Influence of Syllable Train Length and Performance End Effects on Phonation Threshold Pressure in Females

by

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A thesis submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Master of Science

Auburn, Alabama
May 14, 2010

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Abstract

Phonation threshold pressure (PTP) is the minimum amount of lung pressure necessary to initiate and sustain phonation. Phonation threshold pressure is useful in determining overall health of the vocal folds. The purpose of this study was to determine whether the number of syllables collected and/or performance end effects had a significant effect on PTP. Ten adult females with normal voices produced five and seven repetitions of the syllable /pi/ at three pitches. The results were analyzed to determine whether a difference existed in PTP when five versus seven repetitions were collected and whether the typically discarded first and last repetitions differed from the middle three. The results indicated there was no significant difference in PTP when five syllables were collected versus seven syllables or between the first and last repetitions and the middle repetitions. These findings are significant to developing a clinically standardized, effective, and efficient method for collecting PTP.

Acknowledgements

I would like to extend my heartfelt thanks to my thesis advisor, Dr. Laura Plexico, for her endless help, support, and encouragement with this project. I would also like to thank Mrs. Mary Sandage for her faith in my abilities and advice in completing the research for this project. I also greatly appreciate the contributions of my committee members, Dr. Michael Moran and Dr. Rebekah Pindzola. Finally, I would like to thank my husband and my parents for their continued support and encouragement.

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I. INTRODUCTION

Phonation threshold pressure (PTP) is the amount of lung pressure required to initiate and sustain the vibration of the vocal folds (Titze, 1988; Verdolini, Titze, & Fennell, 1994). Phonation threshold pressure has been shown to be a clinically useful indicator of the health of the vocal folds. Titze hypothesized that PTP values would vary with several different factors, including the transglottal pressure coefficient, the mean damping coefficient, or the viscosity of the vocal folds, the velocity of the mucosal wave, the prephonatory half-width, or the glottal width, and the thickness of the vocal folds. According to Titze, there is a direct relationship between PTP and the transglottal pressure coefficient, the mean damping coefficient, the mucosal wave, and the glottal width. That is, when any one of these is lowered, PTP also decreases. Titze also hypothesized that there was an indirect relationship between PTP and the thickness of the vocal folds. That is, if the vocal folds increased in thickness, PTP would decrease. Titze's hypotheses have been studied and supported by a number of researchers. However, the methods used to study PTP have varied across researchers.

While many researchers have used a method similar to the indirect method described by Smitheran and Hixon (1981) to measure PTP, there is no standard procedure for the collection of PTP values. As a result, a number of procedural and environmental variations exist in the current literature. In their article, Smitheran and Hixon recommended collecting a syllable train with seven repetitions of the consonant-vowel combination /pi/, and determining PTP from the average of only the middle three syllables in order to control for “performance-end effects” (p. 142). However, in more recent literature, while some researchers have followed the recommendations and collected syllable trains with seven repetitions, other researchers have collected syllable trains with only five repetitions. Additionally, researchers have varied in which syllables within the train they averaged in order to determine PTP. Differences in assessment methods may affect the reliability of PTP in both clinical and research settings. Thus, the specific purpose of this study is twofold. The first goal is to determine whether varying the number of repetitions of syllables affects the measurement of PTP. The second goal is to examine whether the first and last repetitions of the five syllable sample as well as the first two and last two repetitions of the seven syllable sample are significantly different from the middle three repetitions.

While this study will only address two of the many variables in the collection of PTP measurements, it is important to recognize the other variables that can affect PTP outcome. Some variations are procedural, while others are environmental and participant related. The potential effect of these variables on PTP outcome will be discussed.

There are six primary procedural differences within the literature: variations in the vowel used in conjunction with /p/, variations in the methods for collecting pitches to be studied, variations in the directions given to obtain the correct degree of loudness, variations in the number of repetitions of each syllable per trial, variations in the syllables within the train chosen to calculate PTP, and variations in the method of calculating PTP. The one procedure that remains constant across studies discussed is the rate at which the syllables are repeated.

In addition to procedural differences that can affect PTP, there are nine variables with regard to the environment and the participant that can directly affect the outcome of PTP measurements in an individual. These include the age of the participant, the sex of the participant, the level of humidity in the testing room, the participant’s level of hydration, medication being taken by the participant, the participant’s vocal training, the presence of any vocal fold pathologies, the participant’s cigarette usage, the participant’s alcohol usage, and hormonal changes in female participants. Just as the procedural differences are important to note, these other environmental variables are also important to consider when measuring PTP and when comparing PTP results across studies. The above variables were controlled to the extent possible in this study. However, in order to collect standardized normative data future research should focus on the specific effects of each of these variables on PTP.

The ability to accurately measure PTP is important for both clinical and research purposes as PTP provides a measure of the ease and efficiency with which the vocal folds vibrate (Titze, 1988; Verdolini, Titze, et al., 1994). Measurements of PTP can also provide information regarding the condition of the vocal folds, as abnormally high PTP values can indicate the presence of vocal fold pathologies or inefficient glottal closure. The variations in methodology should be accounted for if PTP is used to gather evidence regarding the benefit of any surgical, behavioral, or combination therapy. Thus, all of the above mentioned differences are important to understand and potentially control for if PTP is to be used as a datum point for comparison within and between research studies.

II. LITERATURE REVIEW

Phonation Threshold Pressure

Phonation threshold pressure (PTP) is an important measurement in the assessment and treatment of voice disorders. It has been indicated that PTP could vary anywhere from 1 to 7 cmH_2O and still be considered normal (Jiang, O’Mara, Conley, & Hanson, 1999). Originally called oscillation threshold pressure, PTP was defined by Titze (1988) as the “lung pressure required to initiate vocal fold vibration” (p. 1536). Indicating the importance of PTP to the sustainment of vocal fold oscillation, Verdolini, Titze, et al. (1994) expanded upon Titze’s (1988) definition by describing PTP as the “minimal subglottal pressure required to initiate and sustain vocal fold oscillation” (p. 1001). Chan, Titze, and Titze (1997) distinguished between PTP required for oscillation onset and oscillation offset. Onset PTP is defined as the “minimum lung pressure that initiates vocal-fold oscillation from rest” (p. 3722) and offset PTP is defined as the “minimum lung pressure that sustains vocal-fold oscillation after it has begun” (p. 3722).

Chan et al. (1997) indicated that the amount of PTP required to initiate vocal fold oscillation is greater than the PTP required to sustain vocal fold oscillation. To initiate vocal-fold oscillation, the onset PTP must be great enough to overcome the adducted vocal folds. The onset pressure must also reach a level where the absorbed energy is greater than the dissipated energy. Specifically, the absorbed energy supplied by airflow must be great enough to overcome energy losses incurred by the friction and dissipation of energy in the tissues (Lucero, 1999; Titze, 1988).

As discussed briefly above, offset PTP is the pressure required to sustain oscillation (Chan et al., 1997). The PTP observed at the offset of phonation is lower than that observed at the onset of phonation. It has been suggested that this outcome is the result of hysteresis. Hysteresis occurs as a result of several factors. As oscillation is initiated at phonation onset, energy supplied from the airflow is transferred to and absorbed by the vocal folds. As the amplitude of oscillation increases, the absorbed energy will also increase. However, this transfer of energy cannot increase indefinitely. Rather, the amount of energy transferred will increase until oscillation reaches a certain amplitude. Specifically, it is the “amplitude at which the point of airflow separation moves within the glottis” (Lucero, 1999, p. 427). Airflow separation occurs when the airflow separates from the glottal wall as it exits the glottis. The point of airflow separation depends on whether the glottis is convergent or divergent. In a convergent glottis the point of airflow separation is higher in the glottis than in a divergent glottis because of the changing glottal shape. Thus, when the point of airflow separation moves from its point in a convergent glottis to its new point in a divergent glottis, the surface area of the vocal folds that can absorb energy is reduced. The reduced surface area results in a decrease in the amount of energy being transferred to and absorbed by the vocal folds. The vocal folds, however, can maintain oscillation as long as the absorbed energy is greater than or equal to the dissipated energy (Lucero, 1999). At the point where the absorbed energy becomes less than the dissipated energy, vocal fold oscillation will cease (Lucero, 1999). In summary, reduction in the oscillation amplitude in combination with the hysteresis effect contributes to a lower offset PTP value.

Studies on PTP have demonstrated that there is a hysteresis effect between onset PTP and offset PTP, where offset PTP is consistently lower than onset PTP (Chan et al., 1997; Lucero, 1995; Plant, Freed, & Plant, 2004; Titze, Schmidt, & Titze, 1995). Titze et al. studied onset PTP and offset PTP in a body-cover model developed to represent vocal fold mucosa. They found that PTP was higher during the onset of vocal fold oscillation and lower during the offset of vocal fold oscillation, with a difference of 0.5 cmH_2O. The range for onset PTP was found to be between 3.8 and 6.6 cmH_2O and the range for offset PTP was found to be between 3.3 and 5.6 cmH_2O.

Chan et al. (1997) were also interested in the difference between onset and offset PTP and elaborated on the findings of Titze et al. (1995). Chan et al. used the same body-cover model of the vocal folds proposed by Titze (1988). However, their study examined how PTP was affected by membrane thickness and viscosity. Chan et al., like Titze et al. (1995), also found a hysteresis effect between onset PTP and offset PTP, with onset PTP being consistently higher than offset PTP. They found that the smallest difference between onset PTP and offset PTP occurred for thin membranes with a low viscosity, with a difference of about 0.4 cmH_2O. The greatest difference found existed when there was a thick membrane and high viscosity, with a difference of 2 to 4 cmH_2O.

Lucero (1995) also studied the difference between onset PTP and offset PTP. However, in order to accurately examine the difference in onset PTP and offset PTP, Lucero thought it was necessary to expand upon the body-cover model used by Titze (1988). Titze created the body-cover model in order to theoretically describe how human vocal folds function. He based the body-cover model on the assumptions that the vocal folds are symmetrical from the midpoint of the glottis, the body remains motionless, and the cover is displaced as the mucosal wave propagates along the vibratory margin in direction of airflow. Titze limited the function of his model to small-amplitude oscillations. Titze found this restriction useful because his primary purpose was to examine PTP at oscillation onset. In focusing solely on small amplitude oscillation, Titze also restricted the results to only oscillations in which the vocal folds were slightly abducted with no glottal closure. According to Titze, large-amplitude oscillation theory involves studying the dissipation of energy in the vocal folds due to vocal fold collision. And it is this dissipation of energy that contributes to a smaller offset PTP than onset PTP. Since Lucero was interested not only in onset PTP, but also offset PTP, he expanded Titze's model to include large amplitude oscillation. With this adjustment, he too found that offset PTP was less than onset PTP. Specifically, offset PTP was found to be 2 cmH_2O while onset PTP was found to be 4 cmH_2O.

Plant et al. (2004) assessed whether there was a difference between onset PTP and offset PTP. The study was conducted on 4 men and 1 woman, all of whom were considered healthy at the time of the study, and had no history of a voice disorder. PTP was assessed by asking the participants to say the phoneme /i/ three times each with a breathy onset, a low pitch with increasing intensity, a medium pitch with increasing intensity, a high pitch with increasing intensity and finally with a glide from low to high pitch. The study found that 2 of the 5 individuals studied had significantly lower offset pressures than onset pressures, while another 2 participants had no significant difference between offset and onset pressures. The fifth participant exhibited higher offset pressure than onset pressure. While PTP will fluctuate in accordance with the frequency at which it is measured, the frequency did not appear to affect whether the onset or offset pressure was significantly higher, lower, or unchanged. The results of this particular study suggest that there is some question about the extent to which hysteresis is observed across individuals.

Factors That Influence PTP

According to Titze (1988), the minimum PTP required to initiate and sustain phonation varies in accordance with five factors: tissue viscosity, mucosal wave velocity, glottal width, vocal fold thickness, and a "prephonatory glottal convergence factor" (p. 1539). After studying the relationship of these factors on PTP, Titze developed an equation that captures the relationship of the five factors. The following equation is based on Titze's original equation (Solomon, Ramanathan, & Makashay, 2007; Titze, 1988).

$$PTP = (k_t/T)(Bc)(w/2)$$

In the above equation, k_t is the transglottal pressure coefficient, T is the vocal fold thickness, B is the mean damping coefficient, c is the mucosal wave velocity, and $w/2$ is the prephonatory glottal half-width. The transglottal pressure coefficient occurs as a result of the trachea and the inferior portion of the glottis contracting while the superior portion of the glottis and the laryngeal vestibule expand. Titze hypothesized that when lowered, this coefficient would cause a decrease in PTP. Titze also hypothesized that PTP can be lowered by decreasing any one of the following: tissue viscosity (or damping), the mucosal wave velocity, or the inferior glottal width. Additionally, PTP is also lowered by increasing the thickness of the vocal folds.

Effect of Tissue Viscosity and Hydration on PTP

Viscosity is a measure of a fluid's resistance to flow—the higher the viscosity, the more resistant the fluid is to flow. Tissue viscosity is a measure of the viscosity of the vocal folds and their resistance to movement. The tissue of the vocal folds is considered to be more viscous than water and less viscous than human tissues including skin, fat, and muscle. Specifically, pure water has a viscosity of .01 poise (P), while the vocal folds have an average viscosity of 0 to 10 P, and human tissues have a viscosity of 100 P (Verdolini-Marston, Titze, & Druker, 1990). Tissue viscosity has been evaluated in conjunction with the hydration of the larynx as it has been shown to be a useful indicator of a client's degree of hydration (Finkelhor, Titze, & Durham, 1988; Sivasankar & Fisher, 2002; Solomon & DiMattia, 2000; Verdolini-Marston et al., 1990; Verdolini, Titze, et al., 1994). If not properly hydrated, the vocal folds increase in viscosity, and therefore become more resistant to flow, while if the vocal folds are properly hydrated, the vocal folds decrease in viscosity and flow more readily. When tissue viscosity has resulted in the vocal folds being more resistant to flow, the term tissue damping is often used to describe this occurrence (Titze, 1988).

Titze (1988) used equation modeling to demonstrate that the less viscous the vocal folds, the easier the onset and sustainment of vocal fold vibration, thus requiring less PTP. Likewise, as the vocal folds increase in viscosity, a greater amount of energy is needed to maintain oscillation at the same rate, thus requiring greater PTP (Finkelhor et al., 1988). Titze's theory on tissue viscosity has been studied both on a theoretical level and by examining the effects of hydration on PTP in canine larynges and human participants. These studies have confirmed that PTP is decreased by lowering tissue viscosity and increasing hydration.

Using Titze's (1988) hypothesis, Finkelhor et al. (1988) studied whether PTP was affected by vocal fold hydration. Their study was based on two assumptions. The first was that the viscosity of the vocal folds could be decreased by increasing the amount of water in the vocal folds and second, that water was the only fluid accountable for vocal fold viscosity. Finkelhor et al. examined four excised canine larynges, each of which was placed into solutions of normal saline, distilled water, which is hypotonic, and 2.7% saline which is hypertonic. The distilled water is hypotonic in that it has less osmotic pressure than the water in the vocal folds. Lower osmotic pressure will result in less water diffusing from one place to another. Thus, if the vocal folds are placed in a solution that is hypotonic, the vocal folds will remain hydrated, because less water will diffuse out of the cells. On the contrary, the 2.7% saline is considered hypertonic because it has a higher osmotic pressure than the water in the vocal folds. This causes the water in the vocal folds to have a higher tendency to diffuse out of the vocal folds into the solution, and therefore represents dehydration of the vocal folds.

Finkelhor et al. (1988) found that all of the larynges had a lower PTP when placed in the hydrating hypotonic solution, and conversely, had a higher PTP when dehydrated as a result of being placed in the hypertonic solution. The larynges submerged in the normal saline solution had PTPs from approximately 5 to 8 cmH_2O while those larynges submerged in the hypotonic solution had PTPs from approximately 3 to 5 cmH_2O. Conversely, those larynges submerged in the hypertonic solution had PTPs from approximately 5 to 11 cmH_2O. Additionally, they found that the more dehydrated the vocal folds (and the higher the vocal fold viscosity or damping), the smaller the range of oscillation, while the better the hydration (and the lower the vocal fold viscosity or damping), the larger the range of oscillation.

Verdolini-Marston et al. (1990) studied the effects of hydration on PTP. Vocal fold hydration was tested by manipulating the relative humidity of the air, the ingestion of decongestant mucolitics, and the amount of liquid intake. Within these variables, the participants were subjected to three different conditions: dry or decreased hydration, wet or increased hydration, and normal or no treatment. Under the dry condition, the relative air humidity in the testing area was decreased to between 30 and 35%. Participants remained in this condition for 4 hours. After 3 hours in the dry condition, 3 teaspoons of a decongestant were administered to the participants (according to the researchers' review of pharmaceutical specifications the peak effect of the decongestant occurred 60 to 90 minutes after ingestion). Participants were asked to avoid drinking any fluids during the testing time.

Under the wet condition, the relative air humidity in the testing area was increased to 85 to 100%. Participants again remained in this condition for 4 hours. At the beginning of the 4 hours, and again after 3½ hours, 2 teaspoons of an expectorant were administered to each participant (according to the researchers' review of pharmaceutical specifications the peak effect of the expectorant occurred 30 to 60 minutes after ingestion). Finally, during the 4 hour period, water was provided and participants were asked to drink as much as possible. Participants reported that they drank between 16 to 64 ounces of water.

For the normal condition, the humidity was not controlled (it was measured at 40 to 55%), no medications were administered, and the amount of fluid the participants drank was not controlled. They found that PTP was lower for the participants when they were subjected to the wet condition, while PTP was higher for the participants when they were subjected to the dry condition. Specifically, the average PTP under the control condition was 4.64 cmH_2O, while the average PTP under the wet condition was 3.44 cmH_2O, and the average PTP under the dry condition was 4.95 cmH_2O.

Verdolini, Titze, et al. (1994) also conducted a study based on Titze's (1988) initial hypothesis that PTP could be decreased by reducing tissue viscosity. In this study, they hypothesized that "hydration level affects vocal fold tissue viscosity inversely," (p. 1001) and that as hydration increased, viscosity would decrease, and the vocal folds would become more compliant. While this study is similar to Finkelhor et al.'s (1988) study of canine larynges, Verdolini, Titze, et al. studied the effects of tissue viscosity in human participants who were given hydration and dehydration treatments.

Twelve adults were used in this study, and each was subjected to three treatments. The treatments were described to the participants as the Tropical Treatment (hydration treatment), the Arizona Treatment (dehydration treatment), and the Naturalist Treatment (control treatment). During the 4 hour long Tropical Treatment the relative humidity was controlled and ranged from 80 to 98%. Similar to Verdolini-Marston et al. (1990), participants were again administered an expectorant, and asked to drink as much water as possible. Reported fluid intake averaged 82 ounces. During the 4 hour long Arizona Treatment the relative humidity was again controlled and ranged from 9 to 32%. A decongestant was administered to all participants, and participants were again discouraged from drinking any fluids. Finally, during the 4 hour long Naturalist Treatment, the humidity was controlled and ranged from 40 to 61%. Unlike Verdolini-

Marston et al, 2 teaspoons of a placebo drug were administered to all participants at the beginning and half way through the treatment. Participants were not given any instructions about fluids, and it was reported that participants drank an average of 14.92 ounces of fluids.

The average PTP under the control condition was 4.98 cmH_2O (range 3.19 to 8.52 cmH_2O), while the average PTP under the wet condition was 4.51 cmH_2O (range 3.09 to 7.34 cmH_2O). Finally, the average PTP under the dry condition was 5.14 cmH_2O (range 3.32 to 8.86 cmH_2O). These results were similar to previous studies (Verdolini-Marston et al., 1990) and demonstrated that hydrating the vocal folds decreased the PTP (because the viscosity was decreased) and that dehydrating the vocal folds increased PTP (because the viscosity was increased). Therefore, PTP was the highest after participants completed the dehydration treatment, while it was the lowest after participants completed the hydration treatment.

Another study conducted by Titze et al. (1995) utilized a physical model of the vocal folds and evaluated whether PTP increased linearly with vocal fold viscosity. Results suggested, once again, that PTP was directly related to tissue viscosity—as viscosity increased, PTP increased, and as viscosity decreased, PTP decreased. The study tested whether this relationship was linear by plotting oscillation onset and offset values (for the same glottal width of 1.5 mm). A linear relationship was observed between PTP and vocal fold viscosity.

Solomon and DiMattia (2000) conducted a study to observe the effects of a vocally fatiguing task on PTP, and whether these effects were altered by vocal fold hydration. Due to the subject of this section, only the PTP results prior to the vocally fatiguing task will be discussed. Four women, aged 22 to 29 years old participated in the study. PTP values were obtained in a sound-proof booth in which humidity was averaged at 29%. Participants were subjected to three hydration conditions, including typical hydration, low hydration, and high hydration. Under the typical hydration condition, participants were responsible for monitoring and reporting the amount of liquid they consumed in the 48 hours prior to testing. They were not permitted to eat or drink dehydrating substances and were asked to limit their voice use during this time. It was reported by the participants that on average, they drank about six glasses of water per day. Under the low hydration condition, participants were allowed only one 16 ounce bottle of water per day prior to the session. Finally, under the high hydration condition, participants were required to drink five 16 ounce bottles of water, and it was suggested that they drink additional fluids if possible.

At typical hydration, participants' PTP values were between 3.5 and 8 cmH_2O. PTP values at high hydration levels were between 4 and 8 cmH_2O. Finally, PTP values at low hydration levels were between 3.5 and 8.5 cmH_2O. These values were not found to be significantly different, according to the authors. They found that only 1 participant had lower PTP values during the high hydration condition than during the low hydration condition. They contributed this finding to possible inadequate dehydration. Additionally, the authors noted that their small sample size of four people limited the conclusiveness of the study's results.

Sivasankar and Fisher (2002) looked at the hydrating effects of nasal breathing versus oral breathing. They hypothesized that oral breathing would dehydrate the vocal folds and subsequently raise PTP. Similarly, they hypothesized that nasal breathing would not dehydrate the vocal folds and therefore would not cause an increase in PTP. The study was conducted using 20 female participants, aged 21 to 36 years (M = 25). Participants were assigned either to the oral-breathing group or the nasal-breathing group. Participants in the nasal breathing group sat for 15 minutes, breathing orally, and not speaking. Those participants in the nasal breathing group sat with their mouths closed and breathed through their noses for 15 minutes without speaking.

The PTP values of those in the oral breathing group increased after the oral breathing task. Oral breathing increased the mean control PTP by 0.8 ± 0.4 cmH_2O at the low pitch, 0.8 ± 0.4 cmH_2O at the comfortable pitch, and 0.7 ± 0.6 cmH_2O at the high pitch. As expected, the PTP values of those in the nasal breathing group decreased after the nasal breathing task. Specifically, nasal breathing decreased the mean control PTP by 0.7 ± 0.4 cmH_2O at the low pitch, 0.5 ± 0.3 cmH_2O at the comfortable pitch, and 0.9 ± 0.5 cmH_2O at the high pitch. These results were consistent with the hypothesis that oral breathing would dehydrate the vocal folds. Furthermore, this study was consistent with others in that PTP values were higher for dehydrated vocal folds. The results also showed that PTP decreased slightly with nasal breathing, leading Sivasankar and Fisher (2002) to suggest that perhaps nasal breathing hydrated the air in the vocal tract, and thereby hydrated the vocal folds, causing lower PTP values.

A study conducted by Verdolini, Min, Titze, Lemke, Brown, Mersbergen et al. (2002) examined whether the documented increase in PTP due to dehydration occurred as a result of systemic dehydration, secretory dehydration, or a combination of the two. The researchers studied 2 men and 2 women aged 21-28 years old (M = 25). All participants were reportedly healthy at the time of the study and underwent a physical examination to confirm their health status. Over the course of 5 days, the participants underwent a series of treatments including furosemide (Lasix), which is a diuretic treatment, diphenhydramine hydrochloride, which is an antihistamine treatment, and a placebo in the form of a sugar pill. The participants' fluid intake was monitored during all treatment conditions. Under the placebo condition, participants were restricted to 8 ounces of fluid per hour. When either of the other treatment conditions was studied, the participants were restricted to 4 ounces of fluid per hour. The researchers found that PTP increased after the Lasix treatment by almost 0.5 cmH_2O. However, there were no statistically significant differences between PTP under the placebo condition and the antihistamine treatment. PTP was collected only at high pitches in this particular study. As a result, Verdolini et al. suggested that systemic dehydration as a result of diuretics can increase vocal fold viscosity and increase PTP at high pitches.

Grini-Grandval, Bingenheimer, Maunsell, Ouaknine, and Giovanni (2002) studied the effects of an aerosol hydration treatment on PTP in 6 healthy female subjects aged 22 to 35 years old (M = 29). The researchers first collected PTP under normal conditions at a modal pitch and a high pitch. Once normal PTP measurements were collected, the participants were subjected to a 15 minute treatment of serum physiologic aerosol designed to superficially hydrate the vocal tract, after which PTP measurements were again collected. The researchers found that at the modal pitch, PTP decreased from 3.79 cmH_2O prior to the hydration treatment to 3.15 cmH_2O after the hydration treatment. Similarly, at the high pitch, researchers found that PTP decreased from 4.07 cmH_2O prior to the hydration treatment to 3.30 cmH_2O after the hydration treatment. The findings of

Grini-Grandval et al. once again confirm the indirect relationship between PTP and hydration status.

Tanner, Roy, Merrill, and Elstad (2007) also conducted a study on the effect of hydration treatments on PTP. In their study, the researchers examined the effects of hypertonic saline, nebulized isotonic saline, and nebulized sterile water (hypotonic) on PTP. The researchers hypothesized that the hypertonic saline would facilitate hydration of the vocal folds, while the isotonic saline would reduce the viscosity of the vocal folds without changing the balance of the surface epithelium. Finally, the researchers hypothesized that the sterile (hypotonic) water would simply remain on the vocal fold surface, but would not induce dehydration.

Sixty women aged 18 to 50 years old (M = 28) participated in the study conducted by Tanner et al. (2007). All participants were reportedly healthy at the time of the study. Prior to the administration of the hydrating solution, each participant underwent 15 minutes of oral breathing intended to dehydrate the larynx. The researchers found that PTP increased significantly (by approximately 0.5 cmH_2O) from the beginning of the study to the conclusion of the oral breathing task. However, no statistically significant differences were observed after the treatments, although the PTP of the groups receiving the various treatments was consistently lower than the PTP of the control group. For the purpose of this paper, the important conclusion of the study is the support of the indirect relationship between hydration and PTP.

The above studies, with the exception of Solomon and DiMattia (2000), support Titze's (1988) theory that PTP is directly related to tissue viscosity. The study conducted by Finkelhor et al. (1988) on excised canine larynges demonstrated that in a controlled situation, the PTP required to initiate oscillation increased as the viscosity of the vocal folds increased. This study also demonstrated the indirect relationship of tissue viscosity to hydration. Grini-Grandval et al. (2002), Sivasankar and Fisher (2002), Tanner et al. (2007), Verdolini-Marston et al. (1990), and Verdolini, Titze, et al. (1994), Verdolini et al. (2002) all conducted studies using human participants and found results which supported Titze's theory and Finkelhor, et al.'s initial findings. The results found by Solomon and DiMattia did not support Titze's theory. However, as mentioned above, their aberrant findings could be attributed to the participants not achieving sufficient dehydration. Finally, Titze et al. (1995) conducted further studies using a physical model, which again supported the initial theory on the relationship of PTP and tissue viscosity.

Effects of Mucosal Wave Velocity on PTP

Titze (1988) also suggested that PTP could be lowered by decreasing the mucosal wave velocity. The mucosal wave is a surface wave that moves along the surface of the vocal folds in the same direction as the air that is moving through the glottis. The mucosal wave is called such because it is seen along the epithelium and the superficial layer of the lamina propria, which together are known as the vocal fold mucosa. The mucosal wave moves both vertically and horizontally. The wave moves vertically as the leading edge of the vocal folds separates, and then begins to diverge as the upper edge of the vocal folds begins to separate. Horizontally, the wave travels mediolaterally as the leading edges of the vocal folds diverge to the midline, followed by the upper edges of the vocal folds (Nasri, Sercarz, & Berke, 1994). The mucosal wave is often described in terms of its velocity which is based on the phase delay that occurs between the opening of the leading edge of the vocal folds and the upper edge of the vocal folds. The velocity, or speed with which the mucosal wave travels, is directly linked to the amount of energy which is transferred from the airflow to the tissue of the vocal folds as well as the stiffness of the vocal folds.

According to Titze (1988), mucosal wave velocity is related to the ease with which the superficial layer of the lamina propria moves. Hirano (1981) identified that the vocal folds are composed of five different layers. From most superficial to most deep the layers are: the epithelium, the superficial layer of the lamina propria, the intermediate layer of the lamina propria, the deep layer of the lamina propria, and the vocalis muscle. These layers increase in stiffness and thus decrease in compliance from superficial to deep. It is the superficial layer of the lamina propria where the mucosal wave is observed. The easier this layer moves, or the more compliant the layer, the lower the mucosal wave velocity. The compliance, or stiffness of the lamina propria, is related to the viscosity of the vocal folds. That is, the as the stiffness of the vocal folds increases (thereby decreasing compliance), the viscosity of the vocal folds also increases. Vocal fold viscosity can be related back to the hydration of the larynx, as described in the section above on viscosity and hydration. With lower mucosal wave velocity, which occurs in conjunction with lower viscosity, less PTP is required to initiate movement of the vocal folds (Titze, 1988).

Effect of Glottal Width on PTP

Finally, Titze (1988) indicated as the size of the glottis decreases PTP also will decrease. If there is an opening in the glottis, it will be more difficult to build up subglottal pressure without the airtight seal found with complete glottal closure. Therefore, the smaller the glottal width, the less PTP required to initiate vocal fold vibration. Titze exemplified the importance of glottal width to PTP. He stated that a glottis that was slightly divergent required only 2.15 cmH_2O to sustain oscillation, while a glottis that was slightly convergent required 5.54 cmH_2O to sustain oscillation. The smaller amount of PTP needed in a divergent glottis to sustain oscillation can be explained due to greater positive lateral intraglottal pressure required when the glottis is convergent, versus when the glottis is divergent.

Titze et al. (1995) conducted a study in which they constructed a physical model of the glottal airway and manipulated the glottal width to examine the effects of different widths on PTP. They found that PTP does increase with increasing glottal width. However, they also noted that if the glottal width is decreased to zero, PTP does not continue to drop to zero as well. Instead, the lowest PTP that was noted occurred when the glottal width was between 0.0 and 1.0 mm. However, as the glottal width approached 0 mm, they found PTP increased. The finding that PTP increased deviated from the theoretical expectation that PTP would decrease linearly with decreased glottal width. Titze et al. found that when the glottal width was less than 1.0 mm, collision occurred between the vocal folds, thereby nullifying the small amplitude restriction. Based on the results, Titze et al. reasoned that the linear relationship described by Titze (1988) between PTP and glottal width did not apply when the glottal width was less than 1.0 mm.

Lucero (1996) sought to explain the nonlinear relationship between PTP and glottal width observed by Titze et al. (1995). Lucero argued that Titze et al.'s explanation for the nonlinear relationship between PTP and glottal width was inaccurate because in their study the vocal folds were slightly abducted at the beginning of the oscillation. Based on this, Lucero argued that the nonlinear relationship between PTP and glottal width could not be a result of glottal closure. Lucero suggested instead that the resistance that existed as a result of the viscosity of the glottis could be the reason for the nonlinear relationship. He noted that that the contradiction to Titze's (1988) theory occurred only at small glottal widths, which was exactly where, according to Lucero, increased viscosity causes significant air pressure losses.

Lucero (1996) studied his hypothesis by using Titze's (1988) model and assuming a rectangular glottis and applying the small amplitude oscillation restriction. However, he added the additional component of viscosity. Lucero stated that when the glottal width is large, any pressure loss due to viscosity is negligible—which agrees with earlier findings of a linear relationship between PTP and a glottal width of greater than 1.0 mm. However, Lucero argued through equation modeling that as the glottal width becomes smaller, the effects of viscosity become important, and will cause PTP to increase because of the increased viscosity of the vocal folds.

Chan et al. (1997) also conducted a study using the same physical model of the vocal fold mucosa used by Titze et al. (1995). Similar to Titze et al.'s study, Chan et al. also concluded that PTP tended to increase when the glottal width was less than 3.0 mm. Additionally they noted that as the glottal width increased above 3.0 mm, PTP remained the same in a rectangular and slightly divergent glottis. Their findings contradicted earlier thoughts that PTP would be the lowest in a divergent glottis and highest in a convergent glottis (Titze, 1988). Instead, they found that the lowest PTP was always found in a rectangular prephonatory glottis. Chan et al. attributed this finding to the location of the airflow separation found in a divergent glottis. Specifically, it was found by Guo and Scherer (1993) that the point of airflow separation occurred in a divergent glottis just downstream from the point of least constriction.

Effect of Vocal Fold Thickness on PTP

The speed at which the vocal folds vibrate is directly related to their length, mass, and stiffness. When the vocal folds are stretched they become longer, thinner, stiffer, and less massive, which results in a faster rate of vibration, causing a higher fundamental frequency. Conversely, when the vocal folds are relaxed, they become shorter, thicker, less stiff, and more massive, which results in a slower rate of vibration and thus a lower fundamental frequency. Fundamental frequency is the rate at which the vocal folds vibrate. The higher the fundamental frequency, the higher the rate of vibration of the vocal folds, while the lower the fundamental frequency, the slower the rate of vibration of the vocal folds.

In his article, Titze (1988) hypothesized that PTP was directly related to fundamental frequency. That is, PTP would increase as the vocal folds were stretched, thinned, and stiffened as the fundamental frequency increased. As indicated, one of the primary changes in the vocal folds with an increase in fundamental frequency is an increase in the length of the vocal folds. As the vocal folds are stretched and lengthened, they become stiffer, and therefore more resistant to change. To overcome this increase in resistance, increased air pressure is required to exert a change, or initiate oscillation (Slavit, Lipton, & McCaffrey, 1990; Verdolini-Marston et al., 1990). Additionally, when the vocal folds are lengthened and stiffened, they expectedly become thinner. Recall that the thickness of the vocal folds was hypothesized by Titze to be inversely proportional to PTP. Thus, the less thick and more stiff the vocal folds are, the higher the PTP that is required for oscillation. Finally, with the vocal folds being longer, thinner, and stiffer, there is increased tension in the mucosal cover which directly affects the mucosal wave velocity. Recall that mucosal wave velocity, according to Titze is also directly proportional to PTP. In summary, when fundamental frequency is increased, the vocal folds are lengthened, stiffened, and tensed. Increases in these three properties cause an increase in PTP. Therefore, an increase in fundamental frequency results in an increase in PTP.

Several studies have evaluated the effect of frequency on PTP (Finkelhor et al., 1988; Plant et al., 2004; Sivasankar & Fisher, 2002; Solomon et al., 2007; Verdolini-Marston et al., 1990; Verdolini, Titze et al., 1994). One of the earliest studies was conducted by Finkelhor et al. Recall that Finkelhor et al. studied PTP in excised canine larynges. While their primary focus was on the effects of hydration, Finkelhor et al. also changed the length of the vocal folds by attaching a micrometer system to the tip of the thyroid cartilage. Using a micrometer allowed the researchers to precisely measure and control the amount by which the vocal folds were stretched. As vocal fold length increased, the PTP also increased. At the smallest length, PTP ranged from approximately 1 to 4 cmH_2O, and at the longest length PTP ranged from approximately 8 to 22 cmH_2O. This manipulation of vocal fold length resulted in the observation that as fundamental frequency increased, PTP also increased.

Verdolini-Marston et al. (1990) conducted a study that was similar to Finkelhor et al.'s (1988) in that they were primarily concerned with the effects of hydration on the vocal folds. However, Verdolini-Marston et al. used human participants instead of excised canine larynges to conduct their study. They studied 3 male and 3 female participants, aged 25 to 46 years old (M = 36.7). They indicated that at the time of the study, all participants were healthy and that 5 of the 6 participants studied had received some degree of voice training. The study showed that for all participants the low and modal pitch productions required a similar and lower amount of PTP when compared to the high pitch productions that required a higher PTP. Specifically, the average PTP required for a low pitch was 3.64 cmH_2O, for a modal pitch was 3.44 cmH_2O, and for a high pitch was 5.96 cmH_2O.

Verdolini, Titze, et al. (1994) conducted another study with the primary purpose of examining the effects of hydration on the vocal folds. However, data was also collected regarding the relationship between fundamental frequency and PTP. Twelve healthy adults (9 females and 3 males) aged 20 to 30 years old (M = 23.8) participated in this study. Results of the study again showed that the highest pitch required the greatest PTP. Specifically, PTP measurements at a high frequency were on average 4 to 5 cmH_2O greater than measurements at the low and modal frequencies. The average PTP at the low pitch was measured to be 3.20 cmH_2O with a range from 3.09 to 3.32 cmH_2O. At the modal pitch the average PTP was measured to be 3.19 cmH_2O with a range from 3.10 to 3.24 cmH_2O. Finally, the average PTP at the high pitch was measured to be 8.24 cmH_2O with a range of 7.34 to 8.86 cmH_2O.

Sivasankar and Fisher (2002) studied 20 healthy female students aged 21 to 36 years old (M = 25). They found that at the high pitch PTP was higher than at the low and modal percentile pitches. Due to the nature of the study, specific numbers are not provided. However, by interpreting the graphs it is possible to see that at a low pitch, or at 10 percent of the participants' range, PTPs ranged from approximately 3 to 4.5 cmH_2O. At a modal pitch, or at 20 percent of the participants' range, PTPs ranged from approximately 2.5 to 3.5 cmH2O. However, at a high pitch, or 80 percent of the participants' range, PTPs ranged from approximately 5.5 to 6 cmH_2O.

Titze's (1988) theory that PTP would decrease with an increase in vocal fold thickness has been tested in numerous studies. Vocal fold thickness has been controlled by using the known relationship of vocal fold thickness to fundamental frequency, that the thicker the vocal folds, the lower the fundamental frequency, and in turn, the thinner the vocal folds, the higher the fundamental frequency. Results of studies, whether conducted on excised canine larynges, as in Finkelhor et al., (1988), or on human participants as in the majority of studies, were all similar (Plant et al., 2004; Sivasankar & Fisher, 2002; Verdolini-Marston et al., 1990; Verdolini, Titze, et al., 1994). Simply, all the studies discussed, as well as others that had similar results, showed that generally PTP was always lower for low and modal pitches than it was for high pitches (Plant et al., 2004; Sivasankar & Fisher, 2002; Titze et al., 1994; Verdolini-Marston et al., 1990; Verdolini, Titze et al., 1994). These results support Titze's prediction that PTP will increase as vocal fold thickness decreases.

Assessment of Phonation Threshold Pressure

Measures of PTP are obtained through measurement of tracheal pressure. Tracheal pressure is one of three measures used to derive laryngeal airway resistance which is a measure of the degree of opposition to the airflow provided by the larynx. Laryngeal airway resistance occurs as a result of constrictions at various levels of the larynx, including the vocal folds and the ventricular folds. Researchers have used the procedure to obtain laryngeal airway resistance described by Smitheran and Hixon (1981) in order to obtain measurements of PTP. Thus, while the purpose of this paper is not to obtain measurements of laryngeal airway resistance, the procedure used to obtain measures of laryngeal airway resistance will be used discussed in terms of its use for obtaining PTP.

Direct Assessment

Prior to the indirect method developed by Smitheran and Hixon (1981) the only means of calculating translaryngeal pressure, which was needed to calculate laryngeal airway resistance, was directly. There are three different methods that directly assess laryngeal airway resistance. In one method a percutaneous catheter is used and a hypodermic needle is inserted through the cricothyroid membrane and into the trachea. This needle is connected to a tube that transmits the results to a pressure transducer (Lofqvist, Carlborg, & Kitzing, 1982; Plant & Hillel, 1998; Plant & Younger, 2000; Plant et al., 2004; Smitheran & Hixon, 1981). While this method provides an accurate measure of subglottic pressure, it is not only uncomfortable, but also involves risk as to the insertion and placement of the catheter (Bard, Slavit, McCaffrey, & Lipton, 1992).

In a second method, a translaryngeal catheter is used and a small transducer is inserted through the nasal passages and into the trachea through anesthetized vocal folds (Plant & Hillel, 1998; Lofqvist et al., 1982; Smitheran & Hixon, 1981). However, the transducer and the anesthesia can affect phonation, resulting in potentially inaccurate measurements (Bard et al., 1992). Finally, in a third method described an intraesophageal catheter is used and the participant is asked to swallow a small balloon. The balloon is connected by a tube to a transducer, which allows the pressure in the balloon to be measured. The subglottic pressure can then be calculated based on esophageal pressure. In addition to being uncomfortable for the patient, this method is also time consuming (Bard et al., 1992; Lofqvist et al., 1982; Smitheran & Hixon, 1981). Although direct methods for assessing laryngeal airway resistance are either invasive or intrusive, they are still valuable for research because they provide the most accurate measurement of the exact amount of pressure located below the glottis at the initiation of vocal fold vibration.

Indirect Assessment

Due to the invasive or intrusive nature of direct methods for obtaining measurements of laryngeal airway resistance, they are generally not appropriate for use in a clinical setting. In response to the need for a method that could be used in a clinic setting, Smitheran and Hixon (1981) developed an indirect method for measuring laryngeal airway resistance that is noninvasive.

The indirect method for measuring laryngeal airway resistance is based on the theory of fluid dynamics. The theory of fluid dynamics indicates that when valves within a fluid filled system are adjusted in a manner that enables upstream pressure-flow events (i.e., tracheal pressure) to be predicted from downstream pressure-flow events (i.e., oral pressure), it is possible to use the measurements of the pressure-flow events downstream as an estimate of the pressure-flow events that have occurred upstream. Smitheran and Hixon (1981) applied this theory to air-filled systems. Thus, if the laryngeal, velopharyngeal, and oral valves are adjusted appropriately, it is possible to use measurements of oral pressure to estimate tracheal pressure. In order to manipulate the laryngeal, velopharyngeal, and oral valves to an appropriate position, the utterance used to measure oral pressures must be carefully considered.

According to Smitheran and Hixon (1981), the ideal utterance to create the appropriate valving combination described above is one which alternates a voiceless stop-plosive with a vowel. Voiceless stops have two phases to their production—a phase in which the airflow is blocked and a phase in which the airflow is released. During the blocked phase, the laryngeal valve is open while the velopharyngeal and oral valves are closed. During the phase in which the airflow is released, the laryngeal valve remains open and the velopharyngeal valve remains closed, but the oral valve opens. During the production of a vowel, the laryngeal valve is open, but constricted, while the velopharyngeal valve is closed and the oral valve is open and relatively unconstricted.

When the laryngeal, velopharyngeal, and oral valves are adjusted in the above manner for the blocked phase of the voiceless stop, there is a brief moment when the pressure in the oral cavity is identical to the lower airway and tracheal pressures. The peak oral pressure observed during production of a voiceless stop corresponds with the moment there is equilibrium between the oral and tracheal pressures. Using this knowledge, Smitheran and Hixon (1981) argued that the peak oral pressure can be used to estimate the pressure in the trachea. The researchers discussed in this paper were interested in calculating tracheal pressure as a means of measuring PTP.

The indirect assessment of laryngeal airway resistance involves the participant repeating the utterance /pi/ a set number of times at a rate of 1.5 syllables per second. Smitheran and Hixon (1981) initially decided to use the syllable /pi/ as the basic unit because of the ease with which it could be produced and measured. However, they also had several other requirements for the syllable they chose. First, it had to comply with the above constraints—a voiceless stop followed by a vowel. Second, the syllable had to be simple and easily produced by children and adults, with or without any neuromuscular disorders. Third, the syllable had to be an utterance similar to connected speech. Fourth, the syllable had to provide data that was able to be easily and quickly analyzed to calculate laryngeal airway resistance. Fifth, the syllable had to be one that could be easily and accurately measured. Based on this criterion, Smitheran and Hixon decided on the syllable /pi/.

Smitheran and Hixon (1981) chose the phoneme /p/ as opposed to the other voiceless stop-plosives (i.e., /t/ and /k/) for six reasons. First, Shipp (1973) documented that during the production of /p/, the peak oral pressure occurs at the moment when oral pressure and tracheal pressure are in equilibrium, thus meeting one of the main components of the theory. Second, /p/ is not only one of the first phonemes acquired in language development, but it is acquired prior to /t/ and /k/, therefore extending the application of this measurement to young children. Third, because /p/ is the most anteriorly produced phoneme of the three voiceless stop-plosives, oral pressure can be the most easily measured with the least interference from the tongue and the least discomfort to the participant. Fourth, the seal created between the lips during the blocked phase of /p/ is greater than the blockage created between the tongue and the alveolar ridge during the production of /t/ and the blockage between the tongue and the palate during the production of /k/, which ensures an airtight seal. Fifth, because /p/ is produced anteriorly, placement of the tube to measure oral pressure will not interfere with articulation as much as it would in a more posteriorly produced consonant. Finally, because the valve seal occurs at the lips for the production of /p/ it is easier for the examiner to ensure that an adequate seal has been formed as compared to the seal in /t/ and /k/. This is particularly important when working with patients with structural or neuromuscular disorders.

Smitheran and Hixon (1981) also documented the reasons for which they chose the vowel /i/, a high, front vowel produced with the lips in an unrounded position. They based their use of /i/ on the findings of Thompson and Hixon (1979). Thompson and Hixon documented that when /i/ (and other high vowels) are produced with other non-nasal consonants, the velopharyngeal valve is closed in an airtight position. Since an airtight velopharyngeal seal is one of the essential constraints set out above, Smitheran and Hixon chose the vowel /i/. Second, since /p/ is also produced anteriorly, the anterior production of /i/ ensures that production of the syllable occurs in only one region of the oral cavity. This makes production of the syllable easier for both normal participants as well as participants with neuromuscular disorders. Third, the production of /i/ does not require lip rounding or involved movements of the lips or jaw, which reduces the risk of an air leak in the face mask.

To gather laryngeal airway resistance data, Smitheran and Hixon (1981) instructed the participants to inhale twice as much air as they would normally and to produce seven repetitions of /pi/ on a single expiration using normal pitch, loudness, and quality. Smitheran and Hixon told the subjects to take a breath of twice the normal length before an utterance to ensure that respiration would be similar to that seen during connected speech. They instructed the subjects to use normal pitch, loudness, and quality so that the subjects would use their larynx as they would during normal connected speech. Subjects were also instructed to produce the seven syllables with equal stress on each syllable and at a rate of 1.5 syllables per second. Smitheran and Hixon felt it was important that the stress on each syllable was equal in order to control the degree to which the laryngeal valve was used for each syllable. Finally, they decided upon the rate of 1.5 syllables per second because Thompson and Hixon (1979) demonstrated that if syllables were produced at rates below 1.5 syllables per second, the velopharyngeal port did not always achieve an airtight seal.

In their initial study, Smitheran and Hixon (1981) recorded two different measures, oral air pressure and airway-opening flow. Oral air pressure and airway-opening flow are both necessary to calculate laryngeal airway resistance. The oral air pressure was recorded by securing a mask to the subject’s face. A catheter was then threaded through a small opening in the mask, into the subject’s mouth, where it was positioned down the midline approximately 1.0 cm behind the central incisors. The other end of the catheter was connected to a differential air-pressure transducer. The airway-opening flow was measured through the use of the face mask, with a double-coned, one-square inch, pneumotachograph that was also connected to a differential air-pressure transducer.

Once Smitheran and Hixon (1981) obtained seven acceptable oral pressure peaks, they analyzed the data. In order to be considered acceptable, each oral pressure peak had to have a rapid rise in flow and a rapid fall in flow. The first two and last two vowel segments in each syllable train were not used to control for “performance end-effects” (p. 142), leaving only the middle three vowels in the train. Using measurements from these vowel segments, Smitheran and Hixon were able to calculate laryngeal airway resistance using the following equation:

$$\frac{tracheal\ pressure - pharyngeal\ air\ pressure}{translaryngeal\ flow}$$

Smitheran and Hixon tested the reliability of the measures they obtained with an intraclass correlation which yielded a reliability coefficient for the subjects of .96. While they specifically addressed the reliability of the procedure in terms of calculating laryngeal airway resistance, the high coefficient is important when using the above method for calculating PTP.

Since PTP is calculated in the same manner as tracheal pressure, the above method proved to be a useful and reliable procedure for obtaining measurements of PTP (Hixon, Weismer, & Hoit, 2008). Based on this, a number of researchers have utilized the above procedure to calculate PTP Smitheran and Hixon (1981) calculated tracheal pressure in the following manner:

> The peak oral pressures on the third, fourth, fifth, and sixth productions of /p/ were identified on the records and interconnected with those for their adjacent mates by straight lines. The contour formed as a result of this linear interpolation

> between the four oral pressure peaks was taken to represent the prevailing tracheal pressure associated with the middle portion of the syllable train. Next, the time points midway between the designated pressure peaks on the records were identified and the corresponding interpolated pressures were noted. Thus, a separate estimate of tracheal pressure was provided for each of the three vowels analyzed (pg. 142).

Validation of the Indirect Method

Lofqvist et al. (1982) conducted a study to test the accuracy of the indirect method described by Smitheran and Hixon (1981). In their study, they tested the indirect and direct method simultaneously. Lofqvist et al. measured subglottal pressure by passing a miniature transducer through the nose and glottis, and positioning the transducer in the posterior commissure about 2 cm below the glottis. They used a second identical transducer in order to measure oral pressure. This second transducer was also passed through the nose and located in the pharynx about 4 cm above the glottis. The participants were reported to have a typical vocal quality and complete velopharyngeal closure. The researchers instructed the participants to repeat the syllable /pa/ 20 times. Once the syllable repetitions were recorded, Lofqvist et al. measured the pressure in the middle of the second vowel of the utterance. The direct measure was obtained from the output of the transducer in the trachea, while the indirect measure was obtained from the oral pressure curve.

Lofqvist et al. (1982) found a mean difference between the two measurements of 0.088 cmH_2O. A Pearson product moment correlation was used to assess the relationship between the direct and indirect method. They reported a correlation coefficient of 0.92, which indicated that measurements obtained through the indirect method were a valid estimate of the actual pressure found in the glottis. Lofqvist et al. added one note that measurements found during the indirect method should be taken from the middle of the vowel between voiceless consonants. They indicated that airflow occurring during the aspiration portion of a stop consonant could result in an inadequate representation of subglottal pressure (Lofqvist, 1975).

Plant and Hillel (1998) also conducted a study in which they simultaneously measured subglottic pressure and laryngeal airway resistance through the use of the direct and indirect methods. They collected laryngeal airway resistance measurements directly by inserting a 21 gauge needle into the trachea through the cricothyroid membrane, and connecting the needle to a pressure transducer with tubing. Plant and Hillel collected measurements of laryngeal airway resistance indirectly by placing a mask over the participant's nose and mouth and threading an 8 cm section of tubing, which was also connected to a pressure transducer, through the mask into the participant's mouth. Participants were then asked to say /pa/ at 1.5 to 2.0 syllables per second.

A total of 60 syllables were analyzed. Initial results showed that the oral air pressure correlated closely with the subglottic pressure during lip opening. In order to better compare the results of the indirect and direct method, laryngeal airway resistance was calculated. Discrepancies between the two methods varied from an underestimation of laryngeal resistance by -44% to an overestimation of laryngeal resistance by 50%. Plant and Hillel (1998) found that in general, the indirect method overestimated laryngeal resistance because it did not account for the decrease in subglottic air pressure which occurred when the lips parted.

Based on their results Plant and Hillel (1998) concluded that the indirect method had two limitations. First, that it measures oral air pressure instead of subglottic pressure, and second, that the air pressure and air flow are measured at different times. Plant and Hillel stated that this result demonstrates the importance of measuring subglottic air pressure continuously. They did confirm that when the lips are closed during the blocked phase of /p/ the oral air pressure is equal to subglottic pressure. However, they went on to caution that once the lips open and once voicing occurs, the subglottic pressure is no longer equal to oral pressure. Once again, although the two above studies focused on the reliability of Smitheran and Hixon’s (1981) procedure for calculating laryngeal airway resistance, the reliability found is important since PTP is one of the measures required for determining laryngeal airway resistance.

In 2009, Titze suggested an alternate method of indirectly obtaining PTP which involved the use of a semi-occluded vocal tract, as opposed to the alternation of a fully occluded vocal tract and an unoccluded vocal tract. Titze stated that the lip and jaw movements during the production of /p + vowel/ made it difficult for the participant to produce constant steady state pressures. According to Titze, without constant steady state pressures, obtaining an accurate measurement of PTP is difficult. As a result, Titze suggested the use of a semi-occluded vocal tract to obtain more accurate measures of PTP. In his research, he instructed participants to phonate for 3 to 5 seconds as quietly as possible at five predetermined pitches. Five repetitions were collected at each pitch. Titze found that with a 2.5 mm diameter straw placed between the lips, PTP values were comparable to the normal PTP values collected using the method described by Smitheran and Hixon (1981). Titze maintained that the use of the thin straw resulted in a semi-occluded vocal tract and therefore eliminated extraneous lip and jaw movement.

Procedural Differences Across Studies Using the Indirect Method

A number of researchers have used the indirect method as discussed by Smitheran and Hixon (1981) to obtain measurements of PTP. While the basic method has remained the same, six procedural differences exist in the literature. Differences exist in regards to variations in the vowel used in conjunction with /p/, variations in the methods for collecting pitches to be studied, variations in the directions given to obtain the correct degree of loudness, variations in the number of repetitions of each syllable per trial, variations in the syllables within the train chosen to calculate PTP, and variations in the method of calculating PTP. The one procedure that remains constant across studies discussed is the rate at which the syllables are repeated.

Variations in the vowel used in conjunction with /p/. As discussed above, Smitheran and Hixon (1981) had specific reasons for choosing the combination of /p/ and /i/ together. Nonetheless, while a number of researchers have continued to use /pi/ (Fisher & Swank, 1997; Grini-Grandval et al., 2007; Roy, Tanner, Gray, Blomgren, & Fisher, 2003; Sivasankar, Erickson, Schneider, & Hawes, 2008; Sivasankar & Fisher, 2002; Solomon & DiMattia, 2000; Solomon et al., 2007), other researchers have used the vowels /a/ (Fisher & Swank, 1997; Grini-Grandval et al., 2002; Plant & Hillel, 1998) and /ae/ (Chang & Karnell, 2004; Holmberg, Hillman, & Perkell, 1988; Verdolini-Marston et al., 1990; Verdolini-Marston, Sandage, et al., 1994; Verdolini, Titze et al., 1994; Verdolini et al., 2002) in conjunction with /p/. The vowel chosen to measure PTP is important because of differences in velopharyngeal closure during vowel production. In order to meet the criteria described by Smitheran and Hixon, there must be airtight velopharyngeal closure during vowel production. Research as to whether velopharyngeal closure greatest during the production of /i/, /ae/, or /a/ has been inconclusive.

Thompson and Hixon (1979), as discussed above, conducted a study evaluating velopharyngeal closure during production of the vowel /i/. One hundred and eleven participants were involved in the study. Each participant was asked to produce /i/ in isolation. Productions of /i/ were made at each individual’s modal pitch with normal loudness and quality. The researchers chose to examine production of /i/ in their study because of Moll’s (1962) results which suggested that /i/ was produced with strong velopharyngeal closure. Moll examined the amount of velopharyngeal opening during vowel production by calculating the percent of productions in which velopharyngeal opening was evident. He found that 14% of productions of the vowel /i/ exhibited some degree of velopharyngeal opening, while 38% of /ae/ productions and 37% of /a/ productions exhibited some degree of velopharyngeal opening. He also found that velopharyngeal height for high vowels including /i/ was significantly greater than the velopharyngeal height found during the production of low vowels. Based on their study, Thompson and Hixon found that during production of /i/ there was no nasal airflow, which implied that complete velopharyngeal closure occurred during productions of /i/.

A study conducted by Moon, Kuehn, and Huisman (1994) studied velopharyngeal closure during the vowels /u/, /i/, /a/, and /ae/ in isolation. Production of /i/ across participants was shown to have a mean velopharyngeal closure force of 44.42 grams, which was second in closure force only to production of /u/, which had a velopharyngeal closure force of 55.57 grams. The researchers noted that the difference between these two vowels in closure force was not significantly different. Productions of /a/ and /ae/ both had significantly less velopharyngeal closure force as compared to productions of /u/ and /i/. Specifically, production of /a/ had 31.3 grams of closure force, while production of /ae/ had 30.15 grams of closure force.

A study conducted by Lewis, Watterson, and Quint (2000) examined the nasalance scores during production of the vowels /i/, /u/, /ae/, and /a/. Nasalance scores were measured during the vowels in sentences and during sustained vowel production. The sentences were divided so that each sentence was loaded with only one type of vowel: high front, high back, low front, and low back. The fifth sentence contained a mixture of all of the vowel types. The following nasalance scores were computed based on the sentence task, and are listed from lowest to highest: 8% low back vowels (/a/), 8% low front vowels (/ae/), 10% high back vowels (/u/), 11% mixed sentence, 12% high front vowels (/i/). During the sustained phonation task, the scores were as follows, again from lowest to highest: 10% low back (/a/), 10% low front (/ae/), 10% high back (/u/), 20% high front (/i/).

While early studies suggest that the vowel /i/ is produced with the most adequate velopharyngeal closure as compared to other vowels (Moll, 1962; Moon et al., 1994; Thompson & Hixon, 1979) a more recent study measuring nasalance scores suggests that velopharyngeal closure during production of /i/ may not be as adequate as previously thought (Lewis et al., 2000). Because inadequate velopharyngeal closure can affect PTP outcome, it is important that a constant vowel be used across studies in order to make the results comparable.

Variations in the methods for collecting pitches to be studied. Smitheran and Hixon (1981) conducted their study of the indirect method for evaluating laryngeal airway resistance with participants who used modal pitch in order to more accurately duplicate normal conversational conditions. However, because many researchers are interested in the relationship between pitch and PTP as discussed by Titze (1988) and Finkelhor et al. (1988), many studies have varied the pitches at which PTP was measured. All of the researchers interested in the effect pitch had on PTP measured PTP at low, modal, and high pitches. However, differences exist across studies as to how the low, modal, and high pitches were determined.

There is one method that has been frequently used across studies to determine low and high pitches. Participants were asked to begin at a comfortable pitch and glide up to the highest pitch they could reach, and then again begin at a comfortable pitch and glide down to the lowest pitch they could reach. The participants’ individual pitch ranges were measured in semitones, and the low pitch was determined to be the lowest note they could produce plus 10% of their total range in semitones, while the high pitch was determined to be the lowest note they could produce plus 80% of their total range in semitones (Roy et al., 2003; Sivasankar & Fisher, 2002; Sivasankar et al., 2008; Solomon & DiMattia, 2000; Solomon et al., 2007; Tanner et al., 2007; Verdolini-Marston et al., 1990; Verdolini-Marston, Sandage, et al., 1994; Verdolini, Titze et al., 1994). It should be noted that one study did not determine the participants’ high and low pitches, but instead provided a predetermined low and high pitch to all men and a predetermined low and high pitch to all women (Chang & Karnell, 2004). Additionally, one study used a constant high pitch for women, and a constant high pitch for men (Verdolini et al., 2002).

Six methods were identified in the literature for determining the modal pitch. In one method of determining the modal pitch, the average of each participant's modal pitches was calculated during the rote task of counting from one to five (Verdolini-Marston et al., 1990). In a second method used to obtain modal pitch participants were instructed to count slowly from one to five. Then the /i/ in “three” was matched to a note on a keyboard (Verdolini-Marston, Sandage, et al., 1994; Verdolini, Titze, et al., 1994). In a third method, researchers required a similar counting task, but had participants count from 1 to 5 or 1 to 10 followed by 1 to 3. The /i/ in the final “three” was matched to a note on a keyboard (Roy et al., 2003; Solomon & DiMattia, 2000). In a fourth method used to obtain modal pitch, a conversation sample was collected and participants were asked to do a rote counting task to ensure that the modal pitch was accurate (Fisher & Swank, 1997). A fifth method used to determine modal pitch involved using 20% of the participants’ pitch range, as measured in semitones (Sivasankar & Fisher, 2002). One final method involved providing one predetermined modal pitch to all men and one predetermined modal pitch to all women (Chang & Karnell, 2004).

A study conducted by Zraick, Skaggs, and Montague (2000) examined the validity of seven different methods of determining modal pitch. In this study, participants were asked to do the following tasks: count from 1 to 10, read the “Grandfather Passage” for 10 seconds, produce spontaneous speech for 10 seconds, sustain /a/ for eight seconds, produce “um-hum” with mouth closed, count from one to three and sustain the /i/ in the word “three” for one second, and produce “uh-huh” with the mouth open. Zraick et al. found that in men and children there was little difference between the modal pitches found in each of the seven tasks. The lack of difference between task for men and children demonstrated that any one of the above tasks would elicit similar modal pitches. However, when results were calculated from the tasks performed by women, Zraick et al. found a statistically significant difference in the modal pitches for the different tasks. Due to the differences found, they concluded that to find the most accurate modal pitch in women, several of the above methods should be used and the resulting modal pitches averaged.

Variations in the directions given to obtain the correct degree of loudness. Similar to their recommendations for pitch, Smitheran and Hixon (1981) conducted their study with participants using a normal loudness, once again to more accurately duplicate normal conversational conditions. However, because most researchers using Smitheran and Hixon’s method were interested in PTP, they were interested in the specific amount of air needed to initiate vocal fold oscillation. Thus, researchers calculated PTP based on syllable production at threshold level.

Two different methods have been used to instruct participants as to the degree of loudness necessary to calculate PTP. For one method, participants were instructed to produce the syllable at a level just above phonation threshold and at a level just below phonation threshold. Participants then produced the syllable at threshold level. For each trial at threshold level the examiner reminded each participant to produce the syllables as quietly as possible (Verdolini-Marston et al., 1990; Verdolini, Titze, et al., 1994). In another commonly seen method participants were not asked to phonate at suprathreshold and subthreshold levels. Instead, they were asked to phonate just loud enough to initiate vocal fold vibration (Chang & Karnell, 2004; Fisher & Swank, 1997; Hodge, Colton, & Kelley, 2001; Roy et al., 2003; Sivasankar & Fisher, 2002; Sivasankar et al., 2008; Solomon et al., 2007; Solomon & DiMattia, 2000; Verdolini-Marston, Sandage, et al., 1994; Verdolini et al., 2002). One cue used to elicit this level of loudness was to speak "as softly as possible but not to whisper" (Grini-Grandval et al., 2007; Sivasankar & Fisher, 2002, p. 174), while another cue used was to produce "soft syllables just above a whisper (Sivasankar et al., 2008, p. 1497).

Variations in the number of repetitions of each syllable per trial. While Smitheran and Hixon (1981) recommended and tested the indirect method based on repeating the syllable /pi/ seven times, researchers have also deviated from this number of repetitions. Several studies have required their participants to repeat the syllable string only five times (Chang & Karnell, 2004; Fisher & Swank, 1997; Holmberg et al., 1988; Sivasankar & Fisher, 2002; Sivasankar et al., 2008; Verdolini-Marston et al., 1990; Verdolini-Marston, Sandage, et al., 1994; Verdolini, Titze, et al., 1994; Verdolini et al., 2002). However, several researchers were consistent with Smitheran and Hixon and required their participants to repeat strings of seven /pi/ syllables (Roy et al., 2003; Solomon & DiMattia, 2000; Solomon et al., 2007; Tanner et al., 2007). In one study, participants repeated only three strings of syllables (Grini-Grandval et al., 2002).

The discrepancy between studies in the number of repetitions of the syllable can introduce variability as a result of possible performance end-effects, as discussed by

Smitheran and Hixon (1981) above. While performance end-effects have not been discussed in the literature, it is possible that the syllable sample size could affect the reliability of the data. It is unknown whether the syllables usually discarded would influence PTP outcome. Additionally, throughout the literature, there is variability in whether five syllables or seven syllables were collected. If there is a difference in outcome between the two sampling methods then the comparability of those studies would be called into question.

Variations in the syllables within in the train chosen to calculate PTP. Smitheran and Hixon (1981) eliminated the first two and last two vowel segments from each train of seven, and analyzed only the middle three vowels. They also analyzed the third, fourth, fifth, and sixth productions of /p/ for their calculations. A number of researchers also measured only the middle three vowels to analyze their results (Chang & Karnell, 2004; Fisher & Swank, 1997; Roy et al., 2003; Sivasankar & Fisher, 2002; Sivasankar et al., 2008; Solomon & DiMattia, 2000; Solomon et al., 2007; Verdolini-Marston et al., 1990; Verdolini-Marston, Sandage, et al. 1994; Verdolini, Titze, et al., 1994). One group of researchers discarded the first and last syllable out of seven total syllables and therefore analyzed the middle five syllables (Tanner et al., 2007). Finally, Verdolini et al. (2002) examined the second through the fifth peaks and discarded only the first peak in the syllable train.

Variations in the method of calculating PTP. The most commonly seen method of calculating PTP is based on the procedure developed by Smitheran and Hixon (1981).

They measured PTP by analyzing the peak oral pressure of the middle three vowels. In a later study, Anderson (1999) used a different method of calculating PTP in which "phonation threshold pressure was calculated from the first pressure peak prior to a sharp increase in intensity level" (p. 42). Once this was determined, "the peak pressure level during the bilabial consonant of the first syllable in the train with voice onset was recorded as PTP" (p. 42).

Rate of syllable repetition. Throughout the literature, the rate of syllable repetition was one of the few variables which remained constant across studies. Participants have been instructed to produce the consonant strings at a rate of 1.5 syllables per second, and many studies used a metronome set at 92 beats per minute to cue the participants to the correct rate (Chang & Karnell, 2004; Hodge et al., 2001; Roy et al., 2003; Sivasankar & Fisher, 2002; Sivasankar et al., 2008; Solomon & DiMattia, 2000; Solomon et al., 2007; Verdolini-Marston et al., 1990; Verdolini-Marston, Sandage, et al., 1994; Tanner et al., 2007; Verdolini, Titze, et al., 1994; Verdolini et al., 2002).

Variables That Can Affect PTP Results

There are ten variables with regard to the testing conditions and the participant that can directly affect the outcome of PTP measurements in an individual. These include the sex of the participant, the age of the participant, the level of humidity in the testing room, the participant's level of hydration, medication being taken by the participant, the participant's vocal training, the presence of any vocal fold pathologies, the participant's cigarette use, participant's alcohol use, and hormonal changes in female participants.

Sex of the participant. Using results from excised human larynges Chan and Titze (1999) found that, on average, the vocal folds in males were three to five times more stiff and viscous than those found in females of the same age. As a result, one would expect men to have higher PTP levels than females of the same age. Based on their findings Chan and Titze hypothesized that PTP would be higher in males than in females. In a study looking at the differences in phonation threshold flow (PTF) between participants with and without vocal fold pathologies, Zhuang, Sprecher, Hoffman, Zhang, Fourakis, Jiang et al. (2009) found that PTF measurements in males were significantly higher than in females. They attributed this to the fact that males have longer vocal folds than females.

Age of the participant. The age of the participants is an important factor to both consider and document in PTP studies because of changes that occur in the larynx as a result of normal aging. In their study on the viscoelastic properties vocal folds, Chan and Titze (1999) also addressed the effects of age and gender on vocal fold viscosity. While they stated that not all the differences seen between participants could be attributed to age and/or gender differences, they saw a distinct pattern. They found that vocal fold stiffness appeared to increase with the participants' age. Thus, the older the participant, the more stiff and viscous the participants' vocal folds were. Given the above discussion on vocal fold viscosity, this would lead to the conclusion that older participants would have a higher PTP than younger participants.

A later study was conducted by Hodge et al. (2001). The primary purpose of their study was to examine differences in vocal intensity between young and elderly speakers, but PTP was also measured. A control group of 17 male participants aging from 25 to 35 years old (M = 30) was used along with an elderly group of 11 male participants aging from 68 to 85 years old (M = 77). Average PTP was found to be 2.2 cmH2O for the control group, while the average PTP for the elderly group was 1.9 cmH2O. The researchers reported a statistically insignificant mean difference between the groups.

Nonetheless, additional studies that did not measure PTP have noted differences between the larynxes of the young and elderly. One study conducted by Hirano, Kurita, and Nakashima (1983) found that as both males and females aged the cover of the vocal folds became thicker, while the density and elasticity of the vocal folds decreased. They also found that in subjects over the age of 40, the density of the intermediate layer of the lamina propria decreased. In males over the age of 50, they found that the deep layer of the lamina propria significantly increased in thickness and density, while in females, changes in the deep layer were found to be insignificant.

Another study suggested that there is an increase in elastin fibers as individuals age, as well as an increase in the density of the superficial layer of the lamina propria (Hammond, Gray, Butler, Zhou, & Hammond, 1998). Both the increase in elastin fibers and the increase in density increase the viscosity of the vocal folds, and thus could increase PTP. Changes observed in the vocal folds as a result of aging suggest that the age of the participants should be documented in studies measuring PTP. The participants' age should also be considered before making any direct comparisons between studies.

Level of humidity in the testing room. The humidity in the testing room is a variable that needs to be considered when collecting PTP data because of its effect on hydration. Humidity has been used in studies as a method of hydrating and dehydrating the vocal folds (Verdolini-Marston et al., 1990; Verdolini-Marston, Sandage, et al., 1994; Verdolini, Titze, et al., 1994). The following humidity values have been used to represent humidity under everyday circumstances: 40 to 55% (Verdolini-Marston et al., 1990); 30 to 40% (Verdolini-Marston, Sandage, et al., 1994); 40 to 61% (M = 52.39) (Verdolini, Titze, et al., 1994); 24 to 32% (M = 29) (Solomon & DiMattia, 2000).

Morrison and Rammage (1994) suggested a humidity value of 30% in order to maximize laryngeal health. An additional study conducted by Hemler, Wieneke, and Dejonckere (1997) found that human vocal folds are sensitive to changes in humidity. In this study the effects of humidity during the sustained production of the vowel /a/ were evaluated using perturbation measures of jitter and shimmer and calculating the noise-to-harmonic ratios. Each participant was exposed to three different humidity conditions for ten minutes. The dry room had a relative humidity of 2.1 ± 4.1%, the standard room had a relative humidity of 45 ± 11%, and the humid room had a relative humidity of 100%. While the authors did not find a statistically significant difference in noise-to-harmonic ratio for any of the conditions there was a statistically significant increase in jitter and shimmer between the standard room and the dry room. Because of their finding, they concluded that human vocal folds are susceptible to dry air. For this reason, humidity should be documented and considered when collecting and comparing PTP data, especially when hydration effects are not being studied (Solomon & DiMattia, 2000; Verdolini-Marston et al., 1990; Verdolini-Marston, Sandage, et al., 1994; Verdolini, Titze, et al., 1994).

Participant's level of hydration. As discussed in the *Tissue Viscosity and Hydration* section, the participant's degree of hydration plays an important role in PTP measurements. Titze's (1988) theory suggested that PTP will increase with increased viscosity, or decreased hydration. Additionally, numerous studies have concluded that PTP increases with dehydration and decreases with hydration (Finkelhor et al., 1988; Sivasankar & Fisher, 2002; Sivasankar et al., 2008; Titze et al., 1995; Verdolini-Marston et al., 1990; Verdolini, Titze, et al., 1994). Within the clinic, hydration status should be taken into consideration when measuring PTP because of the influence hydration has on PTP outcome. Additionally, when examining PTP measures across studies it is important to note participants' hydration levels not only for comparison purposes, but also for reliability of the measure.

Medication being taken by the participant. Certain medications can increase or decrease hydration which directly affects measurements of PTP. The use of expectorants and mucolitics has been shown to affect participants' levels of hydration (Verdolini et al., 1990; Verdolini, Titze, et al., 1994). Medications used to treat asthma are also important to consider. Lavy, Wood, Rubin, and Harris (2000) conducted a study in which they found that the use of inhaled steroids for the treatment of asthma caused a change in the mucous of the larynx in 50% of patients and supraglottic hyperfunction in more than 40% of patients studied. Both of these outcomes, if present, can increase PTP.

However, it has been documented that the use of oral contraceptives does not significantly affect measures of perturbation or frequency, which are important in collecting accurate PTP. A study conducted by Amir, Biron-Shental, and Shabtai (2006) examined the voices of women who were and were not taking oral contraceptives at the time of the study. The women involved in this study were asked to produce the vowels /a/, /i/, and /u/ at a modal pitch and normal loudness. Acoustic analyses were conducted to measure the participants' mean fundamental frequency, jitter, relative average perturbation (RAP), pitch period perturbation quotient (PPQ), shimmer, amplitude average perturbation quotient (APQ), noise to harmonics ration, and the voice turbulence index. The researchers found no statistically significant difference in fundamental frequency, frequency perturbation measures, amplitude perturbation measures, or noise indices between the group of women taking oral contraceptives and the group of women not taking contraceptives. These findings suggest that the use of oral contraceptives should not cause any statistically significant differences between subjects.

Participant's vocal training. Vocal training, whether for singing, playing musical instruments, acting, or any other activity, can increase the participant's vital capacity and decrease residual volume (Awan, 2001). The larger vital capacity allows people with vocal training to produce higher fundamental frequencies than those people with no vocal training (Awan, 2001). Borrego, Gasparini, and Behlau (2007) conducted a study on the effects of vocal training on radio announcers. They found an increase in the mean, minimum, and maximum fundamental frequency from pre-training to post-training, as well as an increase in frequency range as measured in hertz and semitones. Vocal training thus not only increases fundamental frequency range, but it teaches more efficient and less effortful use of the voice. These three factors, the increased fundamental frequency range, the more efficient use of the larynx, and the reduced effort required to produce voice, as compared to those with no vocal training can all affect PTP. It would be expected that a person with vocal training would have a lower PTP due to the ease and efficiency with which the larynx is used. Because evidence suggest that participants with vocal training would have a lower PTP outcome, it is important to document whether they have had vocal training when collecting PTP. It is also important to consider the presence or absence of vocal training when comparing PTP across studies.

Presence of any vocal fold pathologies. Vocal fold pathologies such as nodules, polyps, or other growths on the vocal folds affect not only the weight of the vocal folds, but also the efficiency of glottal closure. Edema of the vocal folds, whether caused by allergens, or as a result of some other irritation including smoking, can also increase the weight of the vocal folds as well as affect the degree of glottal closure. Increased vocal fold weight can increase PTP because more pressure is required to blow the folds apart and initiate phonation (Jackson-Menaldi, Dzul, & Holland, 1999). Additionally, inadequate glottal closure can affect PTP because it is more difficult to build up subglottal pressure (Chan et al., 1997; Titze, 1988; Titze et al., 1995). The presence of gastro-esophageal reflux disease (GERD) can also affect the integrity of the vocal folds. A study conducted by Ross, Noordzji, and Woo (1998) found that GERD can cause irritation to the larynx, in turn causing vocal fold pathologies.

A study conducted by Berry, Reininger, Alipour, Bless, and Ford (2005) used a finite element model of vocal fold vibration to predict the effects of scarring on the vocal folds. Berry et al. chose to use a model in order to more carefully examine the effects of the size and position of the scar on the vocal folds and on the viscoelastic properties of the vocal folds—a study they maintained would not be possible on human subjects because of ethical and feasible limitations. They found that scarring of the vocal folds substantially increased PTP and decreased fundamental frequency.

Another important consideration is the presence of laryngeal musculoskeletal tension. Anguwarangsee and Morrison (2002) discussed that the presence of laryngeal tension over time can cause permanent tension in the muscles of the larynx. The continued tension can cause vocal fold pathologies to develop, which in turn can affect PTP. Additionally, the continued tension within the laryngeal muscles can also elevate PTP because of the increased amount of pressure required to initiate vibration when the vocal folds are hyperadducted.

Participant's cigarette use. Smoking is yet another factor that can affect not only the larynx, but the measurement of PTP. Cigarette smoke is known to be irritating to the larynx, and can cause dehydration of the mucosa in the larynx, as well as edema, both of which can affect measurements of PTP (Stemple, Glaze, & Klaben, 2000). Sorensen and Horii (1982) studied the fundamental frequency of participants who did and did not smoke. Participants were asked to complete an oral reading task, a spontaneous speech task, and a sustained vowel task. In all tasks it was found that the participants who smoked had a lower average fundamental frequency than those participants who did not smoke.

A later study by Guimarães and Abberton (2005) studied the effects of cigarette smoke on voice by examining participants who did and did not smoke. Participants were asked to sustain the vowels /a/, /i/, and /u/, read out loud, and provide a conversation sample. Guimarães and Abberton found that the participants who smoked were more likely to have laryngeal pathologies, including polyps, chronic laryngitis, cysts, Reinke's edema, nodules, and sulcus vocalis, while those participants who did not smoke had a healthy larynx or minor abnormalities. They also found that those participants who smoked demonstrated lower fundamental frequencies during all speaking tasks as compared to those participants who were nonsmokers. As discussed above, the presence of vocal fold pathologies can cause an increase in PTP. Additionally, a lower than normal fundamental frequency can cause a lower than expected PTP as a result of the increased thickness of the vocal folds (Titze, 1988).

Participant's alcohol use. Frequent alcohol use can cause drying of the vocal folds which could increase PTP (Stemple et al., 2000). Additionally, alcohol consumption can also exacerbate symptoms of GERD which also can directly affect PTP outcomes (Stemple et al., 2000). It is important that each participant's weekly alcohol consumption be noted as the effects of alcohol could cause changes in PTP.

Hormonal changes in female participants. Hormonal changes are another important consideration when measuring PTP. Abitbol, Abitbol, and Abitbol (1999) found that the mucosa was thinner in premenopausal women than in women still ovulating. This decrease in mucosal thickness can affect the measurement of PTP. Additionally, they noted that menopausal women had stiffer vocal folds and reduced amplitude of vocal fold vibration.

It has also been shown that a woman's voice is affected in ways that can affect measurement of PTP during premenstrual syndrome (PMS). Particularly, Abitbol et al. (1999) found that during PMS there was an observed the presence of edema in Reinke's space as well as a decrease in striated muscle tone. A study conducted by Chae, Choi, Kang, Choi, and Jin (2001) showed that premenstrual women demonstrated an increase in jitter and shimmer as well as a lower fundamental frequency. Both the increase in frequency and amplitude perturbation and the lower fundamental frequency can affect PTP. Based on these studies, when doing research and measuring PTP it is important to control for the effect of hormonal changes.

Conclusion. This section has examined the many variables that can either increase or decrease measures of PTP. Factors such as age, humidity, hydration, medication, vocal training, vocal fold pathologies, smoking, alcohol, and hormonal changes can all affect PTP measurements. Based on the literature review, it is important to take these variables and the effects they may have on PTP measurements into consideration when seeing a patient in a clinical situation. It is also important to control for these variables when doing research and to note these variables when comparing results across studies. This is because in order to determine normative data, PTP should be examined without the presence of other variables. Further, in order to compare PTP measurements across studies, it is important to insure that the participants do not differ based on the above variables.

III. JUSTIFICATION

The measurement of PTP is a useful indicator of the health of the vocal folds when conducting vocal assessments, determining treatment, and measuring the effectiveness of treatment (Titze et al., 1995). PTP is of clinical importance because it determines the ease and efficiency with which the vocal folds begin and continue vibrating (Titze, 1988; Verdolini, Titze, et al., 1994). Additionally, measurement of PTP can provide clinical insight into the condition of the vocal folds. Specifically, aberrant PTP values can indicate the presence of vocal fold pathologies or inefficient glottal closure. However, the reliability of PTP as an assessment tool is limited because of the lack of assessment standardization across studies.

Variations exist in the literature with regards to the procedure used when collecting and analyzing PTP data. Specifically, variability has been observed across studies for the vowel used in the syllable sequence to collect PTP data, the methods utilized to obtain the pitch values used to measure PTP, the number of syllables elicited, and the procedure used to comprise the PTP measure. Developing a standardized method would not only increase the validity of PTP in assessment, but would provide clinicians with a set of normative data that takes into account the patient's degree of hydration, ease of phonation, and respiratory effort required to phonate.

While there are a number of discrepancies between studies, one that has not received much attention is Smitheran and Hixon's (1981) reference to performance end effects. Smitheran and Hixon chose to collect seven repetitions of the syllable /pi/ and eliminated both the first two and the last two syllables in their analyses of laryngeal airway resistance to account for performance end effects. However, they did not indicate or suggest what exactly they were accounting for. While some researchers have followed Smitheran and Hixon's procedure and have collected seven repetitions (Roy et al., 2003; Solomon & DiMattia, 2000; Solomon et al., 2007), most studied have collected only five repetitions (Chang & Karnell, 2004; Fisher & Swank, 1997; Holmberg et al., 1988; Sivasankar & Fisher, 2002; Sivasankar et al., 2008; Verdolini-Marston et al., 1990; Verdolini-Marston, Sandage, et al., 1994; Verdolini, Titze, et al., 1994;).

The purpose of this study is to investigate two aspects of PTP data collection. The first aspect investigated was whether varying the number of repetitions of syllables (5 syllables versus 7 syllables) influences PTP outcome. The second aspect investigated was whether the first and last repetitions of the five syllable sample as well as the first two and last two repetitions of the seven syllable sample differed significantly from the middle three syllables.

Therefore, there are two specific questions that will be addressed in this study:

(1) Is there a difference in PTP when five syllables are collected and when seven syllables are collected?

(2) Do the typically discarded first and last repetitions in a syllable train differ from the middle three repetitions?

IV. METHOD

Participants

To be included in this study, the participant had to (a) be female and between the ages of 19 and 40, (b) be a nonsmoker, (c) not be pregnant, ovulating (as determined through the use of a First Response^{TM} ovulation test), or premenopausal, (d) have no vocal training, (e) be taking no medications (with the exception of oral contraceptives and vitamins), (f) have no history of asthma (with the exception of childhood asthma), (g) have no indications or report of reflux, (h) have no history of laryngeal pathologies or other laryngeal abnormalities, (i) have no history of any serious respiratory infection or illness, (j) pass a pure tone hearing screening of 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz presented at 20 dB, (k) demonstrate ability to match a pitch to one provided, (l) be stroboscopically examined to ensure that there was no evidence of vocal abnormalities characteristic of vocal pathologies, and (m) be adequately hydrated, as measured objectively using urine specific gravity. If any of these requirements were not met, the participant was not permitted to continue in the study.

For this study, 16 females between the ages of 20 and 36 (M = 24.6; SD = 5.02) volunteered to participate. Out of the 16 participants, 2 were not permitted to continue the study due to their inability to match their low, modal, and high pitches when measured using the Voice Range Profile. Out of the remaining 14 participants, the data of 4 participants was discarded and not analyzed due to not meeting the data restrictions regarding frequency and airflow which will be discussed in detail below. Thus, all final results of this study are based on the data collected from the remaining 10 participants who met all of the above criteria.

Procedure

After receiving permission from Auburn University's Institutional Review Board (IRB authorization number 09-135 MR 0905, approved May 13, 2009) and the Auburn University Institutional Biosafety Committee(IBC), both undergraduate and graduate students in the Department of Communication Disorders at Auburn University were recruited to participate in this study (see Appendix A for recruitment script). Recruitment consisted of one of the investigators reading the recruitment script at the end of several preapproved Communication Disorders undergraduate classes. Additional participants learned about the study from flyers that were posted in public areas (see Appendix B for flyer).

Participants who expressed an interest in the study were provided with an information sheet outlining the basic inclusionary criteria (see Appendix C for screener). The nature of this form allowed a potential participant to indicate that she did not meet the inclusionary criteria without indicating which specific criteria she did not meet (i.e., the participant only indicated no to all the inclusionary criteria, instead of having to specifically indicate that she could not participate because she was pregnant). The participant was also given the opportunity to ask any questions regarding the inclusionary criteria. If the participant met all of the inclusionary criteria, she was contacted by the investigator. At this point, data collection was scheduled on a day that was 7 to 12 days after the first day of her most recent menstrual cycle in order to help ensure the participant would not be ovulating.

When the participant arrived, she was given the appropriate consent form before providing any information or participating in any procedures (see Appendix D for consent forms). Participants were allowed time to review each section of the consent form. After the participant finished reading the consent form, the investigator reviewed the consent form with the participant, asked the participant if she had any questions, and gave the participant the opportunity to withdraw from the study. After reading the consent form, all participants were willing to continue with the study. Each participant was then asked to initial and sign the consent form which was also witnessed by the investigator. By signing the consent form, the participant also agreed that she met all the inclusionary criteria discussed above.

Before beginning, the participant was assigned a participant code to ensure that all information and data that was collected was entirely anonymous. The participant also was asked to provide her age, any use of oral contraceptives, the first day of her last menstrual cycle, and the approximate number of alcoholic beverages she consumed each week, measured by zero drinks, one to three drinks, four to six drinks, or seven or more drinks (see Appendix E for recording form). It is important to note that there were no exclusionary criteria regarding participants' alcohol intake. Data regarding the average amount of alcohol consumption per week was collected as previous research has shown that alcohol use can affect the state of the vocal folds and a participant's hydration.

The participant was reminded at this time that this information and all successive information was completely anonymous as the recording form was labeled with only a participant number and then stored separate from the participant’s consent form. This particular form was also used to record the room temperature and the humidity at the time of the study, as well as the participant’s urine specific gravity and whether or not the participant was ovulating. Details on collecting this data will be discussed below.

Once it was determined that the participant met the inclusionary criteria of the study, a pure tone hearing screening was conducted using a Beltone portable audiometer. All of the portable audiometers are regularly calibrated by Auburn University’s Speech and Hearing Clinic which is part of the Department of Communication Disorders. Participants had to pass the hearing screening at all frequencies in order to continue (see Appendix F for specific instructions given to participants and the recording form). At the time of the screening, the identification number of the specific audiometer was recorded along with the participant’s code, and each of the frequencies tested in the participant’s right and left ears. Each hearing screening was conducted in a sound treated booth. Tones of 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz were presented at 20 dB. In order to continue in the study participants were required to pass all frequencies of the hearing screening.

Once it was determined through the screening that the participant’s hearing was within normal limits, the participant’s pitch range was collected using the Real Time Pitch (RTP) software option for the KayPENTAX Computerized Speech Laboratory (CSL) Model 4500 hardware. Using RTP the participant’s high, low, and modal pitches were calculated. Participants were asked to begin at a comfortable pitch and glide or step up to the highest pitch, stop, and begin again at a comfortable pitch and glide or step down to the lowest pitch possible, excluding glottal fry. For this specific task, loudness of the productions was not controlled. Before the participant completed this task, the investigator modeled what was acceptable and what was not acceptable, including a production of glottal fry. The following information was recorded for each participant: frequency range (Hz), minimum frequency (Hz), maximum frequency (Hz), and semitone range (ST). Based on methods frequently used in the literature, the obtained pitch range and semitone range were used to calculate the 10th, 20th, and 80th percentiles which were designated as the participant's low, modal, and high pitches, respectively.

As indicated, the 20th percentile of the participant's pitch range was labeled the modal pitch. However, in order to increase the accuracy of the obtained modal pitch, it was also determined from a rote counting sample in which the participant was instructed to count from one to three (Zraick et al., 2000). The participant was asked to hold the final /i/ on "three" and the frequency of the /i/ was measured using the CSL. The two resulting modal pitches were averaged to provide the final modal pitch that was used in the study (see Appendix G for the specific instructions given to the participant, the formulas used to calculate the low, modal and high pitches, and the recording form).

Once the participant's low, modal, and high pitches were calculated, the Voice Range Profile (VRP) software option for the CSL Model 4500 hardware was used to insure that the participant could match her high, modal, and low pitches when they were presented (see Appendix H for instructions given to the participant for matching given pitches). In order to check the participant's ability to match pitch, she was presented with a digital tone at each of her individual low, modal, and high pitches. The participant was first asked to match the given tone with a sustained /a/ vowel. The VRP program provided visual feedback to the participant regarding whether her output was above, below, or on pitch. When the participant felt comfortable matching each pitch on a sustained /a/, she was asked to practice matching the pitch using the syllable /pi/. If the participant was unable to match pitch, she was excluded from the research study. As indicated above, two participants were unable to match pitch, and as a result were not able to continue in the study.

Once it was determined that the participant could match pitch, a stroboscopic examination was performed by a certified speech-language pathologist using the KayPENTAX Digital Videostroboscopy System Model 9295 with a rigid 9106 endoscope (see Appendix I for the instructions given to the participant and the recording form). Stroboscopy results were reviewed by a board certified and licensed otolaryngologist, who offered his services, to confirm that there was no evidence of pathology or other abnormalities. The images obtained during the stroboscopic examination were also evaluated by a certified speech-language pathologist with expertise in the area of voice for shape, symmetry, and texture of the vocal folds, presence of mucous, thickness of the mucosal cover, degree of edge pliability, presence of vascular markings, presence of redness, degree of glottal closure, vocal fold mobility, and degree of visibility of the mucosal wave. None of the participants included in this study were found to have a vocal pathology or any other abnormalities. Had any pathologies or other abnormalities been observed during the examination, the participant would not have been able to continue in the study, and the participant would have been referred to a local otolaryngologist, as outlined in the consent form.

While participants' hydration was not manipulated through hydration and dehydration procedures, a measure of urine specific gravity was used to control for the participant's degree of hydration. Urine specific gravity measures the density of the urine.

The denser the urine, the higher the urine specific gravity, and the more dehydrated the person being studied. According to the instruction manual from the Siemens Multistix 9 SGReagent Strips for Urinalysis, normal hydration is indicated by a urine specific gravity range of 1.001 to 1.035 g/ml. In order to participate in the study, participants' urine specific gravity had to be below 1.035 g/ml (see Appendix J for information on the equipment used and instructions given to the participant). The participants' urine samples were collected in a bathroom that was approved by the Auburn University IBC.

Each participant's hydration was tested using Siemens Multistix 9 SGReagent Strips for Urinalysis which measure levels of glucose, bilirubin, ketone, specific gravity, blood, pH, protein, nitrate, and leukocytes. However, for the purposes of this study, only glucose, specific gravity, pH, and protein were measured. It was necessary to measure glucose, pH, and protein in addition to urine specific gravity because those levels can potentially affect the measures of urine specific gravity. All participants were adequately hydrated at the time of the study. However, had a participant not been adequately hydrated at the time of the study, she would have been asked to drink 16 ounces of water and return for retesting.

The participant's urine sample also was used to test for a surge of leutinizing hormone (LH) to determine whether the participant was ovulating. In order to minimize the chances of the participant ovulating at the time of the data collection, participants were only scheduled 7 to 12 days after the first day of their last menstrual cycle. The test was conducted using a First Response^{TM} Ovulation Test (see Appendix K for instructions given to the participant and the recording form). According to the test, none of the participants were ovulating at the time of the study. However, had a participant been shown to be ovulating, she would have been unable to continue the study on that day. Instead, she would have been asked to return 7 to 12 days after the first day of her next menstrual cycle.

Participants next began the PTP task itself. The PTP task was conducted in a quiet room. While neither humidity nor temperature was controlled, they were monitored using an Oregon Scientific weather instrument and recorded with each participant's information. Humidity during the study ranged from 46 to 65%, with a mean humidity of 52% and a median humidity of 52%. During data collection for 13 of the 14 participants, the humidity ranged from 46 to 56%, while for one individual the humidity was 65%. Temperature during the study ranged from 71.8 to 75.9° Fahrenheit with an average temperature of 73.94° Fahrenheit and a median temperature of 74.05° Fahrenheit.

Table 1 outlines each participant's age, use of oral contraceptives, use of alcohol, urine specific gravity measured in mg/dL, room temperature measured in degrees Fahrenheit, and room humidity measured by a percentage, at the time of the study.

Table 1. Participant Demographics

Participant	Age	OC	A	USG mg/dL	T °F	H %
1	23	yes	4-6	1.010	72	46
2	27	yes	0	1.001	74.7	53
3	24	no	0	1.010	71.8	47
4	23	yes	1-3	1.015	74	47
5	36	no	1-3	1.030	75.9	65
6	20	no	0	1.005	73.6	50
7	21	no	1-3	NC	NC	NC
8	20	no	1-3	1.005	73	52
9	20	yes	1-3	1.005	74.3	53
10	23	no	4-6	1.020	75.2	52
11	21	no	4-6	1.010	75	52
12	21	yes	0	1.010	74.1	47
13	20	yes	4-6	NC	NC	NC
14	23	yes	1-3	1.005	72.7	56
15	30	no	0	1.005	73.9	55
16	22	yes	0	1.010	74.9	54

Note. NC = data not collected due to participant not meeting further inclusionary criteria; OC = use of oral contraceptives; A = use of alcohol; USG = urine specific gravity; T = room temperature; H = room humidity.

Participants listened to a pre-recorded tape of the directions for the PTP task during which time they had a chance to practice the task. The tape explained each individual component of the task and gave participants the opportunity to try producing the syllable productions at each frequency as quietly as possible and at a rate of 1.5 syllables per second (92 beats per minute) with a metronome for pacing. While no specific amount of time was given for practice, each participant was asked if they felt comfortable with each part of the directions, and given ample time to ask any questions before the task began. Participants were also reminded that they could ask questions once the task began if the procedure became unclear (see Appendix L for equipment used to elicit PTP and instructions given to participants regarding syllable production, loudness, and pitch).

The participants were first instructed to hold the sanitized Phonatory Aerodynamic System (PAS) face mask over their nose and mouth so that it created an airtight seal. They were then instructed to practice the task of repeating the selected syllable string at a rate of 92 beats per minute (approximately 1.5 syllables per second), which was cued and monitored using a BOSS TU-80 tuner and metronome (Smitheran & Hixon, 1981). Participants were reminded to create an airtight lip seal when producing the /p/ portion of the syllable. Once they were comfortable with this task, the participants were asked to produce the syllable strings at a loudness level just above a whisper. Finally, participants were asked to produce the syllable strings at the specified rate, loudness, and pitch at which PTP data was collected.

After the participant was comfortable with the task, she was asked to again hold the PAS face mask over her nose and mouth, creating an airtight seal. For these trials, the KayPENTAX Phonatory Aerodynamic System (PAS) Model 6600 was used to collect measures of frequency, loudness, airflow, and air pressure. Then, using a metronome set at 92 beats per minute, she was cued to produce five repetitions of /pi/, /pae/, and /pa/ at the predetermined low, modal, and high pitches, and seven repetitions of /pi/, /pae/, and /pa/ at the same predetermined low, modal, and high pitches using a loudness level of “just above a whisper.” Pitches were provided using a Yamaha P-140 electronic piano. For the purposes of this study, repetitions of /pi/ were always produced first and the order in which /pae/ and /pa/ were produced was alternated between participants. That is, the first participant produced /pi/ followed by /pae/ followed by /pa/, while the next participant produced /pi/ followed by /pa/ followed by /pae/. Additionally, each participant produced five syllables and seven syllables in an alternating fashion. Finally, the order in which the pitches were produced was counterbalanced by the investigator. This was done to control for any training effects that might occur from the participant producing the three pitches in the same order during every trial.

Analysis

In order for the participant’s data to be included in the study, the PTP data recorded had to meet the following requirements. Frequency had to be within one semitone of the participant’s low, modal, or high frequency, depending on which frequency was collected. There were no numeric restrictions regarding the loudness of the productions, however, each participant’s productions were perceptually judged to be produced at a level that was as quiet as possible (Verdolini et al., 2002). Airflow measurements had to be negligible (considered to be less than 20 ml/s), since one of the requirements for an accurate indirect measure of PTP was that there was full lip closure during the production of /p/ (Morgan, Triana, & Milroy, 2004; Solomon & DiMattia, 2000). For those participants whose airflow was significant during the production, the resulting PTP values provided an inaccurate representation of the actual PTP that was used at the time of the production. Finally, all of the peaks within the PTP string were judged, via visual inspection, to be of equal height (Milbraith & Solomon, 2003; Verdolini et al., 2002).

Before the analysis was conducted, the peak value of each peak was recorded (see Appendix M for data recording forms). Additionally, the average sound pressure level (dB SPL) was recorded for the entire five and seven syllable string, as well as the airflow measures for the production of each individual peak. For this particular study, only the productions of /pi/ were analyzed (see Appendix N for additional details on analysis).

The first step in calculating PTP values from the five and seven peak samples involved computing the following averages. First, the maximum point of each peak was located and designated as the maximum pressure for that peak. Peak values were located by enlarging each individual peak and moving the cursor to find the maximum value. Those individual pressure values were used in the following averages. For the five syllable string, the average of the first and second peak (P1.P2), the second and third peak (P2.P3), the third and fourth peak (P3.P4), and the fourth and the fifth peak (P4.P5) was calculated, resulting in four separate averages. Likewise, for the seven syllable string, the average of the first and second peak (P1.P2), the second and third peak (P2.P3), the third and fourth peak (P3.P4), the fourth and fifth peak (P4.P5), the fifth and sixth peak (P5.P6), and the sixth and seventh peak (P6.P7) was also calculated, resulting in six separate averages. Each of these averages was also recorded (see Appendix O for average recording forms).

The above average values were then used to address each of the questions in this study. The first question, “Is there a difference in PTP outcome when five syllables are collected versus when seven syllables are collected?” was answered by analyzing the middle three syllables in each string. That is, average of P2.P3 and P3.P4 (also denoted as the two peak average or 2PA) was calculated for the five syllable sample. Similarly, the average of P3.P4 and P4.P5 (also denoted as the two peak average or 2PA) was calculated for the seven syllable sample. The second question, “Do the typically discarded first and last peaks differ from the middle three peaks?” was answered by making two comparisons. The first comparison involved the five syllable train and analyzed the differences, if any, between P1.P2, the average of P2.P3 and P3.P4 (the two peak average), and P4.P5. The second comparison involved the seven syllable train and analyzed the differences, if any, between P1.P2, the average of P3.P4 and P4.P5 (the two peak average), and P6.P7.

V. RESULTS

PTP data were analyzed using NCSS Statistical Analysis and Graphics 2000 software. Raw data were examined visually for skewness and kurtosis. Martinez-Iglewicz test of normality confirmed that all data were normally distributed. To answer the question of whether there is a significant difference in PTP outcome when five syllables versus seven syllables are collected and whether the first, last and middle three syllables of a PTP sample significantly differ from each other, PTP data were analyzed with repeated-measures analysis of variance (RM-ANOVA). The three within-subjects factors were syllable (five or seven), pitch (low, modal, and high), and peak position (first, middle three, and last). Table 2 lists the complete RM-ANOVA results. PTP differed significantly across pitch, $F(2, 18) = 29.35$, $p<.0001$, $\eta^2 = .66$. Newman-Keuls Multiple-Comparison Test was done. Table 3 lists the pairwise comparisons for pitch and reveals that PTP at the high pitch was significantly greater than that for the low and modal pitch. No significant difference was detected for syllable, $F(1, 9) = 2.14$, $p = .178$, $\eta^2 = .005$, or peak position, $F(2, 18) = 2.82$, $p = .086$, $\eta^2 = 005$. A statistically significant interaction was observed between pitch and peak position, $F(4, 36) = 8.86$, $p<.0001$, $\eta^2 = .018$. Pairwise comparisons for the pitch and peak position interaction were not made due to the small amount of variance accounted for by the interaction. No other statistically significant interaction effects were observed.

Table 2. Repeated measures within-subjects analysis of variance results for the effect of syllable, pitch and peak position on phonation threshold pressure outcome.

Source	*df*	PTP		
		MS	*F*	*p*
Syllable	1	6.36	2.14	.178
Error	9	2.97		
Pitch	2	448.76	29.35	<.0001
Error	18	15.29		
Syllable x Pitch	2	.37	.14	.867
Error	18	2.61		
Peak position	2	3.55	2.82	.086
Error	18	1.26		
Syllable x Peak position	2	.21	.39	.685
Error	18	.56		
Pitch x Peak position	4	6.05	8.83	<.0001
Error	36	.68		
Syllable x Pitch x Peak position	4	.14	.45	.774
Error	36	.30		

Note. *df* = degrees of freedom; *MS* = mean square; *F* = Fisher's *F* ratio; *p* = probability.

Table 3. Pairwise comparison for pitch.

Pitch	Mean	Different From
Low	4.74	High pitch
Modal	4.55	High pitch
High	9.38	Low and modal pitch

Table 4 lists the summary statistics for the statistically relevant PTP outcome data. Figure 1 plots PTP outcome data averaged across participants for syllable and peak position. Figure 1 and the summary statistics indicate the lack of substantial change in PTP for five versus seven syllables across the different peak positions. Figure 2 plots PTP outcome data averaged across participants for pitch and peak position. Figure 2 and the summary statistics also indicate the lack of substantial change in PTP across the different peak positions. However, the lack of difference between the low (M = 4.74) and modal pitches (M = 4.55) and significant difference for high pitch (M = 9.38) is clearly observed. Figure 3 plots PTP outcome data averaged across participants for syllable and pitch. Like Figures 1 and 2, Figure 3 also indicates the lack of substantial change in PTP when five versus seven syllables are collected and the significant difference for high pitch (see Appendix P for participant data used to calculate results).

Table 4. Summary Statistics

Syllable	Pitch	Peak Position	PTP *M*	PTP *SD*	PTP *N*
5	Low	First	4.92	1.153	10
5	Modal	First	4.776	1.494	10
5	High	First	8.576	2.619	10
5	Low	Middle	4.712	.918	10
5	Modal	Middle	4.637	1.168	10
5	High	Middle	10.394	2.544	10
5	Low	Last	4.974	1.138	10
5	Modal	Last	4.714	.974	10
5	High	Last	10.004	2.658	10
7	Low	First	4.551	1.257	10
7	Modal	First	4.628	1.427	10
7	High	First	8.227	3.185	10
7	Low	Middle	4.497	1.040	10
7	Modal	Middle	4.101	1.023	10
7	High	Middle	9.608	3.107	10
7	Low	Last	4.778	.883	10
7	Modal	Last	4.462	.975	10
7	High	Last	9.471	3.062	10

Note. *M* = mean; *SD* = standard deviation; *N* = total number in sample

Figure 1. PTP averaged across the 10 participants for each syllable sample and peak position.

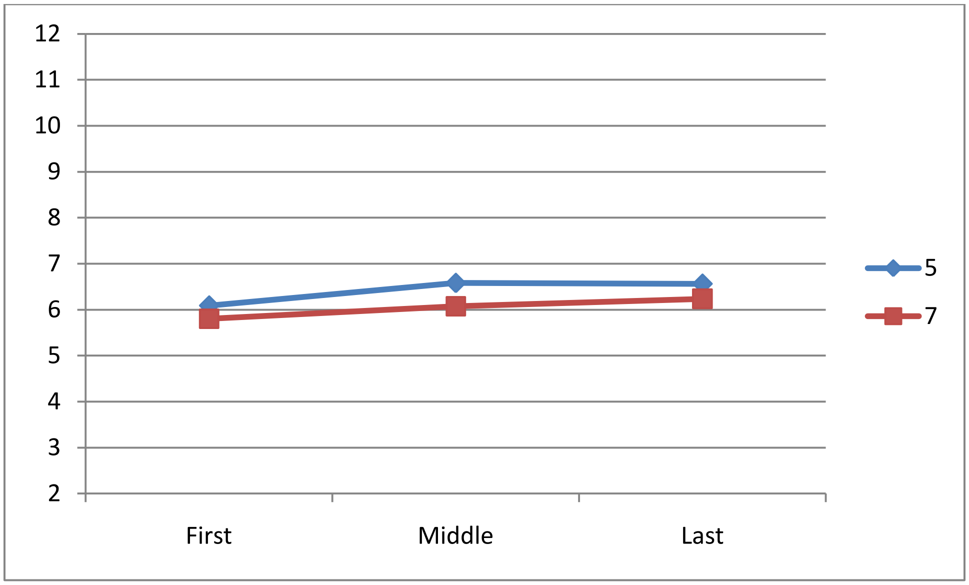


Figure 2. PTP averaged across the 10 participants for each pitch and peak position.

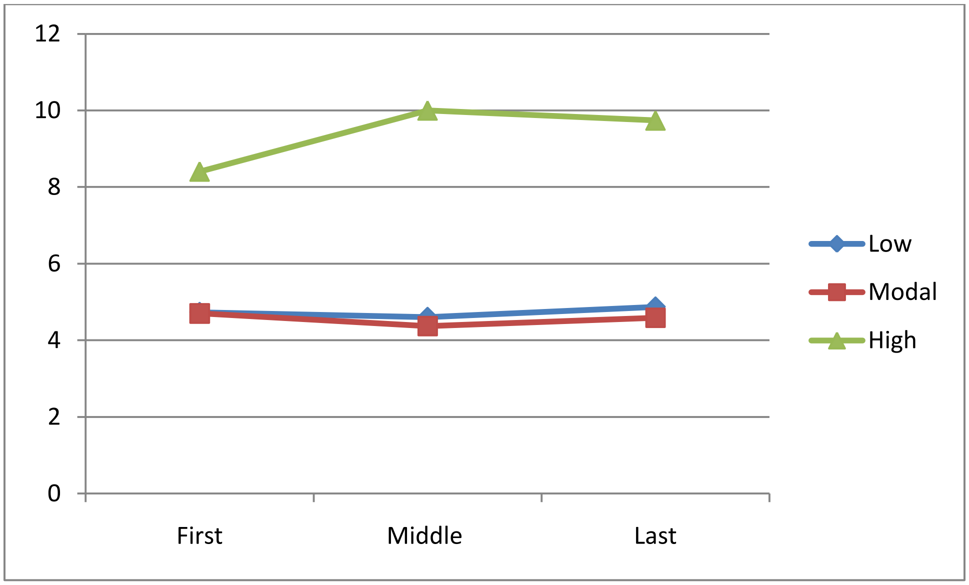
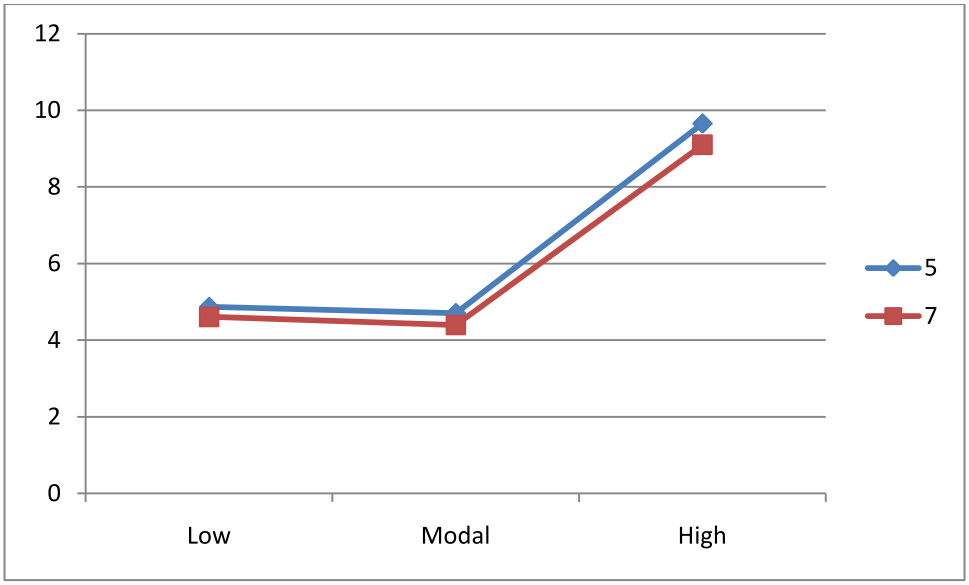


Figure 3. PTP averaged across the 10 participants for each syllable sample and pitch.



Reliability

To establish reliability, 20% of the data (i.e., 2 participants) was randomly selected for reanalysis. To establish intrarater reliability the primary investigator reanalyzed the data. The measurements of PTP were strongly correlated ($r_{intra} = 1.000$). To establish interrater reliability a graduate assistant not directly involved with the study also analyzed the same 20% of the data. The first and second raters measurements of PTP were strongly correlated ($r_{inter} = 1.000$) and yielded a mean absolute difference of 0.0003 cmH_20.

VI. DISCUSSION

Despite extensive research in the area of PTP there is little standardization among the procedures used. While Smitheran and Hixon (1981) defined a procedure that could be used for PTP data collection, successive researchers have both followed and deviated from Smitheran and Hixon's procedure. The lack of standardization has potentially significant repercussions with regard to how different research studies can be compared as it is possible that different methods could result in different results. Additionally, there are a number of factors that if not controlled or recognized could significantly affect PTP results including age, humidity, hydration, medication, vocal training, vocal fold pathologies, smoking, alcohol, and hormonal changes.

While there are many variations in procedures to collect PTP measurements this paper examined just two of the many components of the procedure: the length of the syllable train collected and the existence of performance end effects. When Smitheran and Hixon (1981) developed the procedure that has been used to collect PTP data they indicated that seven syllables should be collected in each syllable train. However, they did not provide a justification for the use of seven syllables. As already discussed, a number of researchers have continued to collect seven syllables. However, other researchers have reduced the number of syllables collected to five. Additionally, in their research Smitheran and Hixon stated that out of the seven syllable repetitions collected the first two and last two repetitions should not be included in the analysis to prevent performance end effects. However, Smitheran and Hixon provided no evidence or discussion of performance end effects. In an effort to reconcile differences in the literature regarding the number of syllables collected and analyzed and to further understand whether or not performance end effects exist, this research addressed two main questions: whether or not there was a difference in PTP when five syllables versus seven syllables were collected and whether or not the typically discarded first and last peaks differed from the middle three peaks.

It should be noted that the current study differed from Smitheran and Hixon’s (1981) method in the targeted loudness level. Smitheran and Hixon instructed their participants to produce the syllable /pi/ at a normal loudness level, while in the present study participants were instructed to produce /pi/ at a loudness level of just above a whisper. This difference exists because Smitheran and Hixon were ultimately measuring laryngeal airway resistance, while this study examined phonation threshold pressure. The ability to determine phonation threshold pressure is dependent on obtaining the minimum lung pressure required to initiate phonation.

Research Findings

The results demonstrated several points. In answer to the first question regarding the number of syllables collected, no significant difference was found in PTP when five syllables were collected versus seven syllables. In answer to the second question regarding potential differences between the first and last peaks and the middle three peaks, this study demonstrated that there was no significant difference in PTP between the typically discarded first and last peaks and the middle three peaks. Based on these results, it appears that performance end effects do not play a significant role PTP outcome.

Additionally, as was predicted and is consistent with earlier studies, PTP at the high pitch was significantly greater than PTP at the low and modal pitches. This was true for both five syllables and seven syllables were collected. Titze (1988) first predicted that there was an inverse relationship between PTP and frequency, or pitch. His hypothesis has been studied by a number of researchers, all of whom confirmed that PTP is significantly higher at high pitches than at low and modal pitches (Finkelhor et al., 1988; Plant et al., 2004; Sivasankar & Fisher, 2002; Verdolini-Marston et al., 1990; Verdolini, Titze, et al., 1994).

Within the literature, average PTP values at low pitches range from 3.20 to approximately 4.5 cmH2O (Sivasankar & Fisher, 2002; Verdolini, Titze, et al., 1994; Verdolini-Marston et al., 1990). Within this study, the average PTP value at the low pitch was slightly higher than those found in the literature at 4.74 cmH2O. Average PTP values at the modal pitch in the literature range from approximately 2.5 to 3.5 cmH2O (Sivasankar & Fisher, 2002; Verdolini, Titze, et al., 1994; Verdolini-Marston et al., 1990). At the modal pitch, the average PTP values within this study were 4.55 cmH2O and once again slightly higher than the averages found in the literature. Finally, at the high pitch, average PTP within the literature ranged from 5.5 to 8.24 cmH2O (Sivasankar & Fisher, 2002; Verdolini, Titze, et al., 1994; Verdolini-Marston et al., 1990). Within this particular study, the average PTP at the high pitch was 9.38 cmH2O. The fact that average PTP values in this study were slightly higher than the averages within the literature at all pitches could be a result of difficulties participants had producing the pitches as quietly as possible while maintaining a tight lip seal, which is discussed in the next section.

Participant Difficulties

As mentioned above, out of the original 16 participants, 6 participants did not meet one or more of the requirements of the study, and therefore, were not included in this research. Of those 6 participants, data was not collected at all for 2 participants. The other 4 participants were able to complete the entire task, but not all of their PTP data met one or more of the requirements for frequency, loudness, airflow, or peak measurement, despite being given repeated chances to perform the task. It should also be noted that the participants whose data met all of the measurement requirements demonstrated certain difficulties in completing the task.

All 14 participants indicated to the investigator that they found producing seven syllables a more difficult task than producing only five syllables and some described that they experienced shortness of breath when producing seven syllables. It is important to note that based on participant reports, all participants were in good health and had no respiratory problems.

Another common difficulty throughout data collection was participant fatigue and frustration as many trials had to be repeated in order to obtain usable data. Participants were observed to have difficulty producing the syllable as quietly as possible while maintaining a tight lip seal. A tight lip seal is imperative in obtaining accurate PTP results. Based on this observation, it is important for clinicians obtaining PTP measurements to emphasize that the patient focus on maintaining a tight lip seal. It should be noted that in a conversation with Dr. Sivasankar at the American Speech Language and Hearing Association (ASHA) convention in November 2009, Dr. Sivasankar indicated that she had difficulties in achieving negligible airflow in her collection of PTP data (M. Sivasankar, personal communication, November 20, 2009). Dr. Sivasankar found that if the facemask was not removed between each individual trial, a build-up of condensation in the mask increased airflow measurements. Her conclusion was that the facemask should be removed between each trial to eliminate effects from any condensation buildup.

An additional difficulty participants had was the ability to repeatedly match their high pitch. Of the 16 original participants, 2 participants were unable to match their high pitch, and therefore were unable to continue participating in the study. Additionally, while the other participants were able to match their high pitch, a number of participants indicated difficulty matching their high pitch while producing the syllable as quietly as possible. Participant difficulty in this area required that the investigator collect repeated trials of data at the high pitch in order to ensure that pitch requirements were met, thereby lengthening the amount of time to collect data. Research has already indicated that PTP is significantly higher when collected at a high pitch. Based on this knowledge, it could be suggested that, in the interest of limiting patient stress, fatigue, and time requirement, PTP be collected only at a modal pitch unless dealing with a patient who routinely uses a high or low pitch.

Clinical Implications

A recent survey of 55 current speech-language pathology professionals found that 44.45% of the professionals surveyed collected PTP data (Sandage, Plexico, & Faver, 2009). Out of the 44.45%, 19% of the professionals surveyed indicated they collected PTP data for clinical purposes and 25.4% of the professionals surveyed indicated they collected PTP data for research purposes (Sandage et al., 2009). This survey of current professionals also indicated a similar disparity between the methods used to collect PTP that was seen in the literature reviewed for this study. The measurement of PTP allows clinicians to use a quantifiable measurement to initially determine and continue to monitor the condition and health of a client's vocal folds. However, in order to be a truly useful, reliable, and clinically efficient measure, the methods for collecting PTP data need to be simplified and standardized. The findings of this study are intended for use as a primary step in the overall simplification and standardization process to aid in the collection of normative data.

The findings that the number of syllables collected do not affect PTP outcome and that performance end effects do not exist are clinically and methodologically important. First and foremost, the results indicate that the PTP outcome from studies in which five syllables were collected are comparable with the PTP outcome from studies in which seven syllables were collected. Additionally, the finding that PTP outcome is comparable whether seven syllables or five syllables are collected suggests that in the future clinicians could collect five syllable repetitions. Clinicians could collect only five syllable repetitions with the assurance of results that would be comparable to those found if seven syllables had been collected.

The results of the present research also suggest that PTP results do not differ whether the first, middle, or last peaks are analyzed. This result suggests that within the five syllable sample clinicians could calculate accurate PTP measurements as long as any three adjacent peaks met the requirements. This knowledge would hopefully help eliminate the need for repeated trials.

Not only would collecting five syllables shorten the amount of time required for data collection, but the ability to use any three consecutive peaks that meet the measurement criteria also has the potential to decrease patient frustration and exertion. Additionally, the fact that healthy participants reported difficulty producing seven syllable repetitions suggests that this task would be even more difficult, and possibly not a viable assessment, when used with patients suffering from respiratory weakness or incoordination as well as other breathing disorders. However, based on the results of this research, clinicians could collect only five syllable repetitions and be confident that the PTP results were accurate and similar to those found when collecting seven syllable repetitions.

Limitations

Despite the clinical implications of the present study, there are a number of potential limitations to the study. The first limitation is the small sample size and limited demographics as only the data from 10 participants was analyzed. Additionally, this particular study was limited to females between the ages of and only females between the ages of 20 and 36 participated. While the study was open to females of all ethnic backgrounds, all 16 original participants were Caucasian. Another potential limitation is that humidity and temperature were recorded, but were not controlled. The varying degrees of temperature and humidity could have affected the accuracy of an individual’s PTP results; however, it is unlikely that the lack of control affected the overall trends that were observed. Conversely, another limitation is the number of factors that were controlled within this study. While the number of controls permitted PTP measurement in ideal participants, it will not always be possible to control these factors when working with clinical populations. Finally, PTP data could have been influenced by the presence of breathiness in participants’ voices when they tried to complete the task as quietly as possible. The presence of breathiness would suggest incomplete glottal closure which ultimately affects the glottal half-width. Titze (1988) originally hypothesized that PTP would vary directly with glottal half-width. That is, as glottal half-width increased, Titze hypothesized that PTP would also increase.

Further Research

Based on the above limitations, there are a number of directions for future research. One particular direction is to focus on obtaining normative data for different populations including men and women of all ages, post-menopausal women, trained singers, and young children. Additionally, while the present research controlled for ovulation, menstruation, and pregnancy, this is a particularly difficult factor to control for in everyday patients. As a result, future research could examine and compare PTP results in women who are ovulating, menstruating, or pregnant. Another direction for future research could be to examine the effect of the vowel used in conjunction with /p/. Smitheran and Hixon (1981) indicated that the vowel /i/ should be used, although other researchers have used both /a/ and /ae/ in their research. Finally, future research could build on the present results and examine other procedural variations including how low, modal, and high pitches are collected and how participants are instructed in producing the target loudness.

Conclusion

This paper sought to explore and clarify two of many procedural variations in the collection of PTP. The small sample size and the restrictiveness of the inclusionary criteria leave room for future research. However, the initial results of this study are clinically significant and serve as a starting point to develop a clinically efficient, useful, and standardized method of collecting and analyzing PTP data.

REFERENCES

Abitbol, J., Abitbol, P., & Abitbol, B. (1999). Sex hormones and the female voice. *Journal of Voice, 13*(3), 424-446.

Amir, O., Biron-Shental, T., & Shabtai, E. (2006). Birth control pills and nonprofessional voice: Acoustic Analysis. *Journal of Speech, Language, and Hearing Research, 49*(5), 1114-1126.

Anderson, J. A. (1999). *Vocal function in subjects with compensated unilateral vocal fold paralysis pre and post medialisation thyroplasty*. Unpublished master's thesis, University of Toronto, Toronto, Ontario, Canada.

Anguwarangsee, T. & Morrison, M. (2002). Extrinsic laryngeal muscular tension in patients with voice disorders. *Journal of Voice, 16*(3), 333-343.

Awan, S. N. (2001). *The voice diagnostic protocol: A practical guide to the diagnosis of voice disorders*. Gaithersburg, MD: Aspen Publishers, Inc.

Bard, M. C., Slavit, D. H., McCaffrey, T. V., & Lipton, R. J. (1992). Noninvasive technique for estimating subglottic pressure and laryngeal efficiency. *Annals of Otology, Rhinology, and Laryngology, 101*, 578-582.

Berry, D. A., Reininger, H., Alipour, F., Bless, D. M., & Ford, C. N. (2005). Influence of vocal fold scarring on phonation: Predictions from a finite element model. *Annals of Otology, Rhinology, & Laryngology, 114*(11), 847-852.

Borrego, M. C., Gasparini, G., & Behlau, M. (2007). The effects of a specific speech and language training program on students of a radio announcing course. *Journal of Voice, 21*(4), 426-432.

Chae, S. W., Choi, G., Kang, H. J., Choi, J. O., & Jin, S. M. (2001). Clinical analysis of voice change as a parameter of premenstrual syndrome. *Journal of Voice, 15*(2), 278-283.

Chan, R. W., & Titze, I. R. (1999). Viscoelastic shear properties of human vocal fold mucosa: Measurement methodology and empirical results. *Journal of the Acoustical Society of America, 106*(4), 2008-2021.

Chan, R. W., Titze, I. R., & Titze, M. R. (1997). Further studies of phonation threshold pressure in a physical model of the vocal fold mucosa. *Journal of the Acoustical Society of America, 101*(6), 3722-3727.

Chang, A. & Karnell, M. P. (2004). Perceived Phonatory effort and phonation threshold pressure across a prolonged voice loading task: A study of vocal fatigue. *Journal of Voice, 18*(4), 454-466.

Finkelhor, B. K., Titze, I. R., & Durham, P. L. (1988). The effect of viscosity changes in the vocal folds on the range of oscillation. *Journal of Voice, 1*(4), 320-325.

Fisher, K. & Swank, P. (1997). Estimating phonation threshold pressure. *Journal of Speech, Language, and Hearing Research, 40*(5), 1122-1129.

Grini-Grandval, M. N., Bingenheimer, S., Maunsell, R., Ouaknine, M., & Giovanni, A. (2002). Phonatory threshold pressure in a healthy population before and after aerosol treatment, a preliminary study. *Review of Laryngology, Otology, and Rhinology, 123*(5), 311-314.

Guimarães, I. & Abberton, E. (2005). Heath and voice quality in smokers: An exploratory investigation. *Logopedics Phoniatrics Vocology, 30,* 185-191.

Guo, C. G. & Scherer, R. C. (1993). Finite element simulation of glottal flow and pressure. *Journal of the Acoustical Society of America, 94*(2), 688-700.

Hammond, T., Gray, S., Butler, J., Zhou, R., & Hammond, E. (1998). Age- and gender-related elastin distribution changes in human vocal folds. *Otolaryngology Head and Neck Surgery, 119*(6), 314-322.

Hemler, R. J. B., Wieneke, G. H., Dejonckere, P. H. (1997). The effect of relative humidity of inhaled air on acoustic parameters of voice in normal subjects. *Journal of Voice, 11*(3), 295-300.

Hirano, M. (1981). *Clinical examination of voice*. New York: Springer-Verlag Wien.

Hirano, M. & Bless, D. M. (1993). *Videostroboscopic examination of the larynx*. San Diego: Singular Publishing Group, Inc.

Hirano, M., Kurita, S., & Nakashima, T. (1983). Growth development and aging of human vocal folds. In D. M. Bless & J. H. Abbs (Eds.), *Vocal fold physiology: contemporary research and clinical issues* (pp. 22-43). San Diego, CA: College-Hill Press.

Hixon, T. J., Weismer, G., & Hoit, J. D. (2006). *Preclinical speech science: Anatomy physiology acoustics perception*. San Diego: Plural Publishing.

Hodge, F. S., Colton, R. H., & Kelley, R. T. (2001). Vocal intensity characteristics in normal and elderly speakers. *Journal of Voice, 15*(14), 503-511.

Holmberg, E. B., Hillman, R. E., & Perkell, J. S. (1988). Glottal airflow and transglottal air pressure measurements for male and female speakers in soft, normal, and loud voice. *Journal of the Acoustical Society of America, 84*(2), 511-529.

Jiang, J., O'Mara, T., Conley, D., & Hanson, D. (1999). Phonation threshold pressure measurements during phonation airflow interruption. *Laryngoscope, 109,* 425-432.

Jackson-Menaldi, C. A., Dzul, A. I., & Holland, R. W. (1999). Allergies and vocal fold edema: A preliminary report. *Journal of Voice, 13*(1), 113-122.

KayPENTAX. (2006). *Instruction Manual: Digital Videostroboscopy System Model 9295*. Lincoln Park, NJ. KayPENTAX.

KayPENTAX. (2008). *Instruction Manual: Phonatory Aerodynamic System (PAS) Model 6600*. Lincoln Park, NJ: KayPENTAX.

KayPENTAX. (2006). *Software Instruction Manual: RealTime Pitch (RTP) Model 5121 (Issue C)*. Lincoln Park, NJ: KayPENTAX.

KayPENTAX. (2006). *Software Instruction Manual: Voice Range Profile Program (VRP) Model 4326*. Lincoln Park, NJ: KayPENTAX.

Lavy, J. A., Wood, G., Rubin, J. S., & Harris, M. (2000). Dysphonia associated with inhaled steroids. *Journal of Voice, 14*(4), 581-588.

Lewis, K. E., Watterson, T., & Quint, T. (2000). The effect of vowels on nasalance scores. *Cleft Palate-Craniofacial Journal, 2000, 37*(6), 584-589.

Lofqvist, A. (1975). A study of subglottal pressure during the production of Swedish stops. *Journal of Phonetics, 3*, 175-189.

Lofqvist, A., Carlborg, B. & Kitzing, P. (1982). Initial validation of an indirect measure of subglottal pressure during vowels. *Journal of the Acoustical Society of America, 72*(2), 633-635.

Lucero, J. (1995). The minimum lung pressure to sustain vocal fold oscillation. *Journal of the Acoustical Society of America, 98*(2), 779-784.

Lucero, J. (1996). Relationship between the phonation threshold pressure and the prephonatory glottal width in a rectangular glottis. *Journal of the Acoustical Society of America, 100*(4), 2551-2554.

Lucero, J. (1999). A theoretical study of the hysteresis phenomenon at vocal fold oscillation onset-offset. *Journal of the Acoustical Society of America, 105*(1), 423-431.

Milbraith, R. L. & Solomon, N. P. (2003). Do vocal warm-up exercises alleviate vocal fatigue? *Journal of Speech, Language, and Hearing Research, 46*, 422-436.

Moll, K. L. (1962). Velopharyngeal closure on vowels. *Journal of Speech and Hearing Research, 5*(1), 30-37.

Moon, J. B., Kuehn, D. P., & Huisman, J. J. (1994). Measurement of velopharyngeal closure force during vowel production. *Cleft Palate-Craniofacial Journal, 31*(5), 356-363.

Morgan, M. D., Triana, M. A., & Milroy, T. J. (2004). Effect of auditory feedback on phonation threshold pressure measurement. *Journal of Voice, 18*(1), 46-55.

Morrison, M. & Rammage, L. (1994). *The management of voice disorders*. San Diego, CA: Singular Publishing Group.

Nasri, S., Sercarz, J. A., & Berke, G. S. (1994). Noninvasive measurement of traveling wave velocity in the canine larynx. *Annals of Otology, Rhinology, and Laryngology, 103*, 758-766.

NCSS Statistical Analysis and Graphics. (2000). [Computer software].Kaysville, UT: NCSS Statistical Power and Analysis Software.

Plant, R. L. & Hillel, A. D. (1998). Direct measurement of subglottic pressure and laryngeal resistance in normal subjects and in spasmodic dysphonia. *Journal of Voice, 12*(3), 300-314.

Plant, R. L., Freed, G. L., & Plant, R. E. (2004). Direct measurement of onset and offset phonation threshold pressure in normal subjects. *Journal of the Acoustical Society of America, 116*(6), 3640-3646.

Plant, R. L. & Youger, R. M. (2000). The interrelationship of subglottic air pressure, fundamental frequency, and vocal intensity during speech. *Journal of Voice, 14*(2), 170-177.

Ramos Pizzaro, C. A. (1998). Vocal function measures in premenopausal and postmenopausal women and their relationships to sex steroid hormone levels. Unpublished doctoral dissertation, University of Wisconsin-Madison.

Ross, J., Noordzji, J. P., & Woo, P. (1998). Voice disorders in patients with suspected laryngo-pharyngeal reflux disease. *Journal of Voice, 12*(1), 84-88.

Roy, N., Tanner, K., Gray, S. D., Blomgren, M. & Fisher, K. V. (2003). An evaluation of the effects of three laryngeal lubricants on phonation threshold pressure (PTP). *Journal of Voice, 17*(3), 331-342.

Sandage, M. J., Plexico, L. W., & Faver, K. Y. Procedural considerations for the assessment of phonation threshold pressure. Manuscript in preparation.

Shipp, T. (1973). Intraoral air pressure and lip occlusion in midvocalic stop consonant production. *Journal of Phonetics, 1*, 167-179.

Sivasankar, M., Erickson, E., Schneider, S., & Hawes, A. (2008). Phonatory effects of airway dehydration: Preliminary evidence for impaired compensation to oral breathing in individuals with a history of vocal fatigue. *Journal of Speech, Language, and Hearing Research, 51*, 1494-1506.

Sivasankar, M., & Fisher, K. V. (2002). Oral breathing increases Pth and vocal effort by superficial drying of vocal fold mucosa. *Journal of Voice, 16*(2), 172-181.

Slavit, D. H., Lipton, R. J., & McCaffrey, T. V. (1990). Phonatory vocal fold function in the excised canine larynx. *Otolaryngology—Head and Neck Surgery, 103*(6), 947-956.

Smitheran, J. R. & Hixon, T. J. (1981). A clinical method for estimating laryngeal airway resistance during vowel production. *Journal of Speech and Hearing Disorders, 46*, 138-146.

Solomon, N. P., & DiMattia, M. S. (2000). Effects of a vocally fatiguing task and systemic hydration on phonation threshold pressure. *Journal of Voice, 14*(3), 341-362.

Solomon, N. P., Ramanathan, P., & Makashay, M. J. (2007). Phonation threshold pressure across a pitch range: Preliminary test of a model. *Journal of Voice, 21*(5), 541-550.

Sorensen, D. & Horii, Y. (1982). Cigarette smoking and voice fundamental frequency. *Journal of Communication Disorders, 15*, 135-144.

Stemple, J. C., Glaze, L. E., & Klaben, B. G. (2000). *Clinical voice pathology: Theory and management* (3rd ed.). San Diego: Singular Thomson Learning.

Tanner, K., Roy, N., Merrill, R. M., & Elstad, M. (2007). The effects of three nebulized osmotic agents in the dry larynx. *Journal of Speech, Language, and Hearing Research, 50*, 635-646.

Thompson, A. and Hixon, T. (1979). Nasal air flow during normal speech production. *Cleft Palate Journal, 16*(4), 412-420.

Titze, I. R. (1988). The physics of small-amplitude oscillation of the vocal folds. *Journal of the Acoustical Society of America, 83*(4), 1536-1552.

Titze, I. R., Schmidt, S., & Titze, M. R. (1995). Phonation threshold pressure in a physical model of the vocal fold mucosa. *Journal of the Acoustical Society of America, 97*(5), 3080-3084.

Titze, I. R. (2009). Phonation threshold pressure measurement with a semi-occluded vocal tract. *Journal of Speech, Language, and Hearing Research, 52,* 1062-1072.

Verdolini-Marston, K., Titze, I. R., & Druker, D. G. (1990). Changes in phonation threshold pressure with induced conditions of hydration. *Journal of Voice, 4*(2), 142-151.

Verdolini-Marston, K., Sandage, M., & Titze, I. R. (1994). Effect of hydration treatments on laryngeal nodules and polyps and related voice measures. *Journal of Voice, 8*(1), 30-47.

Verdolini, K., Min, Y., Titze, I. R., Lemke, J., Brown, K., van Mersbergen, M. et al. (2002). Biological mechanisms underlying voice changes due to dehydration. *Journal of Speech, Language, and Hearing Research, 45*, 268-281.

Verdolini, K., Titze, I. R., & Fennell, A. (1994). Dependence of phonatory effort on hydration level. *Journal of Speech & Hearing Research, 37*(5), 1001-1007.

Zhuang, P., Sprecher, A. J., Hoffman, M. R., Zhang, Y., Fourakis, M., Jiant, J. J., & Wei, C. S. (2009). Phonation threshold flow measurements in normal and pathological phonation. *The Laryngoscope, 119*, 811-815.

Zraick, R. I., Skaggs, S. D., & Montague, J. C. (2000). The effect of task on determination of habitual pitch. *Journal of Voice, 14*(4), 484-489

APPENDIX A

Recruitment Script for undergraduate and graduate students (verbal, in person)

My name is Katie Yendle and I am a graduate student from the Department of Communication Disorders at Auburn University. I would like to invite you to participate in my research study being conducted under the direction of Dr. Laura Plexico to document the effects of procedural differences in determining phonation threshold pressure. You must be 19 years of age or older, a nonsmoker, not pregnant, on no medication other than oral contraceptives, had no vocal training, and not be diagnosed with asthma or gastroesophageal reflux disease, in addition to some other inclusionary criteria.

As a participant, you will be asked to complete a questionnaire with some personal questions, undergo a stroboscopic examination and participate in the collection of phonation threshold pressure measurements. Completion of the measures should take approximately 1 to 1 ½ hours. There is no anticipated risk for participation in the study.

If you would like to participate in this research study, we can arrange a time for us to meet now or I can give you my contact information so we can arrange a time to meet later. If you have questions later, please contact me at kjy0001@auburn.edu or you may contact Dr. Plexico, at 334-844-9600 or lwp0002@auburn.edu.

APPENDIX B

A Research Study of the Methods Used to Determine the Amount of Air Pressure Required to Initiate Vocalization

Are you between 19 and 40 years of age and a nonsmoker?

If you answered **YES** to this question, you may be eligible to participate in a study on Phonation Threshold Pressure.

The purpose of this research is to document the effects of procedural differences on the collection of Phonation Threshold Pressure Data. The time commitment to participate in this study is approximately 1 to 1½ hours.

This study is being conducted by Dr. Laura Plexico in the Department of Communication Disorders at Auburn University. Please contact Dr. Laura Plexico at lwp0002@auburn.edu or 334-844-9620 for more information.

APPENDIX C

Inclusionary/Exclusionary Screener

Confidentiality Note: All information provided by you is for the sole use of this research study, and will not be shared with anyone but those directly involved with the research. Furthermore, answers provided will in no way affect your standing with the University or any other organization.

Please read the following exclusionary criteria to yourself and indicate whether any of the following criteria apply to you. You do not need to indicate which one of the criteria below applies to you.

Do you or have you ever smoked?
Are you pregnant?
Have you had any vocal training?
Are you taking any medications, excluding oral contraceptives?
Have you been diagnosed with asthma?
Have you been diagnosed with reflux or do you feel you experience any symptoms of reflux?
Do you have a history of any kind of laryngeal pathology or voice disorder?
Do you or have you previously had a chronic respiratory infection or serious illness other than typical childhood diseases or viral infections?

If you answered *yes* to *any* of them, we would like to thank you for your time. However, due to the constraints of this study, you will not be able to participate.

If you answered *no* to *all* of them, you may be eligible to participate in this study.

(For females only)
If you are interested in participating in this study, please answer the following two questions. Your answers to these questions will help us determine the best week for you to participate in the study.

When was the date of your last menstrual cycle? ______________________

Are you currently using any type of prescribed birth control such as an oral contraceptive or a patch?

Yes _____ No _____

APPENDIX D

General Informed Consent
For a Research Study Entitled
Procedural Considerations for the Assessment of Phonation Threshold Pressure

You are invited to participate in a research study to investigate the effects of the variety of measurement techniques and client variables that can affect phonation threshold pressure (PTP) outcome. PTP is the amount of air pressure required to begin and continue vibration of the vocal folds, which produces voice. Through this study, we hope to examine the effects of frequency (pitch), vowel, syllable length, and measurement technique on phonation threshold pressure. This study is being conducted by Dr. Laura Plexico, Ms. Mary Sandage, and Katie Yendle (under the direction of Dr. Laura Plexico, Assistant Professor) in the Auburn University Department of Communication Disorders. You were selected as a possible participant because you are:

- between 19 and 40 years of age
- a nonsmoker
- not pregnant
- have had no vocal training
- are taking no medications (with the exception of oral contraceptives)
- have no history of asthma
- do not have reflux
- have no history of laryngeal pathology
- have not had any serious respiratory infection or illness.

What will be involved if you participate? In consenting to participate in this study, you confirm that you meet all of the above criteria. If you decide to participate in this research study, you will be asked to participate in the following procedures in the following order to further determine eligibility for this study:

a) Complete an inclusionary questionnaire that asks some personal questions
b) Pass a hearing screening
c) Provide a pitch range and demonstrate that you are able to match your pitch to one provided

Initials _____

d) Have a stroboscopic examination to determine if the structure and function of your vocal folds are adequate to perform the phonation threshold pressure procedure (this involves the insertion of a 9.5 mm diameter endoscope with a light source located at the end of the scope into your mouth to view the vocal folds).

If you meet all of the previous eligibility criteria, you will be asked to provide a urine sample to measure your hydration. Additionally, if you are a female the urine sample will also be screened to determine where you are in your menstrual cycle. It should be noted that this test provides no indication of whether or not you are pregnant. Once the previously listed criteria have been met, participants will be trained for the phonation threshold pressure measurement, and complete the tasks necessary to calculate phonation threshold pressure. With the exception of the urine sample all of the procedures listed above, including the stroboscopic examination, are routine in any well-equipped voice clinic and have been used in research for many years. Additionally, a stroboscopic examination is a common procedure in ENT offices. All of the procedures are also within the scope of practice of a trained speech-language pathologist. Your total time commitment will be approximately 1 to 1½ hours.

Are there any risks or discomforts? We do not anticipate any risks associated with your participation in this study. If, during the stroboscopic examination, the speech pathologist views anything of concern in your larynx, you will be given appropriate referral information, to an Ear Nose and Throat doctor, to use at your discretion. You can discontinue the study at any time, however expenses for treatment resulting from this study will be incurred by you, the participant. Any information obtained in connection with this study and that can be identified with you will remain anonymous. Your identity and participation in this study will be known only to the primary investigator and co-investigators of this study. After the assessments are completed the primary investigator will remove all identifying information and code all data. After coding the data, one of the investigator or a graduate research assistant will enter all data that is collected into a spreadsheet. The primary investigators will be the only individuals with access to the data that is identified by the participant's name. All information and data will be stored in a secure place under lock and key.

If you change your mind about participating, you can withdraw at any time during the study. **Your participation in this study is entirely voluntary and your refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled.** You are also free to withdraw from the study at any time without penalty or loss of benefits to which you are otherwise entitled. If you choose to withdraw from the study, any information about you and any
data that you have provided will be destroyed upon your request.

Initials _____

Your privacy will be protected. Only anonymous data collected from your participation during this study may be used by Dr. Laura Plexico and the co-investigators for other research purposes or for developing a paper for presentation or publication in a professional journal. If so, none of your identifiable information will be included.

If you have any questions about any aspect of the study, please ask them now or contact Dr. Laura Plexico by phone at (334) 844-9620 or email lwp0002@auburn.edu. She will be happy to answer any questions you might have.

If you should have any questions about your rights as a research participant, you may contact the Office of Human Subjects Research or the Institutional Review Board by phone at (334) 844-5966 or email at hsubjec@auburn.edu or IRBChair@auburn.edu. You will be provided a copy of this form to keep.

HAVING READ THE INFORMATION PROVIDED, YOU MUST DECIDE WHETHER OR NOT YOU WISH TO PARTICIPATE IN THIS RESEARCH STUDY. YOUR SIGNATURE INDICATES YOUR WILLINGNESS TO PARTICIPATE.

____________________________	____________________________
Participant's Signature Date	Investigator obtaining consent Date
____________________________	____________________________
Printed Name	Printed Name
	____________________________
	Co-Investigator Date
	____________________________
	Printed Name
	____________________________
	Co-Investigator Date
	____________________________
	Printed Name

Auburn University Student Informed Consent
For a Research Study Entitled
Procedural Considerations for
the Assessment of Phonation Threshold Pressure

You are invited to participate in a research study to investigate the effects of the variety of measurement techniques and client variables that can affect phonation threshold pressure (PTP) outcome. PTP is the amount of air pressure required to begin and continue vibration of the vocal folds, which produces voice. Through this study, we hope to examine the effects of frequency (pitch), vowel, syllable length, and measurement technique on phonation threshold pressure. This study is being conducted by Dr. Laura Plexico, Ms. Mary Sandage, and Katie Yendle (under the direction of Dr. Laura Plexico, Assistant Professor) in the Auburn University Department of Communication Disorders. You were selected as a possible participant because you are:

- between 19 and 40 years of age
- a nonsmoker
- not pregnant
- have had no vocal training
- are taking no medications (with the exception of oral contraceptives)
- have no history of asthma
- do not have reflux
- have no history of laryngeal pathology
- have not had any serious respiratory infection or illness.

What will be involved if you participate? In consenting to participate in this study, you confirm that you meet all of the above criteria. If you decide to participate in this research study, you will be asked to participate in the following procedures in the following order to further determine eligibility for this study:

a) Complete an inclusionary questionnaire that asks some personal questions
b) Pass a hearing screening
c) Provide a pitch range and demonstrate that you are able to match your pitch to one provided
d) Have a stroboscopic examination to determine if the structure and function of your vocal folds are adequate to perform the phonation threshold pressure procedure (this involves the insertion of a 9.5 mm diameter endoscope with a light source located at the end of the scope into your mouth to view the vocal folds).

Initials _____

If you meet all of the previous eligibility criteria you will be asked to provide a urine sample to measure your hydration. Additionally, if you are a female the urine sample will also be screened to determine where you are in your menstrual cycle. It should be noted that this test provides no indication of whether or not you are pregnant. Once the previously listed criteria have been met, participants will be trained for the phonation threshold pressure measurement, and complete the tasks necessary to calculate phonation threshold pressure. With the exception of the urine sample all of the procedures listed above, including the stroboscopic examination, are routine in any well-equipped voice clinic and have been used in research for many years. Additionally, a stroboscopic examination is a common procedure in ENT offices. All of the procedures are also within the scope of practice of a trained speech-language pathologist. Your total time commitment will be approximately 1 to 1½ hours.

Are there any risks or discomforts? We do not anticipate any risks associated with your participation in this study. If, during the stroboscopic examination, the speech pathologist views anything of concern in your larynx, you will be given appropriate referral information, to an Ear Nose and Throat doctor, to use at your discretion. You can discontinue the study at any time; however, expenses for treatment resulting from this study will be incurred by you, the participant. Any information obtained in connection with this study and that can be identified with you will remain anonymous. Your identity and participation in this study will be known only to the primary investigator and co-investigators of this study. After the assessments are completed the primary investigator will remove all identifying information and code all data. After coding the data, one of the investigator or a graduate research assistant will enter all data that is collected into a spreadsheet. The primary investigators will be the only individuals with access to the data that is identified by the participant's name. All information and data will be stored in a secure place under lock and key.

If you change your mind about participating, you can withdraw at any time during the study. **Your participation in this study is entirely voluntary and your refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled.** You are also free to withdraw from the study at any time without penalty or loss of benefits to which you are otherwise entitled. If you choose to withdraw from the study, any information about you and any data that you have provided will be destroyed upon your request.

Participation in this study is voluntary and it will have no impact on your academic performance or academic standing. That is, you will not receive special accommodations, nor will you receive any extra credit for participating in this study. Your decision about whether or not to participate or to stop participating will not jeopardize your future relations with Auburn University, the Department of Communication Disorders, or Dr. Plexico, Ms. Sandage, or Ms. Yendle.

Initials _____

Your privacy will be protected. Only anonymous data collected from your participation during this study may be used by Dr. Laura Plexico and the co-investigators for other research purposes or for developing a paper for presentation or publication in a professional journal. If so, none of your identifiable information will be included.

If you have any questions about any aspect of this study, please ask them now or contact Dr. Laura Plexico by phone at (334) 844-9620 or email lwp0002@auburn.edu. She will be happy to answer any questions you might have.

If you should have any questions about your rights as a research participant, you may contact the Office of Human Subjects Research or the Institutional Review Board by phone at (334) 844-5966 or email at hsubjec@auburn.edu or IRBChair@auburn.edu. You will be provided a copy of this form to keep.

HAVING READ THE INFORMATION PROVIDED, YOU MUST DECIDE WHETHER OR NOT YOU WISH TO PARTICIPATE IN THIS RESEARCH STUDY. YOUR SIGNATURE INDICATES YOUR WILLINGNESS TO PARTICIPATE.

Participant's Signature Date	Investigator obtaining consent Date
Printed Name	Printed Name
	Co-Investigator Date
	Printed Name
	Co-Investigator Date
	Printed Name

APPENDIX E

Further participant information about participants answering no to all of the exclusionary criteria:

Age: ________ Gender: _____

Date: _______

Participant Code: _________ Room Temperature: ________°F

Urine Specific Gravity: _________ Room Humidity: ________

Last menstrual cycle: _________ Use of birth control: ________

LH: _________

Approximately how much alcohol do you consume per week?

None _____ 1-3 drinks _____ 4-6 drinks _____ 7+ drinks _____

APPENDIX F

Hearing Screening

Procedure. Participants' hearing will be screened using a Beltone portable audiometer. The screening will be conducted in a sound-proof booth to ensure against interference of outside sounds. The audiometer will be calibrated prior to its use. Testing will be conducted at 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz at 20 dB.

Instructions. Participants will be given the following instructions:

(1) I am going to put these headphones on your head.
(2) When you hear a beep, please raise your hand on the side you heard the beep. If you hear the beep in your right ear, please raise your right hand.
(3) Do you have any questions?

Hearing Screening Form

Participant Code: ______

dB: _____

Right ear:	Left ear:
500 Hz _____	500 Hz _____
1000 Hz _____	1000 Hz _____
2000 Hz _____	2000 Hz _____
4000 Hz _____	4000 Hz _____

Audiometer used: Beltone ____________

APPENDIX G

Pitch Range

Procedure for eliciting pitch range and pitch sample values. The participants' overall pitch range will be determined using RealTime Pitch (RTP) software for CSL hardware Model 4500. The following information will be collected from the RTP: frequency range, minimum frequency, maximum frequency, and semitone range. Once the pitch range is collected it will be converted to semitones in the following manner:

$$number\ of\ semitones = 39.863 \times \log\left(\frac{f_2}{f_1}\right)$$

In this equation, f_1 is the lowest fundamental frequency and f_2 is the highest fundamental frequency. Once converted into semitones, the 10th percentile or *low* pitch will be calculated in the following manner:

$$10\% = 1.0595^{\left(\frac{semitones}{10}\right)} \times f_1$$

The 20th percentile or modal pitch will be similarly calculated using the following equation:

$$20\% = 1.0595^{((semitones\ /10)\times 2)} \times\ f_1$$

Finally, the 80th percentile or high pitch will be calculated using the following equation:

$$80\% = 1.0595^{((semitones\ /10)\times 8)} \times\ f_1$$

After collecting the participants' pitch range, the participants' modal pitch will also be collected through a rote counting task using RealTime Pitch.

Instructions for use.

(1) Power on CSL Box Model 4500
(2) Select CSL Model 4500 on the desktop
(3) Select Real-Time Pitch Program
(4) Select Protocols and select Pitch range
(5) Select "Okay" to begin recording and press Spacebar to stop recording
(6) Press Shift and left click on the mouse and drag to select data
(7) Select Numerical Results for analysis
(8) Select "Save As" and save in Yendle folder under participant code

Instructions to participant.

(1) I am going to place these headphones on your head. The microphone should be positioned at the corner of your mouth, two finger-widths from your mouth.

(2) When I tell you to begin start at a comfortable pitch and glide up to the highest pitch you can, just like this [researcher demonstrates]. Do you have any questions? Okay, good.

(3) Now, we’re going to do the same thing, but this time begin at a comfortable pitch and glide down to the lowest pitch you can, without making your voice scratchy. This is how it should not sound [researcher demonstrates]. This is how it should sound [researcher demonstrates]. Do you have any questions?

(4) When I tell you to begin, glide from a comfortable pitch to the highest pitch you can, and then glide from a comfortable pitch to the lowest pitch you can. Do you have any questions? [press record and document outcome] Okay, good.

(5) Now, please count slowly from 1 to 3 and hold the final /i/ on three, like this [researcher demonstrates]. Do you have any questions? [press record and document outcome]

Pitch Recording Form

Participant Code: _______

Frequency Range: ______Hz

Minimum Frequency: ______Hz

Maximum Frequency: ______Hz

Semitone Range: ______ ST

10th percentile: ______ Hz

20th percentile: ______ Hz

80th percentile: ______ Hz

Final /i/: ______ Hz

High pitch: ______ Hz

Low pitch: ______ Hz

Average modal pitch (average of 20th percentile and final /i/): ______ Hz

APPENDIX H

Matching Pitches

Procedure. The participant's high, modal, and low pitches will be individually presented to the participant using the Voice Range Profile (VRP) software for CSL hardware Model 4500. The participant will be given a chance to practice matching his or her low, modal and high pitches as they are presented. Approximately ten minutes will be allotted for this procedure, and less if the participant demonstrates she is capable of matching pitch.

Instructions for use.

(1) Connect XLR male connector on the headset microphone to the 20dB attenuator and connect the 20dB attenuator to the Channel 1 XLR connector on the front of the CSL Model 4500 hardware box
(2) Make sure that VRP Mode button on the front of the CSL Model 4500 box is pressed to automatically set input levels
(3) Select CSL on the desktop
(4) Select Voice Range Profile
(5) Select Options
(6) Select VRP options and check Pitch Target Mode
(7) Move red crosshair cursor on screen across the onscreen keyboard to find desired frequency to be matched; frequency of each key will be indicated at the bottom of the screen
(9) Left mouse click key to present tone

Instructions to participant.

(1) You will hear a tone. Listen carefully to it.
(2) As soon as the tone stops, try to match the pitch as exactly as possible holding an /a/. [investigator demonstrates]
(3) When you have matched the pitch, you will see green bars on the screen. When you are comfortable with this, try matching the pitch while saying /pi/ repeatedly. [investigator demonstrates] Do you have any questions?

APPENDIX I

Stroboscopy

Procedure. Stroboscopy will be performed using a KayPENTAX Digital Videostroboscopy System Model 9295 with a rigid 9106 Endoscope. All examinations will be performed with a disinfected endoscope and Universal Precautions will be utilized with all participants. Participants will be asked to (1) phonate /i/; (2) increase and decrease pitch while phonating /i/; (3) increase and decrease loudness while phonating /i/; (4) produce a staccato /hi/; (5) produce voiced inhalation

Instructions for use.

(1) Turn on cart
(2) Turn on computer and enter password “strobe”
(3) Select File and then New Exam
(4) Select File and then Add/Edit Patient
(5) Type Yendle (*participant code)* and select New Patient
(9) Have participant hold laryngeal microphone to the flat part of the thyroid lamina
(10) Have participant say /i/ to make sure frequency is tracking and check to insure that frequency number on light box is appropriate for the pitch the participant is producing
(11) Attach strobe to camera and focus camera for color and clarity; adjust light if necessary
(12) Instruct patient to lean forward with elbows back and head forward
(13) De-fog lens of scope
(14) Proceed with stroboscopic exam
(15) After the exam, select Video Play Mode to determine whether the collected images are adequate
(16) Save Exam and save exam as Yendle (*participant code*)

Stroboscopy Record Form (adapted from Hirano & Bless, 1993)

Participant Code: _____

VF Edge:	Right:	0	1	2	3	4	5
		Smooth					Rough
	Left:	0	1	2	3	4	5
	Right:	0	1	2	3	4	5
		Straight					Irregular
	Left:	0	1	2	3	4	5

VF Symmetry:	Right:	0	1	2	3	4	5
		Symmetrical					Asymmetrical
	Left:	0	1	2	3	4	5

Mucosal Cover:	Right:	Thin	Normal	Thick
	Left:	Thin	Normal	Thick

Stiffness:	Right:	0	1	2	3	4	5
		Pliable					Stiff
	Left:	0	1	2	3	4	5

Vascular Markings:	0	1	2	3	4	5
Redness:	0	1	2	3	4	5
Mucous:	0	1	2	3	4	5

Degree of Glottal Closure:	0	1	2	3	4	5
	Glottic Plane					Off Plane

VF Mobility:	Right:	Normal	Paresis	Paralysis
	Left:	Normal	Paresis	Paralysis

Mucosal Wave:	Right:	0	1	2	3	4	5
		Normal	Slightly Decreased	Moderately Decreased	Severely Decreased	Barely Perceptible	Absent
	Left:	0	1	2	3	4	5

APPENDIX J

Urine Specific Gravity

Procedure. All participants will be asked to provide a urine sample, which will provide a measure of their hydration as calculated using urine specific gravity. In order to participate in the study, participants' urine specific gravity must be below 1.028 g/ml. If a participant's urine specific gravity is above 1.028 g/ml, which indicates a low level of hydration, she will be asked to consume more water before continuing.

Instructions. Participants will each be given a sheet of paper with the following instructions on it:

(1) The test requires a clean-catch urine sample.
(2) Women need to wash the area between the lips of the vagina with soapy water and rinse well.
(3) As you start to urinate, allow a small amount to fall into the toilet bowl to clear the urethra of contaminants. Then, put a clean container under your urine stream and catch 1 to 2 ounces of urine. Remove the container from the urine stream (Urine Specific Gravity).

Once the urine sample has been collected, the urine specific gravity will be measured using a Siemens Multistix 9 SGReagent Strips for Urinalysis. These strips test levels of glucose, bilirubin, ketone, specific gravity, blood, pH, protein, nitrate, and leukocytes. However, for the purposes of this study, only glucose, specific gravity, pH, and protein will be measured. The following directions from the instruction manual will be followed:

(1) Mix well just before testing
(2) Remove one strip from the bottle and replace the cap
(3) Dip all the test pads of the strip into the urine and immediately remove the strip; begin timing
(4) Compare each test pad to the corresponding row of color blocks on the bottle label and read each pad at the time shown on the label, starting with the shortest time
(5) Read glucose at 30 seconds
(6) Read specific gravity at 45 seconds
(7) Read pH at 60 seconds
(8) Read protein at 60 seconds
(9) Hold the strip close to the color blocks and match carefully; read the pads in good light.

Once the urine specific gravity has been determined, participants will be instructed to pour the contents of the cup into the toilet, flush the toilet, and throw away the cup.

Urine Specific Gravity Recording Form

Participant Code: _______

30 seconds: Glucose: ______mg/dL (only negative or trace amounts acceptable)

45 seconds: Specific Gravity: ______mg/dL (1.001-1.035)

60 seconds: pH: ______ (if greater than or equal to 6.5 add .005 to specific gravity)

60 seconds: Protein: ______mg/dL (< 100 mg/dL)

APPENDIX K

LH Surge

Procedure: The same urine sample will be used to test for an LH surge using the First Response Ovulation Test.

Instructions:
(1) Immerse the entire absorbent tip in the urine for 5 seconds.
(2) With the absorbent tip still pointing downward, replace the overcap and lay the test stick on a flat surface with the result window facing up.
(3) You may see a pink color moving across the result window to indicate that the test is working. Look at the result window at five minutes. Compare the test line to the reference line. The reference line indicates that the test is complete, and you have conducted it correctly.
(4) An LH surge is indicated by: two lines are visible and the color and intensity of the test line is similar to or darker than the reference line.
(5) No LH surge is indicated when two lines are visible but the test line is lighter than the reference line or there is a reference line and no visible test line.

LH Recording Form

Participant Code: ______

LH Surge: Yes _____ No _____

APPENDIX L

Obtaining PTP

Procedure. PTP will be calculated using the KayPENTAX Phonatory Aerodynamic System (PAS) Model 6600. According to the KayPENTAX PAS manual, the face mask must create an airtight seal over the participants' nose and mouth, without creating discomfort for the participant (KayPENTAX Instruction Manual, 2008). A metronome will be used to cue participants to produce the syllables at a rate of 92 syllables per minute. The keyboard will be used to provide pitches for participants.

Instructions for calibration:

(1) Turn on computer
(2) Calibrate PAS hardware to adjust for changes in airflow head resistance over time and to adjust for differences between airflow heads
(3) Attach syringe to PAS external module using cardboard tube
(4) Place unit on solid surface, pull out plunger and click "Yes" to calibrate
(5) Follow on-screen directions
(6) Disconnect syringe from PAS external module and remove cardboard tube

Instructions for use:

(1) Attach adult PAS facemask to external module
(2) Select Protocol
(3) Select Voicing Efficiency
(4) Select New Live Input
(5) Select "OK" to *zero* PAS facemask
(5) Instruct participant to place mask over nose and mouth forming an airtight seal and instruct participant to place tube in mouth between lips and teeth, so it sits 1 to 2 mm behind the front teeth
(6) Select OK to begin collecting data
(7) After data collection, press Spacebar to end recording
(8) Select data to analyze by pressing Shift and left clicking at the beginning of desired sample, and dragging mouse to the end of desired sample
(9) Select the threshold button on the toolbar
(10) Select the analyze button on the toolbar
(11) Select File and Save Signal Data
(12) Save sample according to coding protocol

Instructions for training (adapted from Verdolini-Marston, Sandage et al., 1994).

(1) Now for the measures in this experiment, you will be saying the syllables /pi pi pi/, /pae pae pae/, and /pa pa pa/ over and over again in a special way.

(2) You will say them while you hold the mask the experimenter gives you firmly over your nose and mouth. A little plastic tube will be in your mouth. Don’t worry, the tube is not sharp, and it will not hurt you.

(3) Try putting the mask over your nose and mouth now, and say the syllable /pi pi pi/ several times. Okay, now take the mask away for a moment. As you do this task, it is very important that you press the mask firmly over your nose and mouth so that no air can get out around the sides. It is also important that the little tube not get caught on your tongue or anywhere else, because we wouldn’t get any measurements if it did. The little hole at the end of the tube has got to be free for us to get measurements.

(4) So hold the mask and position the tube so that it sits just 1 to 2 mm behind your front teeth. This way, the hole on the end of the tube won’t get stopped up by your tongue or by anything else. Go ahead, say /pi pi pi/ several times again, pressing the mask firmly, and making sure that the hole in the tube is free. Good!

(5) Now for the measures in this experiment, you will be repeating the syllables /pi pi pi pi pi/, /pae pae pae pae pae/, and /pa pa pa pa pa/ at a rate specified by a metronome. Listen to the metronome for a moment. (Put metronome on at 92 beats/minute, for about 5 seconds. Then turn metronome off). Now put the mask over your face and say the syllables /pi pi pi pi pi/, 5 times, along with the metronome. Go ahead. (Turn the metronome on for about 10 seconds. Turn metronome off.) Good! Try it again. (Same thing, 10 seconds.) Good!

(6) More specifically, you will start to say the syllables /pi pi pi pi pi/ when the experimenter tells you to start, like this: Ready … tick … now … tick … begin … tick …/pi pi pi pi pi/.Listen to me again: Ready … tick … now … tick … begin … tick … /pi pi pi pi pi/. Okay, now the experimenter will turn the real metronome on, and you will practice this several times, until you’ve got the entrance just right. Good!

(7) Now, there are just two more things you have to know about the measurements. The first regards how loud you will say the /pi pi pi/, /pae pae pae/, and /pa pa pa/ syllables. First try saying the syllables just above threshold. This means that you should say the syllables /pi pi pi pi pi/ barely above the level that you think is the quietest possible. For example: “/pi pi pi pi pi/.”

(8) Now try saying the syllables just below threshold. This means that you should say the syllables a little quieter than your softest possible, with voice. Essentially, this amounts to quiet whispering: “/pi pi pi pi pi/” (subthreshold).

(9)Now try saying the syllables just at threshold-as quietly as possible. This means that you should say the syllables as quietly as you can, and still get voice. For example "/pi pi pi pi pi/" (at threshold).
(10) When we collect the data you will repeat /pi/ five and seven times at this loudness level and speed, but at different pitches. You will do the same with /pae/ and /pa/. The pitches will include one conversational pitch (experimenter provides), one high pitch (experimenter provides), and one low pitch (experimenter provides).
(11) Now let's try saying these syllables at the different pitches at your voice threshold. First let's do the conversational pitch just at threshold, as quietly as possible. (Experimenter gives pitch and says: Ready … tick … now … tick …begin…") Good!
(12) Now let's do the same thing at the high pitch just at threshold, as quietly as possible. (Experimenter gives pitch and says: ready…tick…now…tick…begin…) Good!
(13) Now let's do the same thing at the low pitch just at threshold, as quietly as possible. (Experimenter gives pitch and says: Ready … tick … now … tick …begin …) Good!
(14) If you would like we can continue to practice this before we begin to collect data. Would you like more practice?

Instructions for data collection:
(1) Place the face mask over your nose and mouth creating an airtight seal and position the plastic tube so that it is 1 to 2 mm behind your front teeth [examiner checks placement]
(2) Now, just like we practiced, say the syllable /pi/ 5 times with the metronome, at threshold loudness, and at this pitch [examiner plays pitch]. I will start the metronome and play the pitch. When I tell you, begin. I will tell you when to stop. Good! [examiner saves data]
(3) The same instructions are given for collection of all three pitches, all three vowels, and both syllable samples.

Disinfection: After each participant, the following disinfecting process was completed, as described in the KayPENTAX PAS Model 6600 manual:
(1) Remove airflow tubes from airflow head and set aside
(2) Wash PAS components (mask, airflow head, and airflow head-to-mask coupler) in warm water/liquid detergent to remove spit/spitum, coughed up material, etc., that could be on the mask or pneumotach mesh.
(3) Immerse the pneumotach in the either the hospital disinfectant Dakins (0.5% solution) or standard household bleach (diluted to a 20:1 ratio for a 0.25% solution or 10:1 for a 0.5% solution) for 5 to 10 minutes.
(4) Rinse well with water and air dry on a rack

APPENDIX M

Data Collection Sheets:

Participant Identification Number: ______

Sheet 1a: Peak measurements and average SPL for 5 and 7 syllables using /i/

i-5 syllable								Average SPL
Low	5_L_P1i	5_L_P2i	5_L_P3i	5_L_P4i	5_L_P5i			i-5 syllable low
Modal	5_M_P1i	5_M_P2i	5_M_P3i	5_M_P4i	5_M_P5i			i-5 syllable modal
High	5_H_P1i	5_H_P2i	5_H_P3i	5_H_P4i	5_H_P5i			i-5 syllable high
i-7 syllable								
Low	7_L_P1i	7_L_P2i	7_L_P3i	7_L_P4i	7_L_P5i	7_L_P6i	7_L_P7i	i-7 syllable low
Modal	7_M_P1i	7_M_P2i	7_M_P3i	7_M_P4i	7_M_P5i	7_M_P6i	7_M_P7i	i-7 syllable modal
High	7_H_P1i	7_H_P2i	7_H_P3i	7_H_P4i	7_H_P5i	7_H_P6i	7_H_P7i	i-7 syllable high

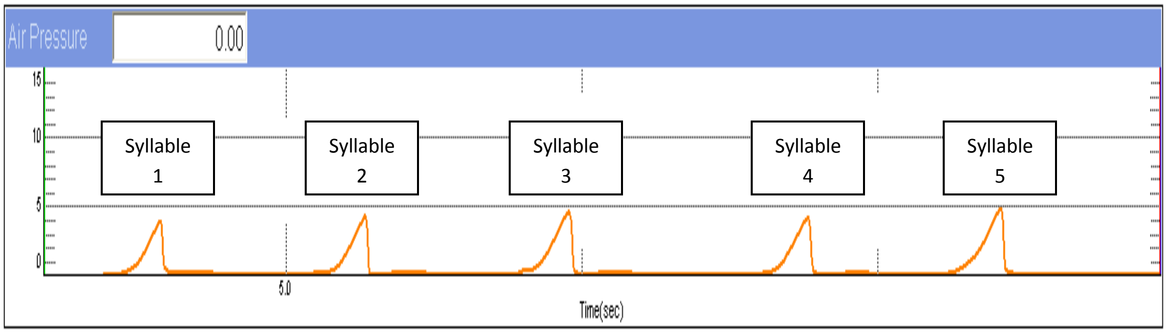
Sheet 1b: Airflow measurements at above peaks for 5 and 7 syllables using /i/

i-5 syllable							
Low	Peak 1	Peak 2	Peak 3	Peak 4	Peak 5		
Modal	Peak 1	Peak 2	Peak 3	Peak 4	Peak 5		
High	Peak 1	Peak 2	Peak 3	Peak 4	Peak 5		
i-7 syllable							
Low	Peak 1	Peak 2	Peak 3	Peak 4	Peak 5	Peak 6	Peak 7
Modal	Peak 1	Peak 2	Peak 3	Peak 4	Peak 5	Peak 6	Peak 7
High	Peak 1	Peak 2	Peak 3	Peak 4	Peak 5	Peak 6	Peak 7

APPENDIX N

PTP Calculation Methods

Figure 4: Example of 5 syllable sample of /pi/



The maximum air pressure of each peak is determined by selecting the peak of interest, zooming in, and then moving the cursor to find the maximum peak value for each syllable. The air pressure is displayed in the box in the upper left hand corner of the PAS software's Air Pressure display (see Figure 1).

The PTP was calculated by first finding the average of syllable one and two, syllable two and three, syllable three and four, and syllable four and five.

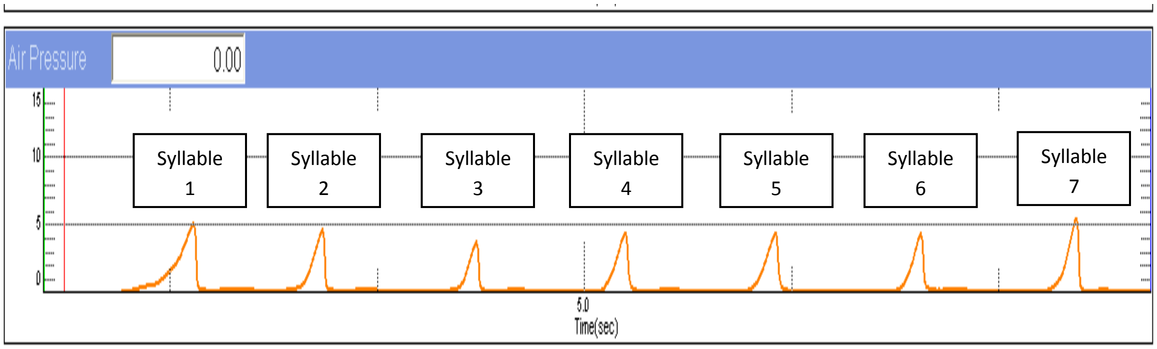
$$\frac{peak_{syllable\ \ 1} + peak_{syllable\ \ 2}}{2} = P1.P2 \qquad \frac{peak_{syllable\ \ 2} + peak_{syllable\ \ 3}}{2} = P2.P3$$

$$\frac{peak_{syllable\ \ 3} + peak_{syllable\ \ 4}}{2} = P3.P4 \qquad \frac{peak_{syllab\ le\ 4} + peak_{syllable\ \ 5}}{2} = P4.P5$$

The average of the averages was then calculated to obtain a final value of PTP.

$$\frac{P2.P3 + P3.P4}{2} = 2PA$$

Figure 5: Example of 7 syllable sample of /pi/



The PTP was calculated by first finding the average of syllable one and two, syllable two and three, syllable three and four, syllable four and five, syllable five and six, and syllable six and seven.

$$\frac{peak_{syllable\ \ 1} + peak_{syllable\ \ 2}}{2} = P1.P2 \qquad \frac{peak_{syllable\ \ 2} + peak_{syllable\ \ 3}}{2} = P2.P3$$

$$\frac{peak_{syllable\ \ 3} + peak_{syllable\ \ 4}}{2} = P3.P4 \qquad \frac{peak_{syllable\ \ 4} + peak_{syllable\ \ 5}}{2} = P4.P5$$

$$\frac{peak_{syllable\ \ 5} + peak_{syllable\ \ 6}}{2} = P5.P6 \qquad \frac{peak_{syllable\ \ 6} + peak_{syllable\ \ 7}}{2} = P6.P7$$

The average of the averages was then calculated to obtain a final value of PTP.

$$\frac{P3.P4 + P4.P5}{2} = 2PA$$

APPENDIX O

Average Recording Forms

i-5 syll.	Avg. P1 & P2	Avg. P2 & P3	Avg. P3 & P4	Avg. P4 & P5			
Low	5LP1.P2i	5LP2.P3i	5LP3.P4i	5LP4.P5i	5L2PAi		
Modal	5MP1.P2i	5MP2.P3i	5MP3.P4i	5MP4.P5i	5M2PAi		
High	5HP1.P2i	5HP2.P3i	5HP3.P4i	5HP4.P5i	5H2PAi		
i-7 syll.	Avg. P1 & P2	Avg. P2 & P3	Avg. P3 & P4	Avg. P4 & P5	Avg. P5 & P6	Avg. P6 & P7	
Low	7LP1.P2i	7LP2.P3i	7LP3.P4i	7LP4.P5i	7LP5.P6i	7LP6.P7i	7L2PAi
Modal	7MP1.P2i	7MP2.P3i	7MP3.P4i	7MP4.P5i	7MP5.P6i	7MP6.P7i	7M2PAi
High	7HP1.P2i	7HP2.P3i	7HP3.P4i	7HP4.P5i	7HP5.P6i	7HP6.P7i	7H2PAi

APPENDIX P

5 Syllable Train

P.	1	2	3	4	5	6	7	8	9	10
T. (°F)	72	74.7	74	75.9	74.3	75.2	75	74.1	73.9	74.9
H. (%)	46	53	47	65	53	52	52	47	55	54
Low P1.P2	4.43	4.95	3.85	5.28	5.45	4.38	7.48	3.14	5.3	4.94
Low 2PA	4.17	4.18	3.29	4.76	6.09	4.7	5.71	3.65	4.89	5.68
Low P4.P5	4.61	5.52	3.41	4.08	6.76	4.6	6.77	3.94	5.44	4.61
Modal P1.P2	5.6	4.8	4.64	3.57	5.68	3.42	7.97	2.54	4.96	4.58
Modal 2PA	4.94	4.21	3.45	4.37	6.38	4.0	6.67	2.93	4.83	4.59
Modal P4.P5	4.79	4.77	3.41	4.31	6.06	4.54	6.43	3.45	5.07	4.31
High P1.P2	6.24	6.12	13.98	10.09	7.44	8.49	9.23	5.26	10.95	7.96
High 2PA	9.31	6.39	14.19	10.67	11.35	11.96	10.55	6.93	13.48	9.11
High P4.P5	9.45	6.73	14.42	9.85	9.91	12.28	11.5	5.91	12.1	7.89

Note: P = Participant; T = Temperature; H= Humidity; Low P1.P2 = Low pitch, average of Peak 1 and Peak 2; Low 2PA = Low pitch, average of Peak 2 and Peak 3 averaged with average of Peak 3 and Peak 4; Low P4.P5 = Low pitch, average of Peak 4 and Peak 5

7 Syllable Train

P.	1	2	3	4	5	6	7	8	9	10
T. (°F)	72	74.7	74	75.9	74.3	75.2	75	74.1	73.9	74.9
H. (%)	46	53	47	65	53	52	52	47	55	54
Low P1.P2	4.38	5.21	3.12	6.31	3.01	6.06	5.68	3.11	3.81	4.82
Low 2PA	5.14	4.31	3.1	5.11	4.01	4.93	5.67	3.17	3.49	6.04
Low P6.P7	5.17	5.21	3.05	5.32	4.35	4.78	6.22	4.55	3.86	5.27
Modal P1.P2	4.17	6.29	3.76	5.59	5.3	3.34	7.38	3.37	3.4	3.68
Modal 2PA	4.35	5.3	3.34	5.38	3.03	3.36	4.32	3.99	2.57	5.37
Modal P6.P7	4.72	5.19	3.08	6.11	4.63	3.79	4.58	4.4	2.94	5.18
High P1.P2	4.54	6.37	12.92	10.99	7.25	6.1	12.77	5.28	10.23	5.82
High 2PA	7.43	6.56	12.57	11.84	7.82	7.64	12.9	6.41	14.93	7.98
High P6.P7	9.4	5.51	11.8	10.03	9.88	8.03	12.26	6.01	15.19	6.6

Note: P = Participant; T = Temperature; H= Humidity; Low P1.P2 = Low pitch, average of Peak 1 and Peak 2; Low 2PA = Low pitch, average of Peak 3 and Peak 4 averaged with average of Peak 4 and Peak 5; Low P6.P7 = Low pitch, average of Peak 6 and Peak 7