
MOCK to ML	-0.11	0.05	.065

Tukey's HSD for Task Effects with Harmonics:Noise Ratios			
Task Comparison	Mean Difference (dB)	SEM (dB)	<i>p</i>
CONV to MOCK	0.38	0.96	.999
CONV to ML	-0.40	0.96	.998
CONV to READ	-0.67	0.96	.981
CONV to /a/	-4.11	0.96	.002*
CONV to MPT	-4.02	0.96	.003*
MOCK to ML	-0.78	0.96	.964
MOCK to READ	-1.05	0.96	.882
MOCK to /a/	-4.49	0.96	.001*
MOCK to MPT	-4.40	0.96	.001*
ML to READ	-0.27	0.96	>.999
ML to /a/	-3.71	0.96	.007*
ML to MPT	-3.62	0.96	.009*
READ to /a/	-3.44	0.96	.014*
READ to MPT	-3.35	0.96	.017*

Tukey's HSD for Task Effects with CI			
Task Comparison	Mean Difference	SEM	<i>p</i>
CONV to MOCK	-0.02	0.02	.880
CONV to ML	-0.06	0.02	.055
CONV to READ	-0.02	0.02	.880
CONV to /a/	-0.07	0.02	.017*
MOCK to ML	-0.04	0.02	.345
MOCK to READ	0.00	0.02	>.999
MOCK to /a/	-0.05	0.02	.151
ML to READ	0.04	0.02	.345
ML to /a/	-0.01	0.02	.990
READ to /a/	-0.05	0.02	.151

Tukey's HSD for Task Effects with Individual Subjects' CQ Standard Deviations (CQ Reported as Percent)			
Task Comparison	Mean Difference	SEM	<i>p</i>
CONV to MOCK	-0.44	0.34	.692
CONV to ML	-1.22	0.34	.005*
CONV to READ	-0.10	0.34	.998
CONV to /a/	0.08	0.34	.999
MOCK to ML	-0.78	0.34	.156
MOCK to READ	0.34	0.34	.852
MOCK to /a/	0.52	0.34	.543
ML to READ	1.12	0.34	.013*
ML to /a/	1.30	0.34	.003*
READ to /a/	0.18	0.34	.984

Tukey's HSD for Task Effects with Individual Subjects' CI Standard Deviations			
Task Comparison	Mean Difference	SEM	<i>p</i>
CONV to MOCK	-0.01	.01	.634
CONV to ML	-0.02	.01	.001*
CONV to READ	0.00	.01	.997
CONV to /a/	0.00	.01	.997
MOCK to ML	-0.02	.01	.080
MOCK to READ	0.01	.01	.834
MOCK to /a/	0.01	.01	.417
ML to READ	0.02	.01	.005*
ML to /a/	0.03	.01	.000*
READ to /a/	0.00	.01	.957

APPENDIX N
GROUP MEANS AND INDIVIDUAL DATA FOR ELECTROGLOTTOGRAPHY MEASURES

Key: Contact quotient, reported as a percent=CQ, contact index=CI. CONV=conversational speaking task, MOCK=mock teaching task, ML=mock loud teaching task, READ=paragraph reading, /a/=a/ vowel. Standard deviation=SD.

Group Means for Electroglossography Measures				
Variables	Voice-Disordered		Control	
	Mean	(SD)	Mean	(SD)
CQ CONV	56.12	3.43	56.87	2.10
CQ MOCK	56.28	4.31	57.21	1.82
CQ ML	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 ML	-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

Key: Voice-disordered=VDis, Control=Con. Contact quotient, reported as a percent=CQ, contact index=CI.
 CONV=conversational speaking task, MOCK=mock teaching task, ML=mock loud teaching task. Standard deviation=SD.

Individual Subject Data for Electroglottography Measures												
Subject	CQ CONV	CQ SD CONV	CI CONV	CI SD CONV	CQ MOCK	CQ SD MOCK	CI MOCK	CI SD MOCK	CQ ML	CQ SD ML	CI ML	CI SD ML
VDis1	55.39	1.56	-0.60	0.08	50.83	3.35	-0.56	0.08	57.94	4.09	-0.52	0.09
VDis2	62.78	2.29	-0.65	0.05	62.65	2.88	-0.67	0.04	58.29	3.93	-0.49	0.07
VDis3	51.61	2.99	-0.47	0.05	52.47	2.67	-0.47	0.05	54.61	3.90	-0.42	0.08
VDis4	60.40	2.62	-0.56	0.04	62.60	2.57	-0.56	0.04	65.58	2.60	-0.53	0.05
VDis5	55.17	2.04	-0.50	0.05	53.29	2.45	-0.49	0.04	56.98	3.85	-0.47	0.06
VDis6	54.61	2.97	-0.55	0.05	53.17	2.28	-0.52	0.05	56.97	3.63	-0.46	0.07
VDis7	53.62	2.93	-0.54	0.05	56.10	2.57	-0.55	0.05	56.12	3.22	-0.49	0.07
VDis8	55.15	2.85	-0.53	0.05	56.85	2.56	-0.52	0.04	59.32	2.37	-0.47	0.05
VDis9	56.33	3.61	-0.50	0.10	58.52	3.05	-0.49	0.10	58.75	2.33	-0.53	0.09
Con1	56.47	1.45	-0.47	0.03	58.77	4.71	-0.48	0.09	56.45	5.22	-0.46	0.14
Con2	59.53	2.49	-0.60	0.06	56.89	3.23	-0.60	0.04	62.05	3.62	-0.57	0.05
Con3	56.40	2.11	-0.47	0.06	59.07	2.76	-0.49	0.07	62.94	3.09	-0.47	0.08
Con4	60.52	3.71	-0.45	0.06	57.07	4.28	-0.35	0.08	54.13	8.74	-0.29	0.10
Con5	54.82	2.79	-0.48	0.05	56.27	3.20	-0.50	0.06	59.25	4.37	-0.47	0.07
Con6	54.39	1.61	-0.60	0.05	56.72	1.57	-0.55	0.07	60.39	2.87	-0.63	0.05
Con7	57.12	1.92	-0.47	0.06	56.99	2.13	-0.45	0.06	59.27	2.59	-0.51	0.09
Con8	57.63	2.46	-0.56	0.05	59.61	3.60	-0.51	0.09	64.59	3.06	-0.38	0.12
Con9	54.99	2.89	-0.57	0.04	53.53	3.38	-0.46	0.07	56.28	3.90	-0.38	0.06

Key: Voice-disordered=VDis, Control=Con. Contact quotient, reported as a percent=CQ, contact index=CI.
 READ=paragraph reading, /a/=a/ vowel. Standard deviation=SD.

Individual Subject Data for Electroglossography Measures								
Subject	CQ READ	CQ SD READ	CI READ	CI SD READ	CQ /a/	CQ SD /a/	CI /a/	CI SD /a/
VDis1	53.91	3.65	-0.54	0.08	54.07	1.26	-0.66	0.04
VDis2	58.24	2.47	-0.56	0.05	54.81	3.83	-0.46	0.06
VDis3	49.55	2.18	-0.45	0.05	48.50	3.03	-0.31	0.06
VDis4	61.47	1.60	-0.54	0.03	54.01	1.56	-0.49	0.03
VDis5	53.67	2.55	-0.48	0.05	44.61	0.51	-0.31	0.04
VDis6	54.17	2.15	-0.54	0.04	61.09	4.73	-0.52	0.05
VDis7	56.99	2.41	-0.54	0.05	50.96	1.56	-0.41	0.04
VDis8	59.95	2.74	-0.54	0.04	60.15	4.51	-0.50	0.06
VDis9	56.88	2.18	-0.50	0.07	56.23	1.02	-0.35	0.03
Con1	51.52	2.44	-0.42	0.05	53.84	3.24	-0.42	0.06
Con2	57.59	3.13	-0.59	0.04	56.27	1.91	-0.52	0.03
Con3	59.11	2.28	-0.54	0.06	57.28	3.79	-0.45	0.05
Con4	57.02	3.49	-0.41	0.08	49.14	1.93	-0.26	0.05
Con5	57.40	1.59	-0.52	0.03	60.30	2.77	-0.49	0.04
Con6	53.39	4.44	-0.56	0.10	57.74	0.85	-0.60	0.08
Con7	57.43	1.36	-0.41	0.04	62.81	1.98	-0.45	0.04
Con8	59.02	3.64	-0.53	0.08	76.10	4.40	-0.54	0.15
Con9	54.62	2.82	-0.47	0.05	55.94	0.98	-0.55	0.02

APPENDIX O
INDIVIDUAL SUBJECT DATA FOR READING UTTERANCE

Key: Voice-disordered=VDis, Control=Con. Contact quotient, reported as a percent=CQ, contact index=CI.
READ=paragraph reading, /a/=a/ vowel. Standard deviation=SD.

Subject	CQ 5%	CQ 95%	CI 5%	CI 95%
VDis1	45.97	67.46	-0.52	-0.45
VDis2	63.39	67.49	-0.66	-0.73
VDis3	46.60	45.90	-0.38	-0.42
VDis4	63.19	61.51	-0.48	-0.49
VDis5	47.70	57.90	-0.36	-0.58
VDis6	51.77	55.04	-0.43	-0.65
VDis7	49.65	52.88	-0.37	-0.63
VDis8	59.75	59.27	-0.44	-0.56
VDis9	57.59	51.40	-0.50	-0.59
Con1	42.28	55.48	-0.27	-0.54
Con2	54.52	60.87	-0.39	-0.67
Con3	60.13	58.32	-0.46	-0.46
Con4	56.44	59.97	-0.36	-0.51
Con5	56.65	60.97	-0.49	-0.58
Con6	53.62	50.29	-0.51	-0.73
Con7	50.76	56.82	-0.48	-0.47
Con8	62.43	47.18	-0.56	-0.59
Con9	54.77	56.78	-0.35	-0.61

APPENDIX P
CORRELATIONS OF SOUND PRESSURE LEVEL TO DEPENDENT VARIABLES

Key: Contact quotient, reported as a percent=CQ, contact index=CI.
CONV=conversational speaking task, MOCK=mock teaching task, ML=mock loud teaching task, READ=paragraph reading, /a/= /a/ vowel. Sound pressure level =SPL.

Correlations of SPL to Respiratory Variables			
SPL to Variable Comparison	Speaking Task	Pearson r	<i>p</i>
SPL to LVI-R	CONV	-.009	.972
SPL to LVT-R	CONV	-.078	.759
SPL to LVE	CONV	.096	.704
SPL to %VC/syl	CONV	.061	.809
SPL to LVI-R	MOCK	.154	.541
SPL to LVT-R	MOCK	.132	.601
SPL to LVE	MOCK	.102	.689
SPL to %VC/syl	MOCK	-.159	.171
SPL to LVI-R	ML	.481	.043*
SPL to LVT-R	ML	.297	.231
SPL to LVE	ML	.637	.004*
SPL to %VC/syl	ML	.284	-.145

Correlations of SPL to Laryngeal Variables			
SPL to Variable Comparison	Speaking Task	Pearson r	<i>p</i>
SPL to CQ	CONV	.396	.104
SPL to CI	CONV	-.072	.776
SPL to CQ	MOCK	.216	.390
SPL to CI	MOCK	.453	.059
SPL to CQ	ML	.111	.662
SPL to CI	ML	.529	.024*
SPL to CQ	READ	.459	.055
SPL to CI	READ	-.138	.584
SPL to CQ	/a/	.322	.192
SPL to CI	/a/	-.063	.804

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