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Laryngeal Airway Resistance in Teachers with Vocal Fatigue

by

Barbara Ellen Kostyk ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science

in

Speech-Language Pathology

Department of Speech Pathology and Audiology

Edmonton, Alberta

Spring 1996

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled Laryngeal Airway Resistance in Teachers with Vocal Fatigue by Barbara Ellen Kostyk in partial fulfillment of the requirements for the degree of Master of Science in Speech-Language Pathology.

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ABSTRACT

A noninvasive technique (Smitheran & Hixon, 1981) was used to compare translaryngeal pressures and flows, laryngeal airway resistances and relative decibel levels in the voices of 16 female classroom teachers aged 24 to 45 years. Subjects were divided into two groups: those with symptoms of vocal fatigue, and those without. Data were collected two times per day: before and after school on the Monday, Wednesay and Friday of the same week. No significant differences in the experimental variables were found between the two groups. Translaryngeal airflow measured in the voices of the fatigued subjects decreased across the sampling period ($p = .0009$). In the control group, translaryngeal air pressure tended to increase across the sampling period ($p = .021$), although the difference was not statistically significant. These findings suggest that both groups experienced and reacted to vocal use demands during the week. The effects of cumulative voice use may have caused both groups to employ behaviors aimed at maintaining habitual laryngeal airway resistance. However, the strategy employed by the experimental subjects may have been less efficient, thereby placing stress on the laryngeal musculature and resulting in symptoms of vocal fatigue.

ACKNOWLEDGEMENT

In 1993, I entered into graduate study for the sole purpose of writing that big, black book known as a thesis. Or so I thought. To my wonder, I discovered planning, implementation and even revision to be rewarding steps along the path to my goal. I also learned the truth of three well-known pearls of wisdom:

1. Many minds are better than one.
2. Research generates more questions than it answers.
3. Always keep an emergency set of laboratory keys in one's pocket, especially when a research participant has arrived and the building is empty.

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General Statement of the Problem

Misuse or overuse of the voice has been associated with fatigue of the laryngeal mechanism (Scherer et al., 1985) and functional or organic dysphonia (Boone & McFarlane, 1988a; 1988b; Darley & Spriestersbach, 1978a; Moore, 1971). Specifically, prolonged or improper phonation may be associated with the following phenomena: (1) fatigue of the laryngeal muscles that provide tension to the vocal folds; (2) fatigue of the respiratory muscles and concomitant loss of subglottal pressure; (3) relaxation of passive tension of the ligaments and membranes of vocal fold tissue; (4) increased viscosity of the vocal fold tissue, resulting in greater friction between adjacent portions of tissue during phonation and impeded vibration; and (5) constriction of blood vessels causing a reduction in local circulatory efficiency, which could impede regenerative processes as well as heat transfer away from the vocal folds (Titze, 1981; 1983).

Because faulty use of the vocal mechanism appears to be a factor in the development of vocal fatigue as well as the majority of voice disorders (Arnold, 1962; Boone & McFarlane, 1988a; 1988b; Darley & Spriestersbach, 1978a; Moore, 1971), individuals who experience vocal fatigue may be at risk for developing functional dysphonia and organic pathologies such as vocal nodules, polyps or contact ulcers. Quantification of vocal fatigue could aid in identifying speakers who are at risk for developing a full-blown dysphonia. Although the symptoms of individuals experiencing vocal fatigue have been well documented, and associated perceptual characteristics of the voice have been identified (Boone & McFarlane, 1988b; Scherer et al., 1985; Titze, 1983), few researchers have dealt quantitatively with the signs of vocal fatigue in functional parameters of the phonatory mechanism. The majority of work that has investigated the laboratory signs of vocal fatigue has focused primarily on acoustic measures (Blager et al., 1993; Brown & Holbrook, 1985; Burzynski & Titze, 1985; Pausewang Gelfer et al, 1991; Scherer et al, 1985; Stone & Sharf, 1973). As a result, little is known about the aeromechanical phenomena associated with voice produced under conditions of vocal fatigue.

Presently, vocal fatigue is thought to be associated with decreased subglottic pressure, perhaps due to impaired laryngeal valving as a result of the following factors: (1) fatigue of the laryngeal muscles; (2) relaxation of the passive tension of laryngeal membranes and ligaments; and (3) impaired vocal fold closure resulting from local edema, the accumulation of fluid in the folds (Titze, 1983). Given that laryngeal valving may be impeded in subjects with vocal fatigue, it is reasonable to expect that these individuals also may experience inappropriate and excessive loss of air through the glottis during voice production. As a result, translaryngeal airflow may be elevated, and laryngeal airway resistance, which is primarily flow-related, reduced. Unfortunately, it is unclear whether such changes in aeromechanical phenomena occur in the laryngeal airways of subjects with vocal fatigue, because laryngeal airway resistance during speech has yet to be studied systematically in this population.

Another drawback of previous research on vocal fatigue is the fact that the durations across which the phenomenon has been studied have tended to be short, usually no more than one hour. Data documenting the cumulative effects of fatiguing voice use over longer durations, such as one week, are lacking. Finally, no published studies have reported whether speakers adopt specific respiratory or phonatory strategies to compensate for vocal fatigue. Based on previous research investigating behaviors developed to compensate for decreased velar and oral port resistances during speech (Dalston et al., 1990; Laine et al., 1988; Putnam et al., 1986; Warren et al., 1989, 1990, 1991), it is possible to hypothesize that individuals with reduced laryngeal airway resistance associated with vocal fatigue may also develop compensatory strategies.

This investigation attempted to address these issues by documenting the effects of vocal fatigue on selected aeromechanical and acoustical variables associated with voice production. The behavior of four phenomena: translaryngeal pressures and flows, laryngeal airway resistances, and relative decibel levels were monitored in data collected from classroom teachers with and without vocal fatigue two times per day across three days of a five day period during the school year.

Literature Review

Vocal Fatigue. Vocal hyperfunction, or the abuse/misuse of the vocal mechanism due to excessive or imbalanced muscular forces, has been associated with fatigue of the laryngeal mechanism (Scherer et al., 1985) and is considered to be an underlying component of the majority of voice disorders (Arnold, 1962; Boone & McFarlane, 1988a; 1988b; Darley & Spriestersbach, 1978a; Moore, 1971). Some behaviors identified as vocally fatiguing include "hard glottal attack" (habitually abrupt voice on [illegible] prolonged talking, habitual talking at inappropriate pitch or loudness levels, and excessive coughing or throat clearing (Boone & McFarlane, 1988a; 1988b). Loud phonation at a low pitch may be particularly fatiguing (Sander & Ripich, 1983). At low frequencies, intensity is believed to be regulated by laryngeal control of glottal resistance. However, at higher frequencies, intensity is thought to be regulated by expiratory muscle control of airflow (Isshiki, 1964). As a result, prolonged loud, low-frequency phonation is likely to place a strain on the laryngeal mechanism.

Vocal fatigue may be likened physiologically to skeletal muscle fatigue in other parts of the body, with some exceptions (Titze, 1983). As with fatigue of other muscles, vocal fatigue is recognized to have peripheral and central components. Fatigue of the peripheral component can occur in the neuromotor transmission mechanism, composed of the neuromuscular junction, muscle membrane and endoplasmic reticulum of the muscle cell, or in the contractile mechanism, composed of muscle fibres (Bigland-Ritchie & Woods, 1984; Titze, 1983). Fatigue in the peripheral component results in a loss of contractile muscle force, even when neural signals to the muscle fibres are uninterrupted. Peripheral fatigue is considered to result from (1) the depletion of acetylcholine, a neurotransmitter involved in the propagation of muscle membrane potentials; (2) the depletion of glycogen and phosphate compounds, which are involved in energy supply to muscles; or (3) the accumulation of lactic acid, a by-product of energy consumption in muscles. Blood circulation may play a role in the removal of lactic acid. However, if sustained muscle contraction raises intramuscular pressure and consequently reduces circulation, lactic acid removal may be inhibited. As a result, edema may develop to dilute the acid accumulation. Finally, muscle fatigue may originate in the central nervous system (Bigland-Ritchie & Woods, 1984; Titze, 1983). Nerve afferents from a fatigued muscle may provide inhibitory stimulation to the motor system, thereby reducing the size of the action potentials to the muscle (Titze, 1983).

Titze (1983) has suggested that prolonged use of the vocal folds in phonation may be more problematic than prolonged muscle contraction occurring in other parts of the body. Because the vocal folds are the only body tissues that regularly vibrate at a high frequency, they may be subject to special stress and fatigue factors associated with rapid acceleration and deceleration. One special factor attributed to vocal fatigue is stress-induced relaxation in non-muscular components of the vocal folds. Specifically, tension of the epithelium, ligaments, joints and cartilages of the larynx may relax following sudden elongation of the vocal folds. This type of fatigue is associated with high frequency phonation. The exact recovery time necessary for non-muscular laryngeal tissues to return to their non-relaxed state is unknown and may range from a second or less to several days.

Power dissipation is another factor in vocal fatigue. Because the vocal folds are constrained anteriorly, posteriorly and laterally but not medially by cartilage, a velocity gradient is created whereby velocity of movement is greatest at the medial midpoint of the vocal folds and least at the boundary-cartilage attachments. This velocity gradient causes friction to be placed on any portion of tissue that is bounded by adjacent portions moving at a different velocity. Mechanical energy from this friction is dissipated as heat. Power dissipation has been shown to be proportional to fundamental frequency, vibrational amplitude and tissue viscosity. The viscosity inside the vocal folds is relatively high and is larger than the viscosity of the mucous deposited on their surface.

When vocal fold viscosity is combined with increased vocal intensity and frequency, more power is dissipated as heat. In order to accommodate this energy loss, either the laryngeal mechanism must become more efficient or the energy supplied by the expiratory breath stream must increase. Because dissipated energy is converted to heat, greater vocal effort may cause the temperature in the vocal fold tissue to rise above the body's if cooling is not provided. The development of vocal fold edema following prolonged overuse may be an attempt by the body to regulate tissue temperature. In addition, formation of edema may increase the laryngeal mechanism's efficiency by reducing viscosity (Titze, 1981; 1983).

In view of the information presented above, it is conceivable that vocal fatigue may have an impact on the aeromechanical forces that operate in the laryngeal airway during phonation. Impaired vocal fold closure associated with reductions in the contractile force of the laryngeal muscles, and stress-induced relaxation in non-muscular components of the folds could result in decreased translaryngeal pressures and increased translaryngeal flows. In addition, the formation of vocal fold edema could impair fold closure thereby allowing increased transglottal airflow. Airflow also could increase as the phonatory mechanism accommodates to power dissipation at the vocal folds by increasing the energy supplied by the expiratory breath stream. However, fatigue of the respiratory muscles could occur as a result of such compensation for fatigued laryngeal tissues. In this case, air pressures and flows measured during phonation could decrease. Because laryngeal airway resistance is calculated as the ratio of translaryngeal pressure to translaryngeal flow, and pressures and flows may be increased or decreased in individuals with vocal fatigue, it is difficult to predict whether these individuals would demonstrate increased or decreased resistances during phonation. Systematic study of air pressures and flows associated with phonation in this population is necessary to elucidate this issue.

Perceptual signs of vocal fatigue. The vocal characteristics and physical sensations of voice users with fatigued phonatory mechanisms have been well documented by researchers (Scherer et al., 1985; Titze, 1985). The voice may sound hoarse or breathy with decreased loudness. In addition, individuals with vocal fatigue may experience loss of voice, pitch breaks, an inability to maintain a typical pitch, reduced pitch and loudness ranges, or a need to use greater vocal effort due to a perceived lack of vocal "carrying power." Physically, fatigued respiratory and laryngeal systems may result in decreased breath support for speech or singing. Other symptoms of vocal fatigue include neck/shoulder tension, throat/neck pain, throat fatigue, throat tightness or constriction, pain on swallowing, an increased need to cough or throat-clear, and discomfort in the chest, ears or back of the neck (Boone & McFarlane, 1988b; Scherer et al., 1985; Titze, 1985).

Acoustic signs of vocal fatigue. Researchers have experienced limited success in quantifying vocal fatigue based on fundamental frequency, intensity and perturbation measures taken before and after completion of strenuous voice tasks. Burzynski and Titze (1985) calculated fundamental frequency, jitter and harmonics-to-noise ratios in two males and three females between the ages of 20 and 25 years before and after two periods of continuous talking. Subjects were required to alternate sustaining the vowel /a/, reading and speaking extemporaneously at comfortable pitch and loudness levels for one hour.

Following the fatiguing task, 15 minutes of complete voice rest were observed, followed by another 20 minutes of talking. Data were sampled immediately prior to the initial fatiguing task, every 10 minutes during the task, immediately following the period of voice rest, and every 10 minutes during the final fatiguing task. There did not appear to be any significant trends in jitter or harmonics-to-noise ratios calculated for individual subjects across the sampling period, or among the five subjects. However, fundamental frequency decreased slightly in four of the five subjects within 30 minutes of the onset of continuous talking. Following voice rest, fundamental frequency was observed to recover slightly in the same four subjects. Increase in tissue viscosity of the vocal folds and relaxation in the non-muscular portion of the folds were discussed as possible explanations for the drop in fundamental frequency.

Researchers also have compared the effects of prolonged loud reading on acoustic variables in professionally trained voice users and individuals without vocal training. Scherer et al. (1985) calculated harmonics-to-noise ratios (a measure of breathiness), jitter (cycle-to-cycle variations in fundamental frequency) and shimmer (cycle-to-cycle variations in amplitude) in the voices of two female subjects (one a trained speaker, the other untrained) before and after repeated fatiguing voice tasks. During each fatiguing task, subjects read loudly for 15 minutes at one octave above the lowest pitch of their range. A diagnostic task was performed before and after each fatiguing task, and consisted of producing seven prolonged /a/ vowels at a comfortable loudness and at the same pitch used in the fatiguing task. Diagnostic and fatiguing tasks were alternated until either the subject or experimenter felt that the fatiguing tasks should be discontinued. A diagnostic task always followed the final fatiguing task. A 15-minute period of voice rest occurred next, followed by another diagnostic task, a second 15-minute rest period and a final diagnostic task. The untrained subject completed one hour of vocally fatiguing episodes, and the trained subject completed 2½ hours. No significant differences over time in any of the three variables were observed in the untrained subject, even though she indicated that the condition of her voice deteriorated consistently during the fatiguing tasks and recovered somewhat during the two rest periods. In the trained subject, shimmer increased significantly over time but returned to prefatigue levels following the first period of voice rest, while jitter increased significantly over time and did not return to prefatigue levels. Although harmonics-to-noise ratios increased significantly over time, post-hoc testing failed to reveal any significant paired comparisons. The trained subject indicated that she felt her voice deteriorated after the first 15 minutes, recovered 1½ hours into the fatiguing tasks, then deteriorated again. She also reported that her voice did not appear to recover during the rest periods. Her self-administered voice ratings were consistently and positively related to the shimmer measures, but not to the other measures. Both subjects exhibited vocal fold edema upon fiberoptic laryngological examination following the final fatiguing task. Finally, both subjects reported that their voices recovered completely by the next day. Because the three experimental variables remained relatively constant in the speech of the untrained subject and harmonics-to-noise ratio comparisons were insignificant for the speech of the trained subject while shimmer returned to prefatigue levels after the first period of voice rest, the researchers concluded that vocal fold edema might not necessarily result in measurable changes in jitter, shimmer or harmonics-to-noise ratio.

Blager et al. (1993) also reported a lack of correspondence between some acoustic variables of voice and vocal fatigue. Average fundamental frequency, harmonics-to-noise-ratio (HNR), harmonic spectral slope (HSS), the short-term perturbation measures jitter and shimmer, and the long-term measures coefficient of variation for frequency (CVF) and coefficient of variation for amplitude (CVA) were calculated in the voices of eight male and eight female university cheerleaders throughout the cheerleading season as part of a larger study measuring the impact of prevention on vocal abuse. Cheerleaders were chosen as subjects because they were believed to be at risk for voice damage due to their extensive use of loud phonation. Voices were recorded at four different times: before the cheerleading season started, after cheerleading camp and the first football game, after information on voice was presented and cheerleading at football games had occurred, and at the end of the cheerleading season. None of the perturbation values changed significantly over time, even though the perceptual quality of some of the voices reflected hoarseness after the first football game. Thus, the results of the vocal perturbation analyses did not support the deterioration that was perceptible in the voice quality of some of the cheerleaders. However, two other measures showed a significant change: HSS slope decreased, and the fundamental frequency of the five males dropped.

Pausewang-Gelfer et al. (1991) investigated the effects of prolonged loud reading on the singing and speaking voices of vocally untrained women and professionally trained singers between the ages of 23 and 38 years. Subjects read aloud for one hour at 80% of their speaking intensity range. Pre- and post-test analyses of fundamental frequency, intensity, jitter ratio, shimmer and signal-to-noise ratio (SNR) were performed on sustained vowels and the first five notes of "The Star-Spangled Banner." For the trained singers, all five variables generally remained stable following the hour of loud reading. For the untrained subjects, fundamental frequency and SNR increased, while intensity dropped in two of the three vowels. Methodological difficulties prevented generalization from the untrained subjects' performances on "The Star-Spangled Banner." The researchers concluded that the untrained subjects' voices were negatively affected by the hour of loud reading, while the voices of the trained singers were not. Unfortunately, no ratings of vocal fatigue were collected from the subjects. As a result, it is unclear whether the acoustic data accurately reflect the presence or absence of symptoms of vocal fatigue. It may be that the hour of loud reading had a negative impact on both groups' vocal mechanisms, but the singers were able to compensate for the fatigue, while the untrained subjects were not.

Aeromechanical signs of vocal fatigue. Given that a number of acoustic measures do not appear to be reliable or sensitive in reflecting fatigue-related changes within the vocal mechanism over time, study of the laryngeal aerodynamics associated with vocal fatigue may prove to be valuable. Aeromechanical phenomena (eg., translaryngeal pressures, flows and laryngeal airway resistances) may be informative because the status of the laryngeal and respiratory systems may be inferred from pressures and flows measured during phonation. Thus, it appears that studying the aeromechanical phenomena associated with voicing in heavy voice users may shed light on the conditions or behaviors provoking vocal fatigue. Unfortunately, such investigations have not been undertaken.

The larynx is a biomechanical valve located between the upper and lower airways. As such, certain valving adjustments of the larynx may cause alterations in differential air pressure and flow across the laryngeal airway. Although laryngeal airway resistance can not be measured directly, it may be calculated from the ratio of translaryngeal pressure (the difference between tracheal and pharyngeal pressures) to translaryngeal flow (airflow through the larynx). Laryngeal airway resistance is stated mathematically as $R_{law} = P_{tl} / \dot{V}_{tl}$, where P_{tl} represents translaryngeal pressure (tracheal pressure minus pharyngeal pressure) and $\dot{V}_{tl}$ translaryngeal flow (Smitheran & Hixon, 1981). The more influential component of the equation is airflow, which is inversely related to laryngeal airway resistance. When pressure is stable, high flows are associated with low laryngeal airway resistance, and low flows with high resistance.

A study by Netsell et al. (1984) indicated that pressure and airflow variables correspond closely to listeners' judgements of voice quality. The non-invasive technique of Smitheran and Hixon (1981) was used to sample translaryngeal pressure and flow in 18 subjects with voice disorders and 30 control subjects who spoke with normal voice quality. In addition, a panel of three listeners used an equal-appearing interval scale to rate the breathiness, roughness and strained quality of the subjects' voices during counting. Subjects' voices were perceived as breathy when pressure was within normal limits (<10 cm H_2O) and airflow exceeded 400 cc/s. A strained quality was associated with low flows and excessive pressures (>10 cm H_2O). Finally, aeromechanical signals characterized by high pressures and flows were associated with the perception of a rough voice. Because vocal fatigue has been associated with breathy and rough phonation (Boone & McFarlane, 1988b; Scherer et al., 1985; Titze, 1985) the correspondence between the aerodynamic data and ratings of voice quality reported by Netsell et al.

(1984) suggests that pressure-flow testing may be sensitive to fatigue-related changes in the vocal mechanism.

Because hyperfunctional phonation is believed to fatigue the vocal mechanism (Scherer et al., 1985), investigations of laryngeal aerodynamics related to faulty voice use may aid in quantifying vocal fatigue. Common manifestations of vocal hyperfunction include unusual respiratory force or observable tension during phonation, excessive force in vocal fold approximation, involvement of the ventricular folds in phonation, and excessive tension in the laryngeal area (Boone & McFarlane, 1988a). In addition, large posterior glottal chinks have been observed during phonation in hyperfunctional voice users (Hillman et al, 1989; Morrison et al., 1986). Through the use of non-invasive pressure and flow sampling techniques, Hillman et al. (1989) found that hyperfunctional voice use is associated with abnormally high transglottal pressure in addition to elevated airflow. The researchers hypothesized that the elevated pressure levels were related to difficulties with voice production, and were attributable to increased muscle activity in the laryngeal area. Heightened activity of the laryngeal musculature was thought to increase the stiffness and tension of the vocal folds, as well as increase the force of phonatory adduction. In addition, elevated pressure levels used by subjects with vocal fatigue to accomplish voicing in the presence of impaired vocal fold approximation or excessive muscular tension were suggested to contribute to increased flow during larger than normal amplitudes of vocal fold vibration. Because vocal hyperfunction generally is associated with both elevated transglottal pressures and flows, laryngeal airway resistance values of individuals who demonstrate this behavior may fall within normal limits and consequently mask laryngeal dysfunction. Hillman et al. emphasize the importance of considering translaryngeal pressures and flows separately in order to avoid this pitfall.

A single aeromechanical investigation of vocal fatigue was undertaken by Reimers Neils and Yairi (1984), who studied the voice production of normal females reading for 45 minutes under three conditions of noise heard through earphones. Although a panel of listeners did not perceive the voice qualities of the readers to change significantly over time, peak airflow values increased across the 45 minute reading period. These findings suggest that pressure-flow testing may be sensitive to fatigue-induced alterations in the vocal mechanism before they are perceived by listeners as changes in voice quality.

Estimation of laryngeal airway resistance. In the past, methods used to sample tracheal pressures for the calculation of laryngeal airway resistance during voice production were either invasive in nature or technically challenging for the experimenter. Sampling tracheal pressure is problematic because it requires that a pressure-sensing probe such as a hypodermic needle be inserted within the trachea, that a sensing probe such as a balloon be positioned within the esophagus, or that the subject be encased in a whole-body chamber. Tracheal and esophageal probes are invasive and uncomfortable, posing physical risks to the subject and requiring the involvement of a physician. In addition, whole-body encasement requires expensive plethysmographic systems that are cumbersome, highly technical and complex to calibrate (Smitheran & Hixon, 1981).

In 1981, Smitheran and Hixon reported a non-invasive and relatively "low-tech" clinical method for estimating laryngeal airway resistance. The method is based on the general theory of fluid dynamics, which predicts that upstream pressure and flow events can be estimated by measurements taken at sites downstream from the events of interest. When applied to air-filled respiratory passages, "upstream" refers to the respiratory source of air pressure and airflow during speech; "downstream" refers to the airways and valves of the larynx, pharynx, mouth and velopharynx. The Smitheran and Hixon technique estimates hard-to-sample tracheal and pharyngeal pressures as well as translaryngeal airflow from pressure and flow measurements taken at the mouth during the production of a controlled utterance (Smitheran & Hixon, 1981).

According to Smitheran and Hixon (1981), the simplest utterance that will result in valving adjustments which allow discontinuous estimations of tracheal and pharyngeal pressures as well as translaryngeal flow is a series of alternations of voiceless stop-plosives and vowels. When these phonemes are alternated repeatedly in a series of consonant-vowel syllable repetitions, oral pressure and airway-opening flow can be measured as representations of tracheal and pharyngeal pressures and translaryngeal airflow, respectively. Smitheran and Hixon (1981) have indicated that the syllable /pi/ should be repeated by the subject during pressure-flow sampling. Use of the phoneme /p/ allows pressure sampling to be obtained with minimal protrusion of a small pressure-sensing catheter into the oral cavity, reducing the likelihood of recording artifact due to tube blockage by saliva, and increasing the likelihood of an airtight seal being formed around the tube by the lips. The vowel /i/ is used in the sample utterance for laryngeal airway resistance estimates because velopharyngeal closure is thought to be airtight during its production in the non-nasal context of /p/ (Smitheran & Hixon, 1981; Thompson &

Hixon, 1979). In addition, the vowel requires a high, front tongue position that complements the anterior focus of /p/, does not involve lip rounding or extensive mandible excursion, and thus simplifies the movement sequence required to repeat the utterance. As a result, minuscule flow artifacts related to articulatory movement are minimized, as is the potential for air leakage around the face mask used to collect flow (Smitheran & Hixon, 1981). Thus, in clinical and laboratory use of the Smitheran and Hixon method, subjects are asked to produce seven repetitions of the syllable /pi/ on a single, continuous expiration produced with normal loudness and pitch. Each syllable is produced with equal stress in order to maximize the consistency of respiratory drive and tracheal pressure. Utterance rate is controlled at 1.5 syllables per second to ensure that the larynx assumes quasi-static resistances while airtight velopharyngeal closure is maintained (Smitheran & Hixon, 1981; Thompson & Hixon, 1979).

Laryngeal airway resistance in normal adults. Many researchers have used the Smitheran and Hixon (1981) method to compile a modest database of laryngeal airway resistance values in healthy adult men and women (Hoit & Hixon, 1989; Hoit & Hixon, 1992; Holmberg et al., 1988, 1989; Langhans, 1989; Leeper & Graves, 1984; Melcon et al., 1989; Stathopoulos, Hoit & Hixon, 1991; Stathopoulos & Sapienza, 1993). However, most investigators have reported that mean laryngeal airway resistance values are highly variable between same-sex subjects of similar age. Hoit and Hixon (1992) investigated the possibility of age-related changes in laryngeal airway resistance among women. Seventy healthy females, aged 25, 35, 45, 55, 65, 75 and 85 ±2 years, served as subjects. Average resistance, estimated during repetition of /pi/ at a comfortable loudness, did not differ statistically with age among any of the seven groups. Resistance was highly variable among subjects within each age group, however, and ranged from 51.32 cm H_2O/LPS (*SD*=16.03) to 58.37 cm H_2O/LPS (*SD*=18.12). Furthermore, the researchers suggested that had they not employed such strict inclusion criteria, intersubject variability in laryngeal airway resistance values would have been even greater.

Stathopoulos et al. (1991) also reported laryngeal airway resistance to be highly variable between subjects of the same sex and similar age. The researchers used the non-invasive procedures of Smitheran and Hixon (1981) to investigate air pressure, flow and laryngeal airway resistance during repetition of the syllable /pi/ as part of a larger study examining chest wall kinematics during whispering and speaking. Ten young adults, five women and five men, served as subjects. Women had an average resistance of 34.53 cm H_2O/LPS (*SD*=13.62) during speaking, and men had an average resistance of 44.55 cm H_2O/LPS (*SD*=13.97).

Yet another study reporting high variability among subjects' resistance means was undertaken by Stathopoulos and Sapienza (1993). The researchers employed non-invasive techniques to investigate air pressure, flow, laryngeal airway resistance and respiratory kinematics during repetition of the syllable /pα/ at three intensities. Five women and five men between the ages of 20 and 30 served as subjects. Although laryngeal airway resistance was highly variable within groups for each loudness condition, resistance generally increased with increases in vocal intensity. Average laryngeal airway resistance values for the women ranged from 28.61 cm H_2O/LPS (*SD*=11.76) in the soft condition, to 67.81 cm H_2O/LPS (*SD*=16.84) in the loud condition. Mean resistance values for the men ranged from 34.34 cm H_2O/LPS (*SD*=14.88) in the soft condition, to 66.08 cm H_2O/LPS (*SD*=39.79) for the loud condition.

Laryngeal airway resistance across longer sampling periods. Given the large intersubject variability in laryngeal airway resistance values reported by researchers, it is possible that individual subjects' resistances may fluctuate within and across specific sampling periods. However, only two published studies have addressed this issue to date. Leeper & Graves (1984) employed non-invasive procedures to investigate the consistency of mean laryngeal airway resistance in fifteen healthy adult women between the ages of 23 and 32 years. Data generated during repetition of /pi/ at a comfortable pitch and loudness were collected two times per day over two consecutive days. Mean resistance did not vary significantly within or across the two days. Laryngeal airway resistance averaged across the four sampling periods was reported to be 38.3 cm H_2O/LPS (*SD*=9.2). In addition, grand means for pressure (*M*=6.4 cm H_2O; *SD*=1.9) and airflow (*M*=200.43 mL/s; *SD*=65.86) did not vary significantly within or across the two days. Accordingly, the researchers concluded that laryngeal airway resistance appeared to be stable over time in females with normal voices. However, it remains unclear whether resistance is stable across longer sampling periods. Furthermore, because the study investigated subjects with normal voices only, it is not known whether the health of the voice affects the stability of resistance over time.

Wilson and Leeper (1992) also calculated laryngeal airway resistance values across two days in young adults between the ages of 22 and 30 years, as part of a larger study investigating the effects of sound pressure level and syllable context on resistance. However, data were collected only once per day. Pressure, airflow and resistance values calculated during repetition of /pi/ at an intensity level in the middle of each subject's range did not vary significantly across the two day period. Laryngeal airway resistance averaged across the two days was 51.7 cm H_2O/LPS (*SD*=31.1) for women, and 33.86 cm H_2O/LPS (*SD*=19.3) for men. Averaged translaryngeal airflow was 174.2 mL/s (*SD*=47.4) for the women, and 274.8 mL/s (*SD*=92.9) for the men. Finally, averaged translaryngeal pressure was 7.6 cm H_2O (*SD*=2.9) for the women, and 7.6 cm H_2O (*SD*=2.8) for the men. Although the researchers concluded that laryngeal airway resistance did not fluctuate significantly across the two days, it remains unclear whether resistance is stable across longer sampling periods, and in voices that are fatigued or dysphonic. Furthermore, it is unknown whether the subjects' resistance values remained stable during each day of testing as only one sample was taken during a 24 hour period.

In summary, it appears that laryngeal airway resistance is highly variable between same-sex subjects of similar age (Hoit & Hixon, 1992; Leeper & Graves, 1984; Stathopoulos et al., 1991; Stathopoulos & Sapienza, 1993; Wilson & Leeper, 1992). Based on the intersubject variability of mean resistance values reported in past investigations, it is reasonable to expect that resistance also may fluctuate in the same subject within and across several days. Although the two published studies investigating the consistency of translaryngeal pressures, flows and resistances have reported that the values do not fluctuate within or across two days, it is unknown whether these parameters remain stable within or across a day when sampled over a longer duration, such as one week.

Furthermore, all published information on the stability of laryngeal airway resistance across extended periods of vocalization is based on normal voice production. Further research is necessary to gather information on the stability of laryngeal airway resistance values in subjects with fatigued or dysphonic voices.

Behavioral compensation for reduced resistance. Physiologists have observed that the human body maintains its biological systems, such as basal temperature and blood circulation, at relatively steady levels. These systems have common features that are fundamental to homeostasis: (1) regulation for the purpose of stability; and (2) control mechanisms to achieve relatively steady-state conditions (Brobeck, 1965). These systems are said to be regulated because they respond to change, and by their activity preserve or attempt to preserve some level of constancy.

The findings of past investigations of air pressure and flow in normal subjects and subjects with varying degrees of velopharyngeal inadequacy suggest that a pressure regulation/control mechanism exists for speech (Dalston et al., 1990; Laine et al., 1988; Putnam et al., 1986; Warren et al., 1989, 1990, 1991). Speakers have been shown to compensate for losses of velar resistance through, among other things, an increase in respiratory effort and expiratory airflow rate (Dalston et al., 1990; Laine et al., 1988; Warren et al., 1989, 1990, 1991). Normal speakers also have been shown to react to reductions in oral port resistance during production of plosive and sibilant consonants (Putnam et al., 1986; Warren et al., 1991). When tiny hollow tubes of different orifice areas were placed between the lips of normal subjects repeating /pi/, airflow through the tubes during subjects' attempts to produce /p/ increased in a linear fashion with increases in orifice size. The data generated from these studies simulating "leaks" during speech production imply that whenever possible, individuals who experience decreased velar and oral port resistances increase respiratory drive in an attempt to maintain intraoral pressure for speech (Putnam et al., 1986; Warren et al., 1991). Accordingly, it is reasonable to expect that individuals who experience fatigue of the laryngeal mechanism might also increase their respiratory effort in an attempt to maintain adequate laryngeal airway resistance. Increases in respiratory effort would likely be associated with elevated pressures, flows, and sound pressure levels during phonation. Unfortunately, such a model of pressure regulation/control at the laryngeal level in vocally-fatigued individuals remains hypothetical because it has yet to be tested systematically in this population.

Summary. Past investigations have studied laryngeal airway resistance values in healthy adult men and women (Hoit & Hixon, 1992; Holmberg et al., 1988, 1989; Langhans, 1989; Leeper & Graves, 1984; Melcon et al., 1989; Stathopoulos, Hoit & Hixon, 1991; Stathopoulos & Sapienza, 1993), but laryngeal airway resistance has yet to be studied systematically in subjects with vocal fatigue. Furthermore, mean laryngeal airway resistance has been shown to be highly variable among same-sex individuals with normal voices and similar ages when vocal loudness has been allowed to vary freely (Hoit & Hixon, 1992; Leeper & Graves, 1984; Stathopoulos et al., 1991; Stathopoulos & Sapienza, 1993; Wilson & Leeper, 1992), suggesting that resistance may fluctuate in the same subject within and across specific sampling periods. Unfortunately, few researchers have investigated this possibility. The studies that have been undertaken (Leeper & Graves, 1984; Wilson & Leeper, 1992) have focused on subjects with normal voices, and have calculated laryngeal airway resistance over the limited duration of two days. Consequently, it remains unclear whether resistance is stable within and across a longer sampling duration, such as five days. It also is unknown whether the health of the voice influences the behavior of laryngeal resistance across extended periods of voice use.

Indeed, few aeromechanical investigations have been carried out on subjects with vocal fatigue, even though preliminary research has shown this group to differ from normals along the dimensions of translaryngeal pressure and flow (Hillman et al., 1989; Reimers Neils & Yairi, 1984). Because the status of the laryngeal and respiratory systems may be inferred from pressures and flows measured during phonation, studying the aeromechanical phenomena associated with voicing in heavy voice users could shed light on the conditions or behaviors provoking vocal fatigue. Furthermore, because faulty use of the vocal mechanism appears to be a factor in the majority of voice disorders (Arnold, 1962; Boone & McFarlane, 1988a; Darley & Spriestersbach, 1978a; Moore, 1971), and vocal fatigue appears to be a sign of faulty voice use (Scherer et al., 1985), quantification of vocal fatigue may aid in identifying individuals who are at risk for developing functional dysphonia and organic pathologies such as vocal nodules, polyps or contact ulcers. Yet, little information exists on translaryngeal pressure and flow relationships in subjects with vocal fatigue for several reasons. First, few researchers have dealt quantitatively with the effects of vocal fatigue. The majority of quantitative research has focused on acoustic measures, and as a result little is known about the aeromechanical phenomena associated with vocal fatigue. In addition, the durations of vocal fatigue studied have tended to be short, usually one hour. Data documenting the cumulative effects of fatiguing voice use over longer durations are lacking. Finally, no published studies have reported whether individuals adopt specific respiratory or phonatory strategies to compensate for vocal fatigue. Based on previous research investigating speech behaviors developed to compensate for decreased velar and oral port resistances (Dalston et al., 1990; Laine et al., 1988; Putnam et al., 1986; Warren et al., 1989, 1990, 1991), it seems likely that individuals with vocal fatigue also develop compensatory strategies aimed at maintaining adequate laryngeal airway resistance. Such strategies could be monitored through the measurement of air pressures, flows and sound pressure levels during phonation.

The study of vocal fatigue in classroom teachers may yield beneficial clinical data, because fatigue may be especially problematic for teachers due to their habitually heavy use of voice. Furthermore, if the effects of fatiguing voice use are cumulative across the work week, classroom teachers may have a greater risk of developing organic laryngeal pathology than individuals who use their voices to a lesser extent. Quantitative assessment of vocal fatigue may aid in the early identification of teachers who are at-risk for developing a full-blown dysphonia. More importantly, it could alert teachers, who rely heavily on their voices for employment, to take precautions against such an occurrence.

STATEMENT OF PURPOSE

In an attempt to generate quantitative aeromechanical data associated with vocal fatigue, the proposed investigation compared mean translaryngeal pressures, flows and resistances and relative decibel levels calculated within and across specific sampling periods in the voices of classroom teachers with vocal fatigue to those calculated in the voices of teachers without vocal fatigue across the same periods.

Hypotheses

The experimenter proposed the following hypotheses with respect to the experimental comparisons planned:

1. Each sampling point for translaryngeal pressure (P), laryngeal airway resistance (R_{law}) and relative decibel level (dB_{rel}) during voice production will be lower in teachers with vocal fatigue than in teachers without vocal fatigue. Each sampling point for translaryngeal airflow ($\dot{V}$) during voice production will be higher in teachers with vocal fatigue than in teachers without vocal fatigue. (Summary: $\downarrow P$, $\downarrow R_{law}$, $\downarrow dB_{rel}$, $\uparrow \dot{V}$.)
2. In teachers with vocal fatigue, translaryngeal airflow measured during voice production will increase across each point of the sampling period, whereas translaryngeal pressure, laryngeal airway resistance and relative decibel level means will drop. (Summary: $\uparrow \dot{V}$, $\downarrow P$, $\downarrow R_{law}$, $\downarrow dB_{rel}$.) No significant fluctuations will occur in the speech of teachers without vocal fatigue.

Design

This research took the form of a mixed 2x6 causal-comparative study implemented on 9 classroom teachers who reported experiencing vocal fatigue and 7 comparison teachers who did not report experiencing vocal fatigue. Such a design allowed the researcher to investigate changes in translaryngeal pressure and flow, laryngeal airway resistance and relative decibel level over time and to extend the findings to the general population of individuals with vocal fatigue (Silverman, 1993).

Variables

Independent and dependent variables were as follows:

Independent Variable 1: Vocal fatigue, having two levels: present and absent.

For the purposes of this study, vocal fatigue was defined arbitrarily by the presence or absence of a number of symptoms reported by the subjects (see Appendix A). Speakers with vocal fatigue reported experiencing five or more symptoms of vocal fatigue at least once per week. Speakers without vocal fatigue reported experiencing no more than one symptom of vocal fatigue once per week or less.

Independent Variable 2: Time of week, having six levels: before and after school on Monday, Wednesday and Friday of the same week.

Dependent Variable 1: Laryngeal airway resistance (cm H_2O/LPS).

Dependent Variable 2: Translaryngeal pressure (cm H_2O).

Dependent Variable 3: Translaryngeal flow (LPS).

Dependent Variable 4: Relative decibel level (dB) of the vocal signal tape recorded during aeromechanical data collection.

METHODOLOGY

Subjects

The experimental group was comprised of nine female classroom teachers with a mean age of 34 years, 3 months (*SD* = 6 years, 9 months) who instructed kindergarten through grade 12. Experimental group subjects reported experiencing 5 or more symptoms of vocal fatigue at least once per week (see Appendix A). Such a threshold was chosen arbitrarily by the experimenter, because no data suggesting an appropriate threshold exist. The comparison group was comprised of seven female teachers with a mean age of 33 years, 9 months (*SD* = 7 years, 4 months) who also instructed kindergarten through grade 12, but who reported experiencing no more than 1 vocal fatigue symptom once per week. An independent-samples *t*-test did not find a significant difference (t_{16}=.04; α>.05) between the mean ages of the experimental and comparison groups.

In order to reduce the possibility of organic laryngeal pathology such as vocal nodules, polyps or contact ulcers occurring in any subjects, the researcher and another speech pathologist familiar with voice assessment techniques evaluated tape recordings of potential subjects' voices using the Wilson Voice Profile (Wilson, 1972; Appendix B). Evaluation was based on subjects' readings of a short passage aloud (Appendix C). Tape recording was performed by the researcher and took place at candidates' schools. Experimental group candidates whose voices received a laryngeal cavity rating of 3 or worse from either evaluator on the open/closed or high/low factors on the Wilson Voice Profile were excluded from participation in the study. Experimental group candidates also were excluded from participation if their voices were judged by either evaluator to contain intermittent or continuous diplophonia, audible inhalation, immature resonance and/or vocal tremor. Comparison group candidates whose voices received a laryngeal cavity rating other than 1 (normal) from either evaluator on the open/closed or high/low factors on the Wilson Voice Profile were excluded from experimental participation.

Comparison group candidates also were excluded if their voices were judged by either evaluator to contain intermittent or continuous diplophonia, audible inhalation, pitch breaks, immature resonance and/or vocal tremor.

All participants were recruited through public and Catholic schools within Edmonton. In order to reduce the possibility that symptoms of vocal fatigue were caused by confounding variables, individuals who reported a history of neurologic disease, vocal fold pathology or gastroesophageal reflux were excluded from experimental participation. In order to reduce the possibility that vocal fatigue symptoms were associated with tobacco use, individuals who smoked also were excluded. In order to reduce the possibility that symptoms of vocal fatigue were associated with a hearing loss, potential subjects were required to pass a hearing examination administered by the principal investigator at their schools (Appendix D). Subjects who developed a cold or other respiratory illness during their participation in the study were excused from participation until they regained their health. Subjects were asked to keep their use of medications and alcohol consistent during the study period in order for aeromechanical and acoustical data recording to reflect habitual physiological conditions for substances that may have affected the voice. Subjects also were asked not to begin or end speaking or singing courses during the study period in order for voice use to remain constant. Subjects were asked to maintain a daily voice diary (Appendix E) in order to monitor their voice use and increase the likelihood that acoustical and aeromechanical data were associated with consistent voicing behaviors. Subjects who reported atypical or unusually excessive voice use during any day of the sampling period were excused from participation for one week in order to allow any effects of the unusual voice use to subside. Finally, although ovulation (the middle seven days between two consecutive menstrual periods) is believed to affect the voice (Higgins & Saxman, 1989), its effects on laryngeal airway resistance are unpredictable. Therefore, subjects were asked to participate in this study at times other than the ovulation period of their menstrual cycles.

Materials and Instrumentation

Instrumentation for estimation of aeromechanical data. The PERCI-PC system (Microtronics Corporation, Chapel Hill, NC), a digital acquisition and analysis array for aeromechanical data, was used to obtain data for translaryngeal pressures and flows, and to calculate laryngeal airway resistance. A schematic diagram of the instrumental hardware array is provided in Appendix F. Intraoral pressure was sensed by a slender polyethylene catheter threaded through a side opening in a full-face rubber anesthesia mask (SCRAM type, Ohio Medical); one end of the catheter was positioned in the subject's oral cavity just behind the lips, and the other end was coupled to a differential air pressure transducer (Setra, model MT239-P). Airflow was collected by the anesthesia mask coupled to a heated pneumotachometer (Fleisch, model MT1FP; heater supply model MT-7324) with rubber tubing. The pressure drop across the pneumotachometer was sensed by two polyethylene catheters coupled to a differential pressure transducer (Setra, model MT239-F). The output signals of the pressure and flow transducers were routed to an analog-to-digital converter (Lab Master DMA) and then to a microcomputer (Zenith 386) for analysis via custom software (PERCI-PC, version 1.71).

Instrumental calibration. The investigator performed calibration for pressure and flow on the PERCI-PC system according to the manufacturer's specifications at the beginning of each day of testing. Pressure was calibrated at 10 cm H_2O using a U-tube water manometer, and flow was calibrated at 0.250 LPS using a rotameter (Gilmont, model D-5400). A written record of pressure and flow calibration factors was maintained in order to monitor the stability of the instrumental array across the experimental period.

Validity and reliability. Campbell et al. (1991) report the correlation coefficients *r* for pressure and flow data generated by the PERCI-PC system in reference to a mechanical model to be very nearly 1. The authors also state that clinical experience and performance data indicate the system is a reliable tool for obtaining and analyzing pressure and flow measurements in human subjects.

Instrumentation for measurement of relative decibel level. An audio cassette recorder (Marantz, model PMD221) and unidirectional microphone (Shure, model 7A815) were used to record subjects' voices during production of the seven-syllable train associated with aeromechanical data collection. Relative decibel levels among the tape recorded data were measured via the VisiPitch (Kay Elemetrics Corp., Pine Brook, NJ, USA) operating on a dedicated microcomputer (Zenith 286).

Instrumentation for measurement of vocal fatigue. A vocal fatigue survey (Appendix G) was completed by subjects at the beginning of each experimental session. The survey was used to monitor participants' perceived levels of fatigue, and to test the validity of subject placements into experimental and control groups.

Procedures

Schedule. This investigation was undertaken during the months of February, March, April, May and June of the 1994-95 academic year. Data were not collected during the first month of the school term in order to allow subjects to establish a consistent pattern of voice use during that period. Permission to recruit subjects was sought from the school boards and from principals within the school systems. Interested candidates were asked to sign a release form (Appendix H) allowing the investigator to contact them by telephone in order to answer questions regarding the study and to determine whether they met the selection criteria based on their answers to a number of questions listed in Appendix I. The investigator then scheduled individual meetings at potential subjects' schools, where candidates were given an information/consent form outlining the purpose and procedures of the study (Appendix J).

Administration of hearing and voice screening examinations were undertaken during the initial meeting at each candidate's school. The meeting lasted approximately fifteen minutes per candidate. Potential subjects subsequently were advised whether or not they were eligible to take part in the study. Aeromechanical and acoustical recording of the voices of selected candidates were scheduled according to the experimental constraints for respiratory health and menstrual cycle mentioned in the "subjects" section. Recording took place on the University of Alberta campus in Corbett Hall, room 2-88. Data were collected from each participant two times a day (before and after school), over three days of a single week (Monday, Wednesday and Friday). Each session lasted approximately 10 minutes.

Hearing screening. The investigator tested candidates' hearing with a portable audiometer (Maico, model MA40). The frequencies 500, 1000, 2000 and 4000 Hz were tested at 20 dB HL under earphones in a room with minimal background noise. The form in Appendix D was used to record examination results. All candidates passed the hearing screening.

Voice evaluation. Candidates who passed the hearing examination had their voices tape recorded by the researcher while they read a short paragraph aloud (Appendix C). Their recorded voice samples then were rated for several dimensions of voice quality (Appendix B) by the researcher and another speech pathologist familiar with voice assessment techniques. Candidates were excluded from experimental participation based on the criteria for voice quality discussed in the "subjects" section of this report. Individuals who did not pass the voice evaluation were referred to the Glenrose Hospital Voice Clinic if they wished. In total, three candidates were referred to the Voice Clinic and one candidate was offered a referral but declined.

Case history questionnaire. All potential subjects were given detailed case history questionnaires (Appendix K) at their schools. Candidates selected for participation were asked to complete the questionnaire and return it to the researcher prior to the first data collection session at the University.

Voice Diary. Subjects selected for participation in the study were asked to maintain a diary of voice use (Appendix E) across 5 days of the aeromechanical data sampling period. Such a diary monitored subjects' voice use and increased the likelihood that aeromechanical and acoustical data were associated with consistent voicing behaviors.

The following procedures were followed during each recording session:

Vocal fatigue survey. In order to test the validity of subjects' placements into experimental and control groups based on subjects' preliminary reports of the presence of vocal fatigue, the experimenter continued to monitor subjects' self-reports of vocal fatigue during the week of aeromechanical and acoustical recording. Participants completed a checklist of vocal fatigue symptoms (Appendix G) at the beginning of each session.

Aeromechanical data collection. Procedures associated with this part of the recording session followed those reported by Smitheran and Hixon (1981). Each subject was seated upright in front of the PERCI-PC instrumental array and placed her mouth and nose into the anesthesia mask, creating a comfortable, airtight seal between the mask and her face (Appendix F). In order to maintain the cleanliness of experimental equipment with which subjects might come into contact, every participant was assigned an individual intraoral pressure tube that was kept in a labelled pouch between sessions. Intraoral pressure tubes were cleaned in Cidex (Johnson & Johnson, Peterborough, ON) before and after use by each subject. The anesthesia mask was cleaned with telephone disinfectant pads (Texwipe PhoneWipe Pads, The Texwipe Company, Upper Saddle River, NJ) just prior to and immediately after use by each subject. Finally, the researcher put on a clean pair of latex gloves for each subject before sampling pressure and flow.

During pressure-flow sampling, subjects produced three evenly-stressed, seven-syllable trains of the utterance /pi/ at a rate of 1.5 syllables per second (Smitheran & Hixon, 1981). Production of a seven-syllable train at this rate on a single expiration reduced the potential for occurrence of separate respiratory gestures per syllable as described by Rothenberg (1982), or for the occurrence of occasional velopharyngeal opening associated with slower rates of speech (Thompson & Hixon, 1979). In order to facilitate performance on a single inspiration, subjects were reminded to inhale adequately at the beginning of each utterance so that they could produce the seven syllables comfortably on one breath. Subjects monitored their rate of syllable repetition by speaking in time to the flashing light of a metronome set at 90 beats per minute. The metronome's sound was turned off in order to reduce background noise during the speech task.

The entire syllable train (seven repetitions of /pi/) were uttered and recorded three times during data acquisition. The first and last vowel segments in each train were discarded to minimize onset and offset effects, leaving the middle five vowels for analysis. Utterances judged by the investigator to be inappropriate with respect to rate and/or syllable stress were rejected, and additional samples were collected until three appropriate samples were obtained.

The sampling procedure yielded both oral pressure and flow data (Appendix L). Peak oral pressure ("A") coincided with the closed phase of the bilabial voiceless plosive /p/ in the sample utterance. At this moment, oral pressure was essentially identical to tracheal pressure. Therefore, the peak oral pressure was used as an estimate of the tracheal pressure at the same moment. By linearly interpolating the pressure contour between adjacent oral pressure maxima, it was possible to estimate the background tracheal pressure ("B") associated with the vowel segment for /i/ occurring between the plosives. An estimate of pharyngeal pressure associated with vowel production was obtained by measuring oral pressure during each vowel ("C", nearly zero), because the pressure difference between the pharynx and oral cavity is essentially nil during vowel production. Finally, airway-opening flow ("D") was used as an estimate of translaryngeal airflow during vowel production because flow through the upper airway is laminar and uninterrupted (Smitheran & Hixon, 1981).

Mean translaryngeal pressure and flow were calculated by the PERCI-PC software during the five vowels of each syllable train, based on cursor placements by the investigator in the software's analysis mode. Two grand means, one of average pressure and one of average flow, were obtained across all three utterance trains. Mean laryngeal airway resistance during the five vowels of each syllable train was estimated by the PERCI-PC software according to the formula: $R_{law} = P_{tl} / \dot{V}_{tl}$, where P_{tl} represents translaryngeal pressure and $\dot{V}_{tl}$ translaryngeal flow. A grand mean of the resistance averages was obtained across all three utterance trains.

Relative decibel level measurement. During data collection, the microphone was placed immediately below the outlet of the flow meter at a 90° incidence as shown in Appendix F. Room temperature and ventilation fan noise were held constant to control for factors that could affect subjects' effort levels and associated relative decibel levels during acoustical recording.

Data Analysis

Hartley's *F*-Max test was used to investigate homogeneity of variance between the group data sets for each dependent variable (translaryngeal pressure, flow, resistance and relative decibel level). No significant differences were found among any of the variances ($\alpha < .01$). Then, a two-factor (2x6) independent analysis of variance with repeated measures on one factor (time) was performed on each of the four dependent variables. The analyses of variance (Bonferroni-adjusted $\alpha = .0125$; $\beta = .80$) were used to test for differences between the experimental and control groups within and across the sampling periods. Matching experimental and control groups for age, sex and location in the menstrual cycle reduced the possibility of potential differences among the means occurring as a result of factors other than vocal fatigue.

Reliability

Twenty percent of translaryngeal pressure, flow, airway resistance and relative decibel values were selected randomly for recalculation by the researcher in order to determine intrarater reliability. Pearson Product-Moment correlations among the twice-measured values were 1.0 for air pressure, airflow and laryngeal airway resistance, and .99 for relative decibel level. In order to determine interrater reliability, twenty percent of the data were selected randomly and measured by a person familiar with pressure and flow analysis using the PERCI-PC, and by a person familiar with relative decibel analysis using the VisiPitch. Pearson Product-Moment correlations were 1.0 for air pressure, .999 for airflow, .998 for laryngeal airway resistance and .94 for relative decibel level.

Ethical Considerations

This study employed non-invasive and painless techniques for the acquisition of aeromechanical and acoustical data that posed no known risks to participants. Subjects were informed of the study's objectives and methods and signed a consent form (Appendix J) if they agreed to take part in the investigation. The consent form informed potential subjects of eligibility criteria, the time commitment necessary for participation and the procedures for pressure-flow sampling and equipment cleaning. The form also indicated that subjects would be required to complete a case history questionnaire, undergo a voice examination, pass a hearing examination, complete a daily voice diary, and fill out vocal fatigue surveys during the experimental sessions. The consent form also outlined how data would be stored and secured during and after the experiment. Finally, subjects were advised that their data would be used only for research purposes, and that they would be free to withdraw themselves and their data from the research at any time without negative consequence.

Participant anonymity was protected by the use of project identification codes on all questionnaires and reports. For the duration of the study, data were stored on 3½" diskettes and kept in a locked room to which only the investigator and project supervisors had access. At the end of the study period, all questionnaires, reports and diskettes remain in a locked room and cabinet with the same restricted access. They will be destroyed at the end of the 5-year period required for their safe-keeping by the University of Alberta (General Faculties Council policy on Research Integrity, 1995).

RESULTS

Means, standard deviations and ranges for the dependent variables (air pressure, airflow, laryngeal airway resistance, relative decibel level) for the fatigued and control groups are reported in Table 1. These data are plotted across the experimental recording period in Figures 1-8.

Translaryngeal Pressure

Analysis of variance did not reveal any significant differences among estimated mean translaryngeal pressures between the two groups during the week of sampling (see Table 1 and Figures 1 and 2). However, within-group pressure differences among the six sampling periods approached statistical significance ($F=2.866$; $p=.021$). Post-hoc testing was used to investigate which among the pressure data sampling periods had contributed to the trend toward change. These tests revealed air pressure differences within the control group ($F=3.737$; $p=.0095$), but not the fatigued group ($F=1.056$; $p=.399$). Air pressure for the control group tended to be lower on Monday morning than on Wednesday afternoon ($F=2.155$), Friday morning ($F=2.131$) or Friday afternoon ($F=2.361$), although these differences did not achieve significance levels at 95% as measured by Scheffe's test.

Translaryngeal Airflow

Airflow values between the two groups did not differ significantly at any point during the week of sampling (see Table 1 and Figures 3 and 4). However, analysis of variance revealed within-group differences in airflow values among the six sampling periods

($F=4.743$; $p=.0009$). Post-hoc testing revealed airflow differences within the fatigued group ($F=4.64$; $p=.002$), but not the control group ($F=1.827$; $p=.138$). Airflow measured in fatigued subjects was higher on Wednesday morning than Wednesday afternoon ($F=3.501$; $p<.05$) or Friday afternoon ($F=2.51$; $p<.05$).

Table 1
Group Means, Standard Deviations, Minima and Maxima for Experimental Variables

		Control Group				Fatigued Group			
Time	Measure	*M*	*SD*	Min.	Max.	*M*	*SD*	Min.	Max.
Mon. AM	P_{tl}	8.05	1.91	5.70	11.34	7.90	2.19	5.69	12.48
	$\dot{V}_{tl}$	186.89	47.16	124.47	257.60	201.07	60.25	122.87	304.33
	R_{law}	44.40	9.07	35.55	62.73	41.47	12.26	27.12	68.38
	dB_{rel}	54.36	3.25	50.30	59.47	53.95	5.00	44.47	58.73
Mon. PM	P_{tl}	8.69	2.67	5.23	13.05	7.41	1.25	5.27	9.14
	$\dot{V}_{tl}$	176.36	51.75	127.73	253.40	198.07	58.75	127.33	310.13
	R_{law}	50.34	8.14	39.84	59.83	39.50	9.33	27.02	54.45
	dB_{rel}	55.57	2.85	51.57	59.73	53.75	5.00	46.57	60.40
Wed. AM	P_{tl}	9.20	2.64	6.35	12.98	8.01	1.59	6.19	11.01
	$\dot{V}_{tl}$	195.21	49.39	131.53	270.53	219.05	76.41	141.53	377.87
	R_{law}	47.96	10.58	35.65	68.47	39.04	9.31	26.51	53.60
	dB_{rel}	55.23	2.79	52.43	59.30	54.07	4.02	49.03	58.93
Wed. PM	P_{tl}	9.58	3.17	6.34	14.31	7.60	1.49	4.75	10.15
	$\dot{V}_{tl}$	187.86	55.30	126.73	269.00	183.92	57.34	116.60	287.40
	R_{law}	51.16	5.75	38.91	56.94	43.66	9.02	29.37	55.39
	dB_{rel}	55.77	3.31	51.93	59.97	54.75	4.79	47.00	60.13
Fri. AM	P_{tl}	9.57	3.35	7.04	15.01	8.06	1.37	5.39	10.56
	$\dot{V}_{tl}$	199.60	53.73	126.60	271.47	208.78	67.61	135.20	332.87
	R_{law}	48.89	12.08	35.07	71.36	41.32	10.29	25.63	54.70
	dB_{rel}	55.24	4.15	48.63	60.90	53.85	3.96	49.30	59.63
Fri. PM	P_{tl}	9.65	3.40	6.33	15.17	7.97	1.30	5.49	10.13
	$\dot{V}_{tl}$	192.41	50.19	130.47	280.47	189.30	57.23	132.67	270.40
	R_{law}	49.84	6.97	42.52	64.40	45.44	12.88	30.06	67.13
	dB_{rel}	54.85	3.30	50.23	59.60	54.04	4.48	47.60	59.57

Note. P_{tl} = translaryngeal air pressure (cm H_2O); $\dot{V}_{tl}$ = translaryngeal airflow (mL/S); R_{law} = laryngeal airway resistance (cm H_2O/LPS); dB_{rel} = relative dB (SPL).

Control Group

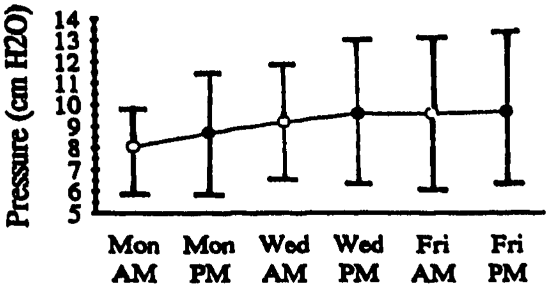

Figure 1. Mean translaryngeal pressure sampled across six sessions.

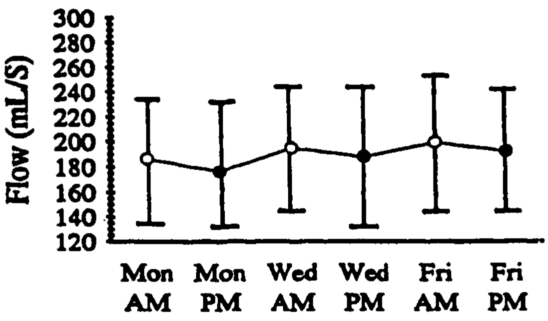

Figure 3. Mean translaryngeal airflow sampled across six sessions.

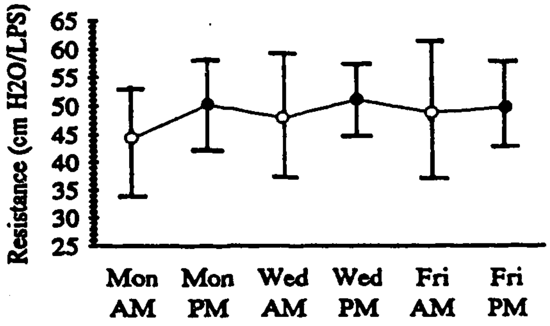

Figure 5. Mean laryngeal airway resistance sampled across six sessions.

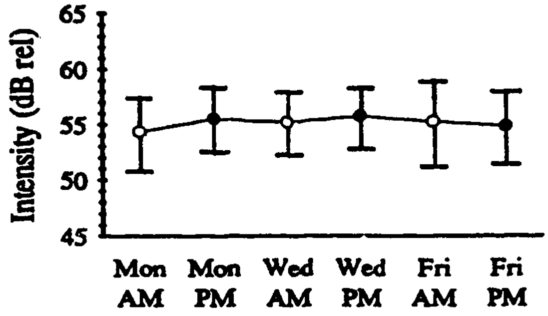

Figure 7. Mean relative decibel level sampled across six sessions.

Fatigued Group

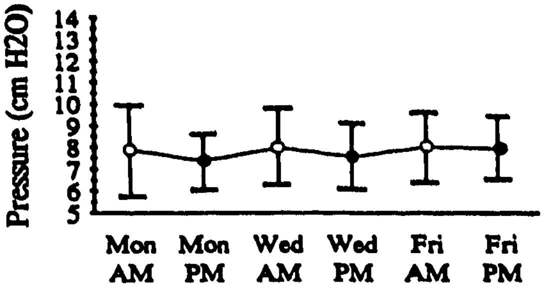

Figure 2. Mean translaryngeal pressure sampled across six sessions.

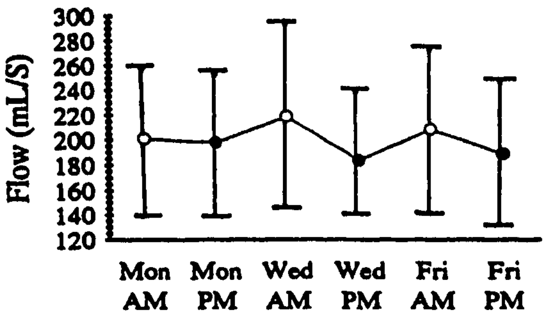

Figure 4. Mean translaryngeal airflow sampled across six sessions.

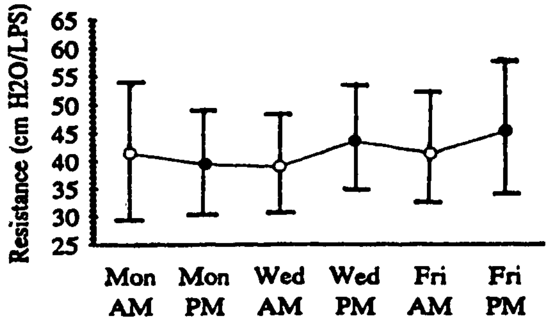

Figure 6. Mean laryngeal airway resistance sampled across six sessions.

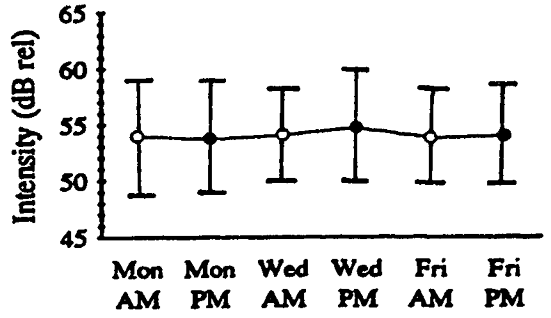

Figure 8. Mean relative decibel level sampled across six sessions.

Laryngeal Airway Resistance

Analysis of variance did not reveal any significant differences among laryngeal airway resistance means within or between the two groups over the week of sampling (see Table 1 and Figures 5 and 6).

Relative Decibel Level

Analysis of variance did not reveal any significant differences among mean relative decibel levels of the syllable trains analyzed within or between the two groups over the week of sampling (see Table 1 and Figures 7 and 8).

In summary, translaryngeal pressure, translaryngeal flow and laryngeal airway resistance values did not differ between the two groups during the week of data sampling. Relative decibel levels sampled during the week did not differ between or within groups. Mean airflow measured in the speech of fatigued subjects was significantly lower ($p=.0009$) on Wednesday and Friday afternoons than Wednesday morning. Finally, air pressure exhibited a trend toward difference within the control group ($p=.021$). Although the difference was nonsignificant, pressure values tended to be higher on Wednesday afternoon, Friday morning and Friday afternoon than Monday morning.

DISCUSSION

This investigation examined mean translaryngeal air pressure, translaryngeal airflow, laryngeal airway resistance and relative decibel levels in data collected from female teachers with and without symptoms of vocal fatigue across six recording sessions in one week during the last half of the school term. Grand means and standard deviations for the experimental variables, along with norms reported by other investigators, are summarized in Table 2.

Table 2
Pressure, flow and resistance data for women during repetition of /pi/ at normal pitch and loudness

Investigators	P_{tl}		$\dot{V}_{tl}$		R_{law}	
	M	*SD*	*M*	*SD*	*M*	*SD*
Leeper and Graves (1984)	6.43	1.87	200.43	65.86	38.33	9.25
Shaughnessy et al. (1984)	7.10	0.83	140	36	44	14
Holmberg et al. (1988)	5.8	0.9	140	30	42.2	8.1
Netsell et al. (1991)	5.3	1.2	127.1	27.4	42.6	9.2
Stathopoulos et al. (1991)	4.61	0.99	140	30	34.53	13.62
Hoit and Hixon (1992)[a]					51.32	16.03
Wilson and Leeper (1992)[b]	7.6	2.9	174.2	47.4	51.7	31.1
Stathopoulos and Sapienza (1993)	4.75	1.22	120	30	40.62	13.67
Kostyk and Rochet[c]						
Control group	9.12	2.78	189.72	48.67	48.76	8.74
Fatigued group	7.83	1.5	200.04	61.39	41.74	10.36

Note. P_{tl} = translaryngeal air pressure (cm H_2O); $\dot{V}_{tl}$ = translaryngeal airflow (mL/S); R_{law} = laryngeal airway resistance (cm H_2O/LPS).
[a] 35 year-old women.
[b] Loudness at 50th percentile for subjects' sound pressure level ranges.
[c] Data from present study.

At the outset of this experiment, two hypotheses were stated based on a review of the literature pertinent to vocal hyperfunction, vocal fatigue and aeromechanical parameter adjustments during speech in the face of valve incompetence:

1. *Each sampling point for translaryngeal pressure (P), laryngeal airway resistance (R_{law}) and relative decibel level (dB_{rel}) during voice production will be lower in teachers with vocal fatigue than in teachers without vocal fatigue. Each sampling point for translaryngeal airflow ($\dot{V}$) during voice production will be higher in teachers with vocal fatigue than in teachers without vocal fatigue. (Summary: $\downarrow P$, $\downarrow R_{law}$, $\downarrow dB_{rel}$, $\uparrow \dot{V}$.)*

The results of the study were not consistent with this hypothesis. Neither pressure, flow, resistance nor relative decibel level means differed significantly between experimental and control groups. Such a discrepancy suggests that these variables, when averaged over one week, are not sensitive to the presence or absence of vocal fatigue in these subjects. However, it does not preclude the possibility of the groups distinguishing themselves by the manner in which the parameters behave within each subject across the same sampling period.

2. *In teachers with vocal fatigue, translaryngeal airflow measured during voice production will increase across each point of the sampling period, whereas translaryngeal pressure, laryngeal airway resistance and relative decibel level means will drop. (Summary: $\uparrow \dot{V}$, $\downarrow P$, $\downarrow R_{law}$, $\downarrow dB_{rel}$.) No significant fluctuations will occur in the speech of teachers without vocal fatigue.*

Again, the results of this study ran contrary to the hypothesis. The prediction was based on the assumption that the control group would neither experience nor react to vocal fatigue during the week of data sampling, whereas the experimental group would experience, but not react to, vocal fatigue. However, the results of the study, which indicate that translaryngeal pressure tended to increase during the week in the speech of the control subjects whereas airflow decreased in the speech of the experimental subjects, could be interpreted to suggest that: (1) both groups experienced demands on their voices; and (2) each group needed to employ behavioral compensation in the form of increased respiratory effort and/or adjustments in laryngeal airway valving in order to maintain habitual laryngeal airway resistance. In accordance with this theory, the fact that resistance remained relatively constant in both groups across the sampling period suggests that each group's compensatory behaviors were successful. Mathematically, it also suggests that the observed fluctuations in airflow and, to a lesser extent, pressure, were not large enough to affect laryngeal airway resistance means. Finally, the fact that relative decibel levels remained steady across the week of data sampling suggests that both fatigued and control subjects were able to adjust to voice use demands to maintain vocal loudness.

In this investigation, mean air pressure tended to be higher than values reported by some other researchers (see Table 2). Pressure means for both fatigued and control groups correspond most closely to those obtained by Wilson and Leeper (1992). In addition, mean pressure for the fatigued group corresponds most closely to values reported by Leeper and Graves (1984) and Shaughnessy, Lotz and Netsell (1984).

Mean airflow for the subjects in this study, like mean pressure, tended to be higher than flow values obtained by some other investigators (see Table 2). Airflow means for both groups correspond most closely to those reported by Leeper and Graves (1984) and Wilson and Leeper (1992).

Mean laryngeal airway resistance values for subjects in this study compare favorably with data from other investigations (see Table 2).

Methods of intensity measurement among present and past investigations have varied. As a result, comparisons between the relative intensity data obtained in this study and those obtained by other investigators are not appropriate. Consequently, mean intensity is not reported in Table 2.

This study's relatively high pressure and airflow averages may suggest the presence of hyperfunctional phonation in the daily voice use of the present subjects (Hillman et al., 1989). Such a phonatory style could be a by-product of the profession of the subjects who participated in this study. The acoustics and instructor-student dynamics of the grade-school classroom environment, along with the duration of sustained vocal demands across the school day may encourage teachers to develop habitually effortful speaking patterns characterized by higher pressures and flows than individuals whose vocations place lesser demands on the voice. Elevated speech pressures also may suggest the presence of the following: (1) heightened activity of the laryngeal musculature; and/or (2) behavioral compensation to accomplish voicing in the presence of impaired vocal fold approximation due to edema, muscle fatigue or stress-induced relaxation in non-muscular components of the vocal folds (Hillman et al., 1989). A second explanation for the high pressure and flow averages calculated for both groups of subjects in this research compared to averages reported by other investigators may relate to critical volume (ie., deadspace) differences between the flow collection system (mask, connecting tubes and pneumotachometer) used in this study and the systems used by others. Substantial differences would prompt different respiratory responses from the subjects coupled to each system to accommodate for differences in "deadspace" at the interface between the airway openings and the downstream flow resistor to which the subject is coupled. Such discrepancies may explain differences in group data between studies but would be constant for the subjects within a study. In the absence of information on the habitual vocal demands placed on subjects in previous studies, it is unclear whether phonatory style, critical volume or both contributed to this study's relatively high pressures and flows.

Consistency of Aeromechanical Measures Over Time

Several researchers (Leeper & Graves, 1984; Wilson & Leeper, 1992) have monitored aeromechanical parameters of voice production over time. They reported that air pressure, airflow and laryngeal airway resistance values were relatively constant over time, but their findings were not replicated in the present study. Airflow values in subjects with symptoms of vocal fatigue decreased significantly toward the end of the week, whereas air pressure and laryngeal airway resistance remained constant. In subjects who did not report symptoms of vocal fatigue, air pressure tended to increase as the week progressed, while airflow and laryngeal airway resistance remained unchanged. Several experimental factors may have contributed to the variance observed in the present aeromechanical data compared to the relative stability of the data recorded by Graves and Leeper (1984) and Wilson and Leeper (1992), namely duration of the sampling period and the vocal status and habits of the subjects studied. The subjects in this study were monitored across one week of typical voice use whereas the subjects studied by Leeper and his colleagues were assessed across only two days. Furthermore, the participants in the present study were homogeneous with respect to their daily vocal demands (heavy) and included subjects with vocal fatigue, characteristics not identified in the subjects studied by Leeper and Graves (1984) or Wilson and Leeper (1992). The extended sampling period and the nature of the subject groups in the present study may well have introduced the opportunity for more variance in the aeromechanical variables as "wear and tear" accumulated on participants' heavily used voices, some of which were exhibiting symptoms of fatigue.

Aeromechanical Indicators of Vocal Fatigue

Although mean pressure, airflow and resistance did not vary significantly between subjects who reported symptoms of vocal fatigue and those who did not, the groups were distinguished by the manner in which air pressure and airflow values fluctuated across the week of sampling. Whereas airflow decreased significantly over the week of sampling in fatigued subjects while pressure remained relatively constant, pressure tended to increase in control subjects while airflow remained relatively constant. The fact that relative decibel levels for the test utterances in both groups remained constant across the six sampling periods suggests that the observed fluctuations in air pressure and airflow were not associated with vocal intensity variation (Holmberg et al., 1984; Isshiki, 1964; Leeper & Graves, 1984; Stathopoulos & Sapienza, 1993; Tanaka & Gould, 1983; Wilson & Leeper, 1992). Rather, such airflow reductions and pressure elevations suggest that both groups adjusted to sustained voice use and the need to maintain habitual laryngeal airway resistance via different behavioral compensations.

Maintenance of Adequate Laryngeal Airway Resistance

Researchers have proposed a monitoring system for breathing whereby individuals can detect a change in resistance of approximately 0.7 cm H_2O/LPS (Elice & Warren, 1991). Such a detection system also has been proposed for speech, and speakers have been documented to respond to perturbations of oral and velopharyngeal resistance (Dalston et al., 1990; Laine et al., 1988; Putnam et al., 1986; Warren et al., 1989, 1990, 1991). The most successful outcome with respect to maintenance of velar and oral port resistance occurs when subjects coordinate articulatory and respiratory compensations. For example, individuals who respond to imposed reductions in oral pressure (and resistance) by combining lingual valving of the oral port with increases in respiratory effort are more successful at maintaining resistance than are those who increase respiratory effort alone (Putnam et al., 1986; Warren et al., 1992).

If the theory of regulation-control (Warren, 1986) is applied to the laryngeal airway for voicing, then the most efficient method of maintaining adequate laryngeal airway resistance is to combine an increase in respiratory effort with vocal fold valving adjustments in the laryngeal airway. Increasing respiratory effort alone would not maintain laryngeal airway resistance as effectively. Airflow reductions and pressure elevations observed in the present study support such a strategy and compare favorably with data from previous research investigating behavioral compensations measured at the oral and velopharyngeal ports (Dalston et al., 1990; Laine et al., 1988; Putnam et al., 1986; Warren et al., 1989, 1990, 1991). Because airflow dropped in the fatigued subjects and pressure rose in the control subjects, it appears that both groups in the present study experienced and reacted to vocal use demands during the week of data sampling. However, the control group, who did not report any symptoms of vocal fatigue, may have employed the most successful behavioral response to maintain laryngeal airway resistance. The fact that air pressure tended to increase while airflow and resistance remained constant in this group suggests that they coordinated greater respiratory effort with adjustments in laryngeal valving. It appears that the fatigued group, whose speech pressures remained constant across the week while associated airflow decreased, may have relied on laryngeal valving alone to sustain laryngeal airway resistance. Because this method is less efficient and possibly more stressful for the laryngeal musculature, it may not be surprising that these subjects reported symptoms of vocal fatigue. Whether the fatigued group's reliance upon laryngeal valving alone was due to (1) laryngeal focus[1]; (2) poor respiratory control; (3) difficulty with coordination of laryngeal and respiratory behaviors; (4) fatigue of the respiratory muscles; or a combination of these factors is unclear. Each has been associated with vocal fatigue and the disordered voice (Boone & McFarlane, 1988a; 1988c; Burzynski & Titze, 1985; Darley & Spriestersbach, 1978b; Hillman et al., 1989; Scherer et al., 1985; Titze, 1983).

Vocal Fatigue Survey

Subjects' responses on the vocal fatigue survey (Appendix G) generally were consistent with the aeromechanical data obtained during the week of sampling. Control subjects did not report vocal fatigue during the sampling period, either on the severity rating scale or

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[1] Concentrating on the throat as the anatomical site or source of vocal power, rather than projecting the voice via respiratory power and a resonance focus in the middle, "bony mask" of the face (Andrews, 1995; Boone, 1983).

symptom checklist (one or fewer symptoms selected, as per subject inclusion criteria). An exception was one subject whose severity ratings indicated the presence of vocal fatigue, though she did not check off more than one symptom during the week. Experimental subjects' self-ratings on the vocal fatigue severity scale corresponded more closely to changes in the group's airflow means depicted in Figure 4 than did their responses on the symptom checklist. Without exception, each fatigued subject's airflow measurements were lower on Wednesday and Friday afternoons than on Wednesday morning. Interestingly, six of those nine subjects rated their levels of vocal fatigue higher on Wednesday afternoon than Wednesday morning, two subjects' ratings remained the same and one subject rated her fatigue lower during the afternoon. Seven of the nine experimental subjects rated their levels of fatigue higher on Friday afternoon than Wednesday morning, one subject's ratings remained the same and one subject rated her level of fatigue lower on Friday afternoon. With respect to the symptom checklist, those identified on Wednesday and Friday afternoon included an equal number of increases, decreases or correspondences in the number of fatigue symptoms selected by the experimental subjects. It is possible that the checklist did not reflect the subjects' vocal fatigue symptoms accurately or capture them adequately, although only two of the nine fatigued subjects wrote in any other symptoms in the space provided on the survey. Therefore, if there was a coincident relationship between changes observed in the airflow data and subjects' perceptions of vocal fatigue, it may have been reflected more accurately by perceptions of severity, rather than number, of existing symptoms. The fact that some fatigued subjects identified fewer symptoms as the week progressed also may suggest that those individuals were not sensitive to symptoms of vocal fatigue or were not practiced at identifying those symptoms. It also is possible that some of the symptoms were transient, and gave way to other global or less distinct symptoms as the subjects' vocal demands increased across the week.

Threats to Internal and External Validity

The results of this investigation must be interpreted with caution because internal validity, or the extent to which the data reflect valid changes in the experimental variables rather than the effects of confounding influences, may have been threatened by two major factors: the method used to classify subjects into control and fatigued groups, and the influence of subjects' practice with the experimental procedure (Ventry & Schiavetti, 1986). The procedure used to allocate subjects into fatigued and control groups poses a threat to internal validity. Rather than assigning teachers to one of two groups at random and attempting to impose vocal fatigue on one group through the use of fatiguing tasks, this investigation recruited teachers with self-identified, pre-existing conditions of vocal fatigue and then grouped them arbitrarily based on the perceived severity of their symptoms. The threshold of five or more symptoms per week for fatigued-group assignment was chosen arbitrarily by the investigator because no data suggesting an appropriate threshold exist. Furthermore, symptoms of vocal fatigue were reported subjectively by the participants and were impossible to verify. Thus, it is possible that subjects were allocated to their experimental groups based on factors other than the presence or absence of vocal fatigue. The threat of a practice effect on subjects' performances across the duration of the study is acknowledged. Although no data were recorded until the principal investigator was satisfied that each individual was comfortable with the experimental task, it is possible that the pressure and flow differences obtained in this study reflect subjects' experience with the procedure across the week-long sampling period rather than the effects of vocal fatigue.

Several factors also may have threatened this experiment's external validity, or the extent to which the results are generalizable to other subjects and settings (Ventry & Schiavetti, 1986). Small sample size is one such factor. Another is selection bias: it is possible that some individuals participated in this study due to a special interest in the subject matter. Consequently, the sample may not represent the population of teachers with and without vocal fatigue accurately. Finally, because methodological constraints dictated the use of syllable-level utterances for analysis, caution should be employed when generalizing the findings of this research to spontaneous speech.

SUMMARY AND CONCLUSIONS

This investigation compared mean translaryngeal pressures, flows, resistances and relative decibel levels calculated two times per day across three days of one week in the voices of female classroom teachers with and without symptoms of vocal fatigue. Mean pressures and flows for both groups were higher than values reported by other researchers (see Table 2), suggesting either vocal hyperfunction in the present subjects, or critical downstream volume differences among the flow collection devices used in this study and others that could influence subjects' pressure and flow data. Laryngeal airway resistance values were in concert with other reported means (see Table 2). None of the four dependent variables differed significantly between the two groups at any point during the week of data recording. However, within-group fluctuations in air pressure and airflow did distinguish the two groups. These fluctuations are not consistent with the results of prior investigations of laryngeal airway resistance across short sampling periods (Leeper & Graves, 1984; Wilson & Leeper, 1992). In the present study, translaryngeal airflow measured during voice production in fatigued subjects decreased across the six sessions, whereas translaryngeal air pressure during speech production in control subjects tended to increase across the same period. Because relative decibel levels remained unchanged, such fluctuations were interpreted as possible active responses to sustained voice use and the need to maintain laryngeal airway resistance by both groups, rather than fluctuations associated with vocal intensity variation. It was suggested that the control subjects appeared to employ a more efficient means of maintaining laryngeal airway resistance by coordinating increases in respiratory effort with downstream adjustments in laryngeal valving. The fatigued group, however, appeared to have relied solely on laryngeal valving. The absence of perceptual signs or symptoms of vocal fatigue in the control group suggests that efficient behavioral compensation was successful in maintaining a functional vocal mechanism. Furthermore, it was argued that although laryngeal valving alone successfully maintained airway resistance in the presence of fatigue for the experimental subjects of the study, sole reliance upon laryngeal compensatory behaviors may place stress on the larynx. This stress then may be expressed as perceptible and symptomatic characteristics of the vocal fatigue syndrome (see Appendix A).

The results of the present investigation could be interpreted to support the conclusion of Hillman (1989) that chronically elevated air pressures and flows associated with speech production may signal vocal hyperfunction. Because hyperfunction has been associated with vocal fatigue and the development of voice disorders, pressure-flow testing may be useful for identifying individuals who are at-risk for hyperfunctional dysphonia. However, the fact that pressure/flow fluctuations occurred across multiple sampling opportunities during the period of voice use studied in these subjects indicates that evaluations of treatment efficacy likely should be based upon multiple pressure-flow recording sessions per week. If this is not possible, care should be taken to measure pressure and flow at the same time each week. Pressure-flow testing also may be usefully employed for individuals with vocal fatigue at the start and end of the work week to evaluate the efficiency of clients' compensatory behaviors for maintaining adequate laryngeal airway resistance. Finally, the fact that the experimental group in this study complained of vocal fatigue symptoms whereas the control group did not could be interpreted, in light of their respective aeromechanical adjustments across the sampling period, as evidence in support of treatment plans for hyperfunctional phonation patterns that include training in respiratory-laryngeal coordination and voice production strategies that optimize voice projection and discourage reliance on the laryngeal valve alone for vocal power.

Because these results for mean air pressure and airflow, along with the constancy of these measures, are not consistent with the results of previous investigations, replication of this research with a larger number of subjects would be informative. A useful precursor, however, would be a validation of the vocal fatigue survey employed in this study (Appendix G). Future investigations of pressure and airflow in the voices of a larger sample of healthy subjects may clarify the extent to which these variables fluctuate across a week of typical voice use. These data would be useful reference points for a study of the variation in fatigued or dysphonic voices across similar sampling periods and vocal habits. Based on the findings of this research, such an investigation could sample data across three, rather than six points: Monday morning, Wednesday morning, and Friday afternoon. It also would be instructive to compare mean vocal intensity with that of established norms, employing a method of intensity measurement consistent with those of earlier researchers. Finally, the assumption that control subjects in the present study responded actively to sustained voice use and the necessity of maintaining adequate laryngeal airway resistance needs to be tested. This could be accomplished by comparing speech pressures and flows measured in heavy voice users, such as teachers without symptoms of vocal fatigue, to those same parameters in moderate voice users, such as school librarians or custodial staff.

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APPENDIX A

SYMPTOMS OF VOCAL FATIGUE[2]

- Hoarse/husky vocal quality
- Breathy vocal quality
- Loss of voice
- Pitch breaks
- Inability to maintain typical pitch
- Reduced pitch range
- Lack of vocal carrying power
- Reduced loudness range
- Need to use greater vocal effort
- Running out of breath while talking
- Unsteady voice
- Tension in neck/shoulders
- Throat/neck pain
- Throat fatigue
- Throat tightness/constriction
- Pain on swallowing
- Increased need to cough/throat clear
- Discomfort in chest, ears or back of neck

---

[2] Titze, I.R. (1983). Vocal fatigue: Some biomechanical considerations. In Lawrence, V.L. (Ed.), *Transcripts of the twelfth symposium: Care of the professional voice. Part I: Scientific papers* (pp. 97-104). New York: The Voice Foundation.

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APPENDIX B

WILSON VOICE PROFILE

NAME ____________ AGE ____________ GRADE ______ SEX ______ DATE ____________

HOW LONG HAS PROBLEM EXISTED? ____________

WHAT SITUATIONS IS VOICE BETTER/WORSE? ____________

CONSTANT? ____________ VARIABLE? ____________ INTERMITTENT? ____________

(circle one)

VOICE RATING: 1 2 3 4 5 6 7

(normal) (most severe)

LENGTH OF SUSTAINED "ah" ______

"s" ______ "z" ______ Ratio ______

Laryngeal Cavity
Pitch
(high)
+3
+2
(open) -4 -3 -2 1 +2 +3 (closed)
-2
-3
(low)

Resonating Cavity
Nasality
(hypernasal)
+4
+3
+2
(gutteral) -2 1 +2 (effeminate)
-2
(hyponasal)

Loudness Level
(soft) -2 1 +2 (loud)

Vocal Range
(monotone) -2 1 +2 (variable pitch)

CHECK (✓) PRESENCE OR ABSENCE OF ANY OF THE FOLLOWING PERCEPTUAL FEATURES

	YES	NO
INTERMITTENT DIPLOPHONIA	______	______
DIPLOPHONIA	______	______
AUDIBLE INHALATION	______	______
PITCH BREAKS	______	______
ERRATIC PHRASING	______	______
IMMATURE RESONANCE	______	______
VOCAL TREMOR	______	______

MARKING SYSTEM

Primary Feature X ($\cancel{+2}$) Secondary Feature / ($\cancel{+2}$) Noted Feature / ($\cancel{+2}$) Intermittent Feature ⁄ ($\cancel{+2}$)

COMMENTS ____________

____

____
CLINICIAN

APPENDIX C
GRANDFATHER PASSAGE

My Grandfather[3]

You wished to know all about my grandfather. Well, he is nearly ninety-three years old. He dresses himself in an ancient black frock coat, usually minus several buttons; yet he still thinks as swiftly as ever. A long, flowing beard clings to his chin, giving those who observe him a pronounced feeling of the utmost respect. When he speaks, his voice is just a bit cracked and quivers a trifle. Twice each day, he plays skillfully and with zest upon our small organ. Except in the winter when the ooze or snow or ice prevents, he slowly takes a short walk in the open air each day. We have often urged him to walk more and smoke less, but he always answers, "Banana oil!" Grandfather likes to be modern in his language.

---

[3] Darley, F.L., Aronson, A.E., & Brown, J.R. (1975). Appendix D. In Darley, F.L., Aronson, A.E., & Brown, J.R., *Motor speech disorders* (pg. 298). Philadelphia: W.B. Saunders.

APPENDIX D

HEARING EVALUATION FORM

Project I.D. Code.:

Date:

	500 Hz	1000 Hz	2000 Hz	4000 Hz
Right Ear				
Left Ear				

APPENDIX E

VOICE DIARY

Project I.D. Code.:

Date:

1. Did you use your voice in a typical manner (ie., at a typical pitch and loudness and for a typical duration) today? (circle one) YES NO

2. If no, please explain: ______________________________

____

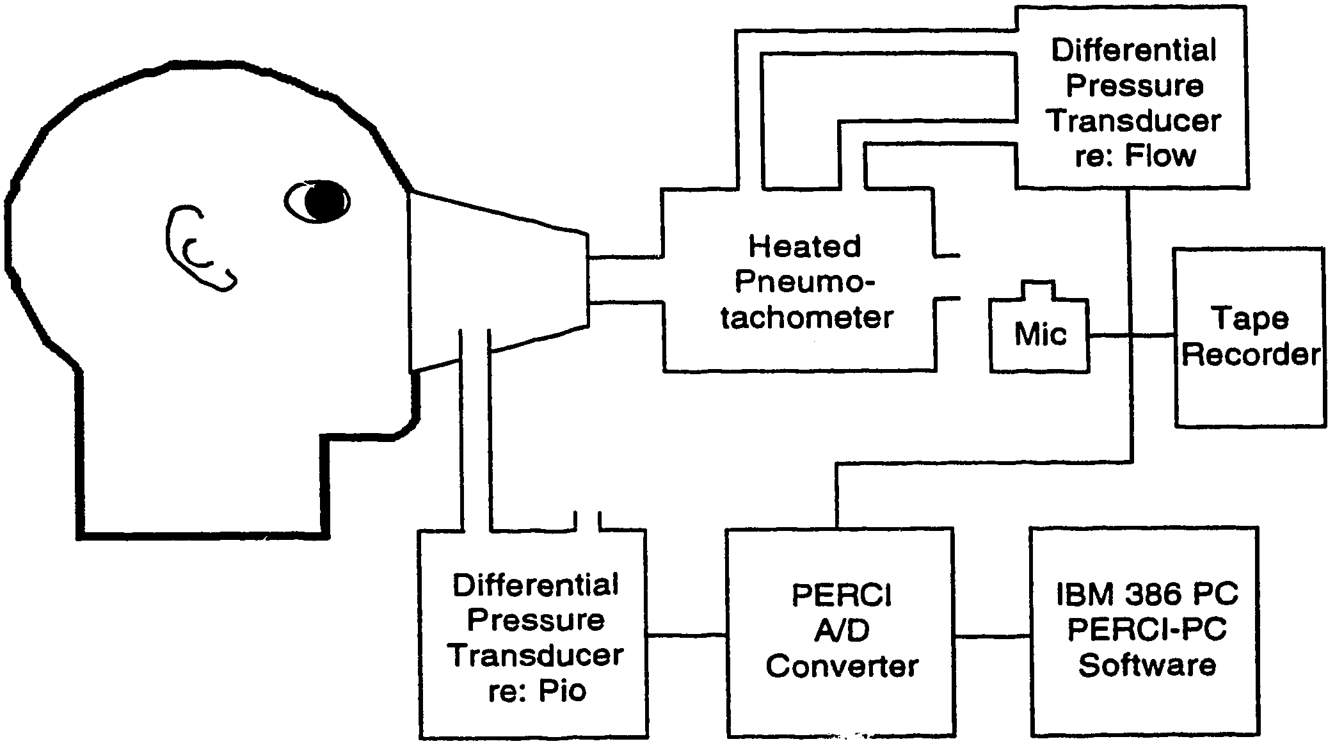
____

____

____

APPENDIX F

SCHEMATIC DIAGRAM - INSTRUMENTAL ARRAY



APPENDIX G

VOCAL FATIGUE SURVEY

Project I.D. Code:
Date:
AM / PM

Please check off any of the following symptoms that you are experiencing at this moment. **Star (*) any symptoms that you think you have because of allergies.**

____ Hoarse/husky vocal quality
____ Breathy vocal quality
____ Loss of voice
____ Pitch breaks
____ Inability to maintain typical pitch
____ Reduced pitch range
____ Lack of vocal carrying power
____ Reduced loudness range
____ Need to use greater vocal effort
____ Running out of breath while talking
____ Unsteady voice
____ Increased need to cough
____ Increased need to throat clear
____ Tension in neck/shoulders
____ Throat/neck pain
____ Throat fatigue
____ Throat tightness/constriction/fullness
____ Pain on swallowing
____ Pain during talking
____ Discomfort in ears
____ Discomfort in back of neck
____ Discomfort in shoulders

Other symptoms:

Please circle the number that corresponds best to your level of vocal fatigue at this moment:

1 2 3 4 5 6 7 8 9 10

None |------- Mild -------| |---- Moderate ----| |------ Severe -------|

APPENDIX H

RELEASE FORM

Release Form for study entitled: "Laryngeal airway resistance in teachers with vocal fatigue."

You are being invited to participate in a research project investigating vocal fatigue by means of air pressures and flows associated with voice production. It is being conducted by Barbara Kostyk, a graduate student in the Department of Speech Pathology and Audiology at the University of Alberta. If you give your permission, Barbara will contact you by telephone to provide additional information regarding the study.

Release of your telephone number is completely voluntary and does not commit you in any way to participate in the study. If you consent to release your telephone number to the researcher, please return one copy of this form to her with your signature.

Thank you for considering this request.

Barbara E. Kostyk
B.Sc., S-LP (C)

I have read the release form for the research project entitled, "Laryngeal airway resistance in teachers with vocal fatigue," to be conducted by Barbara Kostyk. I consent to allow her to contact me by telephone to provide further information regarding this study. I have received a copy of the release form letter.

Signature ______________________ Date ______________________

Printed Name ______________________

Group (circle one): Healthy Fatigued

APPENDIX I

TELEPHONE SURVEY

Name: ____________________ Date of Birth: ____________________
School: ____________________ Phone - Home: ____________________
Grade Taught: ____________________ Phone - Work: ____________________

1. Do you smoke? If yes, how frequently? ______________________________

2. Have you ever been diagnosed with a voice disorder by a physician? If yes, please name the disorder, the physician's specialty and the approximate date of diagnosis:

   ____

3. Have you ever received any professional speaking or singing instruction? If yes, describe (approximate date, activities): ______________________________

   ____

4. Briefly describe your occupation (duties, hours of work): ____________________

   ____

   ____

5. Do you experience acid indigestion? If yes, explain: ____________________

   ____

6. Do you typically experience any of the following symptoms at work, (a) due to voice use, or (b) due to allergies?

   ○ Hoarse/husky vocal quality
   ○ Breathy vocal quality
   ○ Loss of voice
   ○ Pitch breaks
   ○ Inability to maintain typical pitch
   ○ Running out of breath while talking
   ○ Unsteady voice
   ○ Tension in neck/shoulders
   ○ Throat/neck pain
   ○ Throat fatigue

APPENDIX I (Continued)

○ Reduced pitch range
○ Lack of vocal carrying power
○ Reduced loudness range
○ Need to use greater vocal effort
○ Throat tightness/constriction/fullness
○ Pain on swallowing
○ Increased need to cough/throat clear
○ Discomfort in chest, ears or back of neck

7. Do you frequently experience other problems with your voice? If yes, explain:
____
____

8. Have you ever lost your voice? If yes, explain: ______________
____
____

9. Do you ever have problems with your voice when speaking in background noise? If yes, describe: ______________________

10. Does your voice vary? ________ If yes, describe below:
    a. Time of day: Voice best: ______________
    Voice worst: ______________
    b. Situation: Voice best: ______________
    Voice worst: ______________

11. Do you have any allergies? Please list: ______________
____

12. Do you presently have a cold or other respiratory illness? If yes, describe: ____
____
____

APPENDIX I (Continued)

13. Have you ever been diagnosed with a neurological condition (eg. Parkinson's Disease, muscle paralysis/weakness)? If yes, explain: ____________________________________

____

APPENDIX J

INFORMATION/CONSENT FORM

Participant Consent Form for study entitled: "Laryngeal airway resistance in teachers with vocal fatigue."

You are being invited to participate in a research project investigating some aspects of vocal fatigue in female teachers. In this study, fatigue will be related to air pressures and flows inside the mouth associated with voice production. Two groups of people, teachers with and without vocal fatigue, will be included in the study. This research is being conducted by Barbara Kostyk, a graduate student in the Department of Speech Pathology and Audiology at the University of Alberta.

If you give your permission, the researcher will come to your school and test your hearing. The test is necessary to reduce the possibility that symptoms of vocal fatigue in some subjects may be associated with a hearing loss. Also at your school, the researcher will make a tape recording of your voice. Later, the researcher and another speech pathologist will listen to the tape to select subjects who may participate in the study. This will help to ensure that subjects are assigned to the correct experimental group (teachers with vocal fatigue, and teachers without vocal fatigue). The researcher will inform you whether you qualify for participation in the study. If you qualify, you then will be asked to complete a questionnaire about your voice and how you use it.

The project will require your participation across one week during the middle of the school year. During that week, you will be tested six times: before and after school on a Monday, Wednesday and Friday. Each test will take about 10 minutes. Testing will be conducted on the University of Alberta campus in Corbett Hall, room 2-88.

During the experimental sessions, you will be asked to complete a checklist that monitors how your voice feels to you. Next, you will be asked to say a variety of words and sentences out loud while the researcher measures the loudness of your voice. Finally, you will wear over your mouth and nose a small, comfortable mask connected to air pressure and flow sensing instruments while you repeat certain sounds after the researcher. A small plastic tube also will be placed in the front of your mouth while you repeat the sounds. You may breathe freely while wearing the mask.

The researcher will take steps to maintain the cleanliness of materials that you will encounter during your participation in the study. You will use the same mouth tube during every session, and will not share the tube with any other participants. Your tube will be kept clean and in its own labelled pouch between sessions. In addition, the mask that you wear over your mouth and nose will be cleaned with alcohol immediately before you use it. Finally, the researcher will wear clean latex gloves when handling the mask and tube.

You may be required to say some sounds in a manner to which you are unaccustomed. The procedure itself is painless. There are no known risks associated with participation in the study. Information gained by your participation will contribute to our understanding of the voice and how it is affected by daily use in a job such as yours. More importantly, increasing our knowledge of vocal fatigue could aid in the early identification of teachers who may be at-risk for developing fatigue-related voice problems. Early identification, in turn, could help prevent the occurrence of such voice problems in your profession.

In order to take part in this study, you must be a nonsmoker who has normal hearing and no history of neurological disease. In addition, you must be free from colds or other respiratory illness during the week of testing. If you catch a cold during the study, testing will be postponed until you regain your health. When you are rid of your cold, you will be invited to take part in another week of sessions. Because the goal of this study is to measure the effects of fatigue on your voice, it is important that other factors affecting your voice remain constant. Therefore, voice use and your use of things that may affect your voice, such as alcohol or medication, should remain consistent during the week of testing. In order to help you and the researcher monitor the consistency of your voice use, you will be asked to complete a very short "voice diary" at the end of each day during the week of testing. If you use your voice in an unusual, excessive manner during the week, testing will be postponed for seven days in order to allow any effects of the unusual voice use to subside. After that, you will be invited to take part in another week of sessions. Because ovulation (the middle seven days between two consecutive menstrual periods) may also affect your voice, the researcher will ask you to participate in the study at a time when you are not ovulating. In order to estimate when ovulation will occur for you, the researcher will ask you two questions: when your last period began, and when you expect your next period to start. You will *not* be required to track your menstrual cycle in any other way during the study.

Data obtained during the sessions will be stored on computer diskettes. To ensure your privacy, computer data, questionnaire information and hearing examination results will be identified by project ID code only. Only Barbara Kostyk and her project supervisors will have access to the data. In addition, all diskettes will be kept in a locked room to which only they have access. At the end of the study period, all hearing test forms will be destroyed, and the diskettes and questionnaires will remain in a locked room with the same restricted access. The data will be used only for research purposes.

Your participation in this study is completely voluntary. If you agree to participate, you may decide to withdraw from the study at any time without negative consequences. If you consent to participate, please return one copy of this form to the researcher with your signature.

If you have any questions about this project, either before or after you give your consent, please call the researcher, Barbara Kostyk, at 435-2431. If you are interested in receiving a copy of the results of the project, please let her know. Thank you for considering this request. Your participation in the study would be appreciated greatly.

Vocal Fatigue Study
Barbara E. Kostyk, B.Sc., S-LP (C)
Department of Speech Pathology and Audiology
2-70 Corbett Hall
University of Alberta
Edmonton, AB T6G 2G4

I have read the description of the research project entitled, "Laryngeal airway resistance in teachers with vocal fatigue," to be conducted by Barbara Kostyk. I consent to participate. I have received a copy of the consent form letter.

Signature ______________________ Date ______________________

Project Researcher ______________________ Date ______________________

APPENDIX K

CASE HISTORY QUESTIONNAIRE

Project I.D. Code:

Date:

1. Briefly describe your occupation (duties, hours of work etc.): ________________
____
____

2. Describe your daily voice usage and importance of your voice in these situations:
Work: ____
Home: ____
Social/Recreation: ____________________________

3. Have you ever been diagnosed with a voice disorder? ____ If yes, please name the disorder, and the approximate date of diagnosis: ____________________________
____

4. Do you experience acid indigestion? ____ If yes, please explain: ______________
____

5. Indicate the frequency (days per week) with which any of the following symptoms occur at work. Mark symptoms which you do not experience with a '0'. **Star (*) any symptoms that you think are caused by allergies.**

Hoarse/husky vocal quality _____	Increased need to cough _____
Breathy vocal quality _____	Increased need to throat clear _____
Loss of voice _____	Tension in neck/shoulders _____
Pitch breaks _____	Throat/neck pain _____
Inability to maintain typical pitch _____	Throat fatigue _____
Reduced pitch range _____	Throat tightness/constriction/fullness _____

APPENDIX K (Continued)

Lack of vocal carrying power _____
Reduced loudness range _____
Need to use greater vocal effort _____
Running out of breath while talking ____
Unsteady voice _____

Pain on swallowing _____
Pain during talking _____
Discomfort in ears _____
Discomfort in back of neck _____
Discomfort in shoulders _____

6. Have you ever lost your voice? _____ If yes, explain: ____________________
____
____

7. Indicate any other voice problems you experience and their frequency: _________
____
____

8. Does your voice vary? __________ If yes, describe below:
   a. Time of day: Voice best: ____
   Voice worst: ____
   b. Situation: Voice best: ____
   Voice worst: ____

9. Are you frequently in situations where there is much background noise? ______ If yes, explain: ____
____

10. Have you ever received any professional speaking or singing instruction? ______
If yes, describe (approximate date, activities): ____________________________
____

If no, will you be enrolling in such a course within the near future?____________

APPENDIX K (Continued)

11. Do you have any allergies? ______ Please list: ______________________________

____

12. Do you presently have a cold or other respiratory illness? ______ If yes, describe:

____

____

13. Have you ever been diagnosed with a neurological condition (eg. Parkinson's Disease, muscle paralysis/weakness)? ______ If yes, describe: ______________________

____

____

14. Are you currently taking any medications? ______ If yes, please list: __________

____

____

____

15. Do you smoke? ______ If yes, how frequently? ______________________________

16. Do you drink alcoholic beverages? ______ If yes, please describe how frequently:

____

Please inform the researcher of any changes to the above information (ie. occupational status, health, medications, tobacco use, frequency of alcohol consumption) during your participation in the study.

APPENDIX L

SAMPLE PERCI-PC DATA