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The careers of professional voice users depend a great deal on the quality and condition of their voices. Voice students in a university are training their voices for professional use. Vocal health and hygiene are of utmost importance. Often acoustic and aerodynamic measures of the voice are not obtained until after the student experiences vocal difficulties not due directly to technical issues. A record of the student's voice obtained when healthy is useful in evaluating the voice when it is in distress. This paper discusses the advantages to collecting and recording baseline vocal measurements while a student is studying voice. It also explains the kinds of vocal parameters which are most helpful in the evaluation, the instrumentation used to obtain the measurements, as well as the procedures and protocol used in obtaining them. Strategies for using the information and for setting up a system in a university to collect and record students' baseline measurements are also included.

A SINGER'S POINT OF REFERENCE: BASELINE VOCAL MEASUREMENTS DURING STUDY AT A UNIVERSITY

by

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CHAPTER I

INTRODUCTION AND RATIONALE

University-level voice study is a combination of technical advancement, artistic growth and physiological maturation of the voice. In a typical program, students receive weekly applied instruction to hone their technique and are guided by an applied teacher. As they begin formal training, students at a conservatory or university must also learn about the effects of health, daily habits, and environment on their vocal instrument.

Illness, both in terms of general health and that specific to the voice itself is not uncommon among university students. Because this is often the time when students are first becoming aware of their vocal health it is imperative that they have information available to them to help them cope with these kinds of troubles. A record of the student's voice obtained when healthy, that is a baseline assessment of the voice, is useful in evaluating the voice when it is in distress. Often aerodynamic and acoustic measures of the voice as well as overall vocal evaluations are not obtained until after the student experiences vocal difficulties not due directly to technical issues. There are many advantages to collecting and recording baseline vocal measurements while a student is studying voice and it is the purpose of this document to discuss these advantages, as well as explain the kinds of vocal parameters which are most helpful in the evaluation, the instrumentation used to obtain the measurements and the procedures and protocol used in obtaining them. Additionally, suggestions are provided for setting up a system in a university to collect and record students' baseline measurements.

Often the applied voice teacher is the primary source of information for the student. It is the responsibility of the voice teacher to help guide the student through the learning process, and it is often within the voice studio where vocal problems are first detected. When a teacher feels that the student's vocal problem is one that cannot be resolved within the studio, that is, that the problem is perhaps an organic issue involving vocal function or other health issues, he or she will often refer the student to a laryngologist, speech language pathologist (SLP), or voice clinic for an examination and diagnosis. The kinds of symptoms a teacher might notice include an uncharacteristic breathiness or noise in the sound, chronic hoarseness, general illness, or a teacher may simply perceive that the student is having major difficulties with basic phonation and vocal function. Generally when a teacher sends an otherwise healthy student to specialist, it is because he or she has ruled out technical reasons for abnormal vocal production and feels that in order to proceed with vocal training, the student's vocal health must be evaluated by a medical professional.

The world of voice science and research is ever evolving and expanding. In the field of speech language pathology the body of information about voice therapy options and effectiveness is also growing rapidly. The infiltration of voice science information and speech language methodology into the voice studio is occurring more and more often. This is due to the fact that voice teachers are becoming increasingly more educated in these areas, there are an increasing number of voice clinics in the U.S., and there has been major growth of the new field of vocology within the past ten years. As all of the above happens, voice teachers need to know and understand options available to them and to their students so that they can responsibly advise students.

Historically, many singing teachers have been unfamiliar with current practices and the variety of vocal parameters that are analyzed at a voice clinic. Clinical language and evaluation tools are often foreign to singing teachers and such teaching professionals may not know how to interpret results of an evaluation by an SLP or laryngologist. And although speech language pathology books have been published with this information, they are often not directed at singing teachers and may not include information that bridges the gap between the speech pathologist and the average singing teacher. In order to best serve students, it is imperative that teachers learn and understand the various standard measurements evaluated by clinicians so that they can assist students in understanding the assessments made by an SLP or laryngologist at a voice clinic.

The current trend in voice medicine is for laryngologists, SLPs, and a singing specialist to work together in a voice clinic. Thus, when a student makes an appointment with the laryngologist, he or she may also be evaluated by an SLP and possibly by a singing specialist. When appropriate, vocal therapy with an SLP and/or a singing specialist may be necessary for rehabilitation. The bottom line is that when a student goes to a voice clinic, his or her voice will be evaluated. Vocal measurements will be taken.

A student may also be examined with the laryngoscope. If a student has never had vocal problems before, this is usually the first time he or she has ever been examined by a laryngologist or evaluated by an SLP. If the clinician and/or medical doctor had the student's baseline measurements, that is, measurements taken when the student was in good health, the examiner would be able to compare these measurements to those when the student was under vocal duress. This would make the evaluation more specific and informed and allow the examiner to more effectively evaluate the student's vocal problem. Yolanda Heman-Ackah et al. speak to this in an article in the *Journal of Singing* stating that

> "Singing teachers should be familiar with the value of consultation with an expert laryngologist not only during illness and crises, but also prior to training, for evaluation, establishing an individual's "normal" baseline. . . . Anyone who relies on one's voice for his or her profession should have a baseline laryngeal function and videostroboscopic examination with a laryngologist when the voice is functioning optimally and without difficulty" (2008b, 53).

In the case that a vocally ill student does not have his or her own baseline measurements, the clinician or doctor usually compares the student's measurements to the published normative values. Normative data is data collected by scientists from the general public. Doctors and clinicians often assess patients' vocal health by comparing his or her values to normative values. Although measurements of vocal parameters can be compared to normative values, these values are often less useful than expected. There is considerable variability among normal subjects for many of these parameters, and it is often difficult to determine truly abnormal values. This is especially true amongst a population of professional voice users, such as singers, who may be sensitive to even the smallest degree of change from what they normally feel. Additionally, there have been studies which show that normative values for trained singers vary from the normative values of non-singers and there has been speculation for years in the voice science community that trained singers' normative values may considerably differ from that of the general public (Awan 2001, 43-44). This again reinforces the need for personal baseline measurements for comparative purposes.

A university or college setting is the ideal place to set up a program for evaluating baseline vocal measurements. The students are mainly future professional singers and future singing teachers. They will be using their voices professionally throughout their lives and may very well run into vocal problems at some point during their careers. Exposing students to these evaluations educates them to the importance of vocal health, as well as the variety of different ways the voice can be assessed. Additionally, universities generally have a faculty of singing teachers who are curious and excited about vocal science and vocal health. Funding for these kinds of programs may be available at a university, especially when faculty members work unanimously to promote the program's value. Moreover, in a university, an SLP department may be available to the voice faculty for consultation or as a partner in the program.

This paper will discuss the importance of baseline vocal measurements for singers enrolled in a college-level voice study program and to emphasize the importance of such measurements to vocal health and longevity. This paper will identify and define the most common and useful measurement parameters for teachers, SLPs and singers. It will define and explain basic vocal measurements as well as procedures and protocol for taking the measurements in language and format understandable and usable by a voice teacher who may not have extensive clinical training. The paper will also briefly discuss the appropriateness of comparisons made between singers' vocal parameters and normative values. This paper will outline a system for taking baseline vocal measurements in universities with or without the assistance of an SLP department. In an ideal situation, the SLP department would work closely with the voice department and take responsibility for carrying out individual voice assessments for the students. If an SLP department is involved, the voice teachers need to at least be aware of what collected data or measurements are being taken and what they mean. This paper would serve to provide them with this information, as well as give an idea as to what kinds of procedures are involved. If there is no SLP department available, the voice teachers might devise a system to take the measurements themselves in a way that is effective and usable by professional clinicians. Thus the measurements must be reliable and collected with equipment that is familiar to voice clinicians. Procedures and protocols outlined in this paper give the voice teach some basic knowledge of how to take the measurements and could serve as a starting point from which a teacher could begin to develop a system of collection and recording specific to his or her institution and resources.

Of course, SLPs and voice teachers are not totally reliant on numerical values and machines to evaluate vocal production. They are also observing vocal, postural, and other behaviors and use all this information to completely evaluate the student/patient's voice. It is not the purpose of this paper to suggest that this kind of information should be ignored. Rather, it suggests that it be used in conjunction with the values obtained with instrumentation. If there are some instrumental values that can be recorded, those values will be of use in comparisons between evaluators. Numerical data are not subject to human judgment and are objective measures of vocal function. In this way, the SLP and the voice teacher might look at the same measurements, listen to and observe the student/patient, and potentially reach conclusions based on all information available.

Baseline vocal measurements involve a variety of vocal parameters that SLPs and laryngologists use to evaluate the voice. These include aerodynamic as well as acoustic parameters. Because any system that is implemented in a university setting must be time- and cost-effective, it is necessary to narrow the set of measurements to a number that is manageable within economic and time constraints. This paper will address several important acoustic and aerodynamic parameters that are useful in evaluating vocal function that can be effectively measured by a voice teacher and will include suggestions for cost-effective instrumentation for collection and measurement.

Normative Values

In voice science there has been extensive study into what constitutes "normal" in terms of vocal parameters. Unfortunately, because there is no standardization of the measurement of vocal parameters, comparisons between studies and compilations of data are difficult. There are a few published resources, however, which compile the normative data, making it somewhat easier navigate. These published normative data ("norms") are generally accepted in the clinical and research worlds (Radionoff 1996, 26). *Clinical Measurement of Speech and Voice* by Ronald Baken and Robert Orlikoff (2000) *Clinical Examination of Voice* by Minoru Hirano (1981) and *Readings in Clinical Spectrography of Speech* by Ronald Baken and Raymond Daniloff, eds. (1991) are three major sources for normative data. Additionally, there are several speech pathology books which further reduce the normative data into tables and charts aimed to clarify the vast body of research so that useful information is readily available to clinicians and doctors. These books include Raymond Coltan and Janina Casper's *Understanding Voice Problems: A Physiological Perspective for Diagnosis and Treatment* (1996), Shaheen Awan's *The Voice Diagnostic Protocol: A Practical Guide to the Diagnosis of Voice Disorders* (2001), and Moya Andrews' *Manual of Voice Treatment: Pediatrics Through Geriatrics,* 3rd Edition (2006).

The aforementioned resources contain valuable data but are somewhat limited in that the data were gathered from the general population, that is from non-singers, and that the data usually refer to speech production only. Differences in trained singers' respiratory capacity as compared to non-trained singers have been found in several studies (Gould 1977, Gould and Okamura 1974). Ana Mendes et al. (2003) found that the maximum phonational frequency range (MPFR) of singers was significantly altered due to vocal training and further demonstrated that the effects of vocal training on MFPR could been seen after four semesters of college vocal training. A study by W.S. Brown et al. (1991) demonstrated that the speaking fundamental frequencies (SFF) of professional sopranos and tenors were significantly different from those of age-matched non-singers and that "although the nonsinger [*sic*] SFF levels varied significantly as a function of age, those for the professional singers did not" (Brown et al. 1991, 310). Additionally, Sharon Radionoff (1996) has shown that there is indeed a need for normative data for many vocal parameters to be collected specifically from trained singers. In her study, Radionoff found that trained singers indeed have different normative values for acoustic, phonatory and respiratory parameters than non-trained singers or the general public and reports that the study showed that for singers, "the current norms for 67 measures [are] in need of modification" (1996, i).

Along these lines, because singers are often extremely aware of their body and instrument, even the smallest change in vocal production can alert them to a problem with the mechanism. Their heightened sensitivity may alert them to a problem that is in initial stages and not yet outside of published normative values. They may also become aware of an issue that is not yet audible to listeners. Rather than relying exclusively on normative data that may or may not apply to a trained singer, it seems more apt to use personal baseline measures for comparison along with normative data. Baseline measurements for individual singers could possibly allow for even the smallest changes in the voice to be detected.

Although it may not be ideal to use normative data for comparisons with singers, it is inevitable that some may be made by clinicians and doctors. In order to give teachers an idea of what kinds of values are considered “normal” in the general public, tables of normative values for several different vocal parameters are available in appendix A of this paper. These tables are taken and adapted from the resources mentioned above and are a compilation of many years of vocal parameter analysis and study by many different researchers.

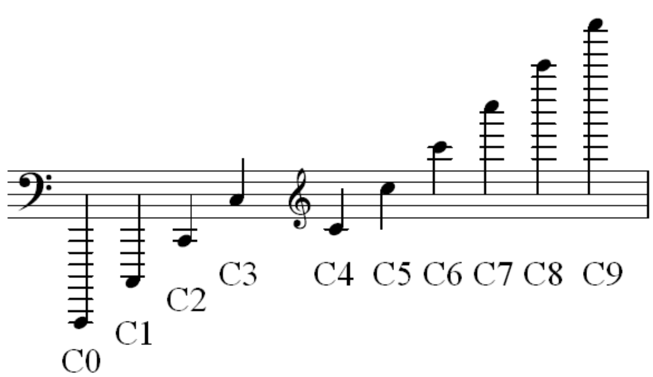
The International Phonetic Alphabet

Throughout this document phonetic sounds produced by the voice will be designated by the symbols of the International Phonetic Alphabet (IPA). These symbols will appear between forward slashes (/ /), as is traditional in the speech-language pathology and scientific literature. A table of some of the sounds of the IPA is located in appendix B.

Pitch Notation

For the purposes of this paper pitches will be referred to using the method of the USA Standards Association. See figure 1 below.

Figure 1. Pitch Notation



CHAPTER II

BASELINE EVALUATIONS

Aspects of clinical vocal measurements that can be particularly daunting to singing teachers include vocal measurements, assessment, and instrumentation. Singing teachers may be intimidated by computer hardware and software and the task of interpreting graphs and numeric values may keep some from attempting to understand the process and results. What happens, then, when a vocally distressed student comes back to the teacher after a clinical evaluation with measurements, diagnoses, and other information from the laryngologist or SLP? If the singing teacher is not familiar with the kinds of parameters measured or the data reported he or she is at a considerable loss as to what is happening physiologically with students. Even the most basic information that instrumentation can provide can be very helpful to any singing teacher who then can assist the student in understanding the evaluative information.

Although it is beyond the scope of this paper to give exhaustive information concerning past studies that evaluate vocal parameters, an effort has been made to inform the reader generally of how informative the parameters are about the voice. There are various outside factors which can influence the results of any clinical assessment and it is never possible to make conclusions about a voice based on a single parameter. It is imperative that all observations are evaluated together in order to assess the vocal mechanism. No single parameter is all-telling or all encompassing. In fact, often the parameters are not as reliable as one might assume and may vary depending on a host of factors including fundamental frequency, gender, and level of training. In conjunction with other baseline measurements, however, individual parameters can help to paint a general picture of the vocal mechanism.

This chapter defines and discusses aerodynamic measurements, acoustic measurements, and videostroboscopy. An effort has been made to briefly define terms common in the clinical world as well as review some of the basic physics responsible for vocal production. This will serve to aid in the understanding of the measurements and their importance.

Aerodynamics: Terms and Definitions

In order to effectively discuss the aerodynamic measurements recommended for evaluation, definitions of important terms are needed. Aerodynamic measurements of voice production include airflow, pressure, and the relationships between the two during phonation (Benninger 2006, 91).

Air moves through the vocal folds from an area of high pressure to an area of low pressure. This is called **flow** (Stemple 1995, 133). When the flow of air is interrupted by the vocal folds adducting, this creates **resistance**. Resistance, then, is an obstacle to flow (Stemple 1995, 133). **Pressure** is the amount of force needed to overcome the resistance of the vocal folds. Joseph Stemple, a well-known researcher, clinician, and professor in the SLP world states in his book, *Clinical Voice Pathology* that "in voice production, respiratory (subglottal) pressure acts as a force building up below the adducted vocal folds, rising until the folds open and are set into oscillation [vibration]" (Stemple 1995, 137). Thus, aerodynamic measures look at how the air is moving through the larynx, how the vocal fold resistance affects the air flow, and vice versa. The sound heard when someone sings or speaks is the vibration of the vocal folds, and this vibration is motivated by the flow of air through the glottis. Depending on the amount of resistance in the vocal folds, different sound qualities are generated. If there is a lot of resistance, one is likely to hear a pressed sound. If there is too little resistance, a breathy sound would likely result.

When we measure flow we look at **flow volume** and **flow rate**. According to Stemple, flow "volume is the total amount of flow that is used during a certain production, such as maximum phonation time." (Stemple 1995, 136). It is usually measured in liters (L) or milliliters (ml). Flow rate is defined by as the amount of flow divided by the amount of time. This would be measured in milliliters per second (ml/s) or liters per second (L/s) (Stemple 1995, 137).

Aerodynamic Parameters

The aerodynamic parameters this paper recommends for baseline measurements are maximum phonation time (MPT), vital capacity (VC), and s/z ratio. These are all widely used by SLPs. The remainder of this section discusses and defines these parameters.

Maximum Phonation Time

Maximum phonation time (MPT) is one of the simplest and most widely used aerodynamic parameters of voicing (Benninger 2006, 91). It measures the ability to prolong a vowel sound and can be an indicator of lung capacity as well as glottal efficiency (Awan 2001, 126). Thus, if overly abnormal results are recorded, it may be possible that either the subject has respiratory dysfunction or that there is incomplete glottal closure. Maximum phonation time is measured in seconds (s) and consists of holding the vowel /a/ for as long as possible. The vowel is produced at a comfortable pitch and loudness and ideally after a deep breath (Benninger 2006, 91).

Studies have shown that men produce significantly longer MPTs than women (Ptacek and Sander 1963). A study by Yanagihara, Koike, and von Leden (1966) suggests that this may be due to the amount of lung capacity available for phonation. Males generally have larger lung capacity, and therefore longer MPTs. MPTs of healthy individuals have been measured from as low as 6.3 seconds (in the youngest and oldest subjects) to 69.5 seconds among healthy young adults (Baken and Orlikoff 2000, 371-372). Fundamental frequency can also affect MPT and there have not been any standard procedures imposed as to number of trials for evaluating MPT. Several studies have been conducted which indicate that more than three trials are necessary for evaluating to the true MPT. Studies have also shown that coaching and encouragement may increase an individual's MPT (Awan 2001, 127-130; Baken and Orlikoff 2000, 370). One must be careful when looking at normative data to understand that there is variability in procedures across different studies. This reinforces the need for strict record keeping when taking measurements, making sure to note the length of time, number of trials, vowel, approximate or exact fundamental frequency of the utterance, and whether or not coaching and encouragement were used. With this information recorded for baseline measurements later comparisons will be more informative.

According to Baken and Orlikoff, "MPT alone cannot serve to distinguish inefficient glottal valving from reduced [air] volume availability or from difficulty in sustaining adequate driving pressure – problems that may well have entirely different pathological bases" (2000, 369). Isshiki, Okamura, and Morimoto (1967) found that MPT measurement "permits only an incomplete evaluation of the glottal condition" and is "of limited clinical use as a vocal function test" (Baken and Orlikoff 2000, 369). Nevertheless, because it can reveal possible problems with breath flow and/or valving and due to its frequent use by SLPs for vocal evaluation and ease of measurement, it is recommended that this measurement be included in baseline measurement evaluations. Since a vocally distressed student is very likely to have this parameter measured, it is important to have a record of his or her baseline measurement.

Vital Capacity

Vital capacity (VC) is defined by Awan as the "maximum amount of air that can be exhaled after maximum inhalation" (2001, 124). In his book, *Principles of Voice Production,* Ingo Titze, director and founder of the National Center for Voice and Speech, defines VC as "the maximum volume of air that can be exchanged by the lungs with the outside; it includes the expiratory reserve volume, tidal volume and inspiratory reserved volume" (2000, 382). It is usually measured in liters or milliliters. It basically indicates the respiratory ability of an individual and shows the amount of air that is available for phonation (Awan 2001, 124). Awan states that "although only a portion of VC is used for most speaking situations (Hixon, Goldman, and Mead 1973), it is important to assess the maximum capabilities of the speech system to determine the system's ability to function under stress (e.g. maximum exhalation, maximum phonation)" (Awan 2001, 124). VC is most commonly measured using a hand-held spirometer (Awan 2001, 124).

Vital capacity differs by gender and height and also tends to decrease with age with averages of 3500ml in ages 18-30 to 2000ml in ages 70-79 (Awan 2001, 127). Usually adult men have a VC of 4000-5000 ml and adult women's VCs range from 3000 to 4000 ml.

S/Z Ratio

Both glottal closure and respiratory ability play a role in determining the MPT. Measuring the MPT does not differentiate between deficits in respiratory function versus laryngeal function and in the 1970s the s/z ratio was introduced as an additional parameter to try to detect glottal inefficiency. (Colton and Casper 1996, 229). In *Understanding Voice Problems: A Physiological Perspective for Diagnosis and Treatment,* Colton and Casper state that "the underlying theoretical construct suggests that individuals with normal larynges should be able to sustain vocalization (i.e., /z/) for a period of time equal to that of sustained expiratory airflow without vocalization (i.e., /s/), resulting in a ratio that approximates 1" (1996, 229). If there is abnormality present in larynges, the ratio would then be greater than one, as the subject would be able to sustain the /s/ longer than the /z/ indicating a possible problem with glottal closure.

One of the most robust studies which indicated the usefulness of the s/z ratio was a study by Eckel and Boone in 1981. This study involved dysphonic adults with and without laryngeal pathology. Ninety-five percent of subjects with vocal fold margin pathology had s/z ratios greater than 1.4, while the control group and patients with dysphonia but without pathology approximated 1.0. In the study, Eckel and Boone concluded:

> When an additive lesion has developed along the glottal margin, vocal fold approximation is less efficient. This decrement in efficiency appears to result in a decrease in glottal resistance, increasing airflow and resulting in shortened phonation time. Alone or in conjunction with other measures, the s/z ratio appears an excellent indicator of poor laryngeal function as a result of glottal margin lesions (1981, 149).

Acoustics: Terms and Definitions

Skilled listeners can infer a great deal from the sound of the voice. Although nothing can be as discriminating as the human ear, equipment can provide information that can be quantified and studied and is a fairly reliable way to have a record of the voice at a particular time. And because there can be a large range of variance amongst individuals due to gender, age, voice use, and general health, acoustic analysis is valuable in that it can test vocal production in individuals throughout time and then the evaluator can make comparisons of the voice over time (Benninger, Jacobson, and Johnson 1994, 142). Our ears may not be able to accurately recall the exact sound of a voice from the past, but instruments can at least record certain qualities of the voice. Acoustic measures are non-invasive and provide a great deal of information about vocal function. Information about fundamental frequency, vocal range and intensity, noise in the sound, perturbances in the production of sound and vowel formant structure and strength can all be evaluated, quantified, and studied.

In order to speak about the above acoustic parameters, one must have basic knowledge of acoustics, that is, the science of sound. Sometimes singers and teachers avoid trying to understand this part of the voice because it involves physics and mathematics. These concepts can often seem abstract and disconnected to the art of music and thus are sometimes ignored with the defense that "we don't need to know this to be able to sing." While this may be true for some singers, it is important that teachers of singing are at least familiar with and have a general understanding of acoustic terms and concepts so that they can read and understand the vocal science and pedagogical literature as well as interpret and comprehend information from vocal clinics and SLPs. Additionally, understanding acoustics is imperative to understanding how the resonators work and allows for a fuller understanding of how vocal sounds are "created, enhanced, and perceived" (Ware 1998, 127). In this section the following terms will be briefly defined: sound waves, frequency, amplitude, intensity, and loudness. It is unnecessary for the purposes of this paper to completely restate information about acoustics that is readily available from other sources. For more in-depth study, discussions, and descriptions of acoustics, the reader is directed to the large body of vocal pedagogy literature.

Sound waves

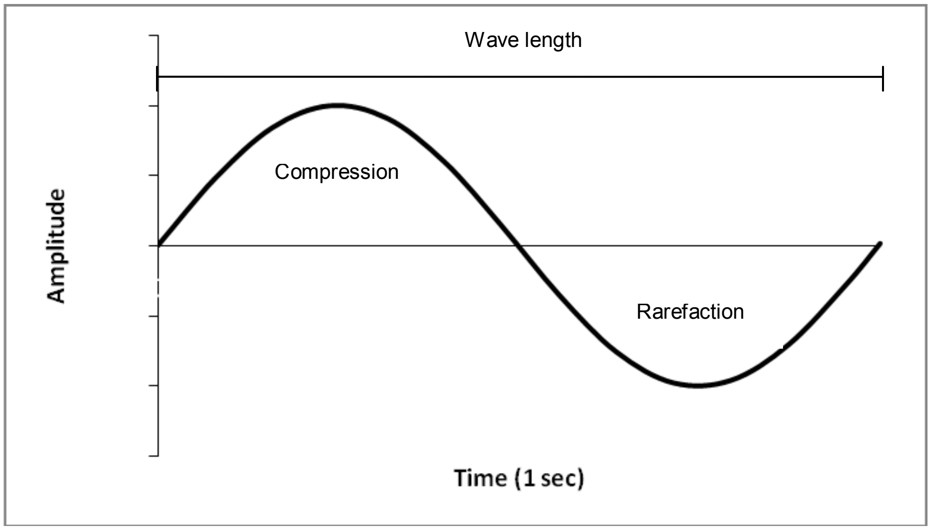
Sound waves are similar to other waves in nature. If a rock is thrown into water, we see waves ripple in the water. Sound waves move like these ripples, except they move from the sound in all directions, rather than just along a surface (Ware 1998, 127-128). In science, sound is defined as "a disturbance of air particles or variation in air pressure that impinges on the auditory mechanism" (Ware 1998, 128). Restated, when we make a sound, waves are generated and expand out from the source of the sound. These waves are disturbances of air particles and when these disturbances reach our ears we hear the sound. The disturbances of waves are caused by the molecules moving closer to each other and then farther apart. It is important to note that the particles do not move very far; the *wave* is what moves. That is, the *disturbance* moves. An example of this concept is "the wave" created in a football stadium. The people only stand up to create "the wave," they do not run around the perimeter of the stadium. Yet, the *wave itself* moves. In sound waves, the particles move a short distance but the wave itself that is the *disturbance*, moves over longer distances.

When particles are disturbed they are displaced and cluster together, creating an area of high density and thus high pressure. This is called **compression**. **Rarefaction** happens when they return to their first position and the density and pressure are lowered.

This keeps happening as long as the source continues to produce the sound. The sound wave moves at about 1,130 feet (345 meters) per second – the speed of sound (Ware 1998, 128).

Graphs are used to map out sound waves and the picture of the wave is called a **wave form**. The wave form for simple harmonic motion is called a **sine wave** or a **sinusoid**. This is why the motion of the wave is sometimes called sinusoidal motion (Ware 1998, 128). Time is plotted on the horizontal axis. Amplitude is plotted on the vertical axis. Amplitude will be described in greater detail below, but it can be understood here as the amount of air molecules that are disturbed and displaced from the original position. Figure 2 shows a simple sine wave. Remember that when air molecules are disturbed and displaced they clustered together and there is an area of compression. On the graph, this is represented by the part of the wave with the greatest amplitude. Thus, when the amplitude is greatest the air molecules are the most displaced (disturbed) and this as an area of compression. Conversely, when the amplitude is at its lowest, that is the molecules are the least displaced and in their original positions, we see rarefaction.

Figure 2. Simple Sine Wave
Wave length = 1 sec; Amplitude = 2dB; Frequency = 1Hz

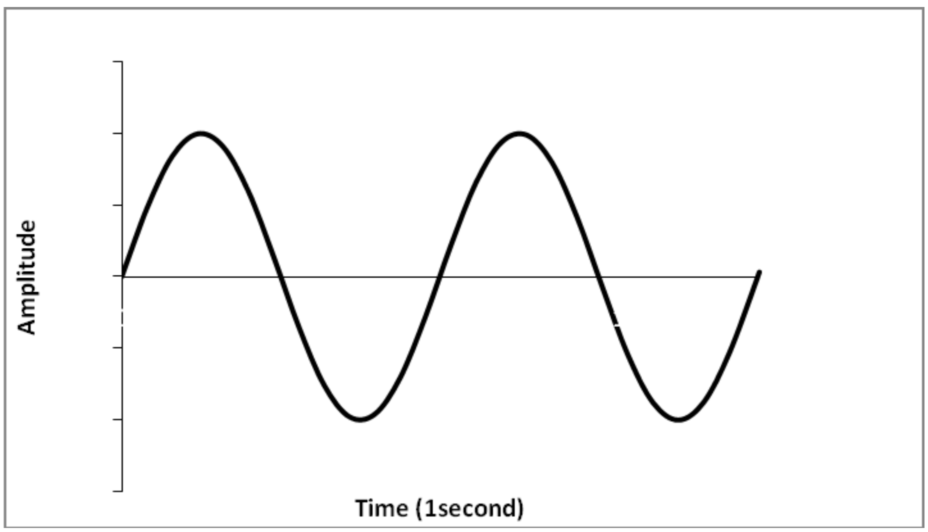


When a sine wave is repeated over and over we hear musical tone. This is sometimes called a vibratory cycle. When sine waves are irregular and have no pattern, we hear noise. As stated by Clifton Ware, "Regular, repeating sound waves in singing are partially determined by vowels, while irregular patterns in speech and singing correspond to the use of consonants" (Ware, 1998, 129).

Frequency

A **period** is the amount of time it takes to complete a cycle of compression and rarefaction (Ware, 1998, 129). A period is measured in seconds. In figure 2 the period is thus 1 second. **Frequency** is the inverse of a period. So, it is measured in cycles *per* second, or hertz (Hz). One hertz equals one cycle per second. In figure 2, the frequency is 1 cycle per second, or 1 Hz. In figure 3 the graph shows two full wave forms, that is, two complete compressions and two complete rarefactions. The frequency is thus 2 cycles per second, or 2 Hz. Comparing the two figures, notice that the lower the frequency the longer the wave length and conversely, the higher the frequency, the shorter the wave length (Ware 1998, 129).

Figure 3. Simple Sine Wave with Frequency of 2Hz
Wave length = 0.5 sec; Amplitude = 2dB



Frequency is perceived by our ears as pitch. Higher pitches correspond to higher frequencies and lower pitches correspond to lower frequencies. Each musical pitch we sing is at a certain frequency. As musicians, we all are familiar with the term "A 440." This is referring to A4, and means that A4 has a frequency of 440 cycles per second, that is, 440 Hz. Table 1 shows the general correlations of frequency to pitch. The octave numbers refers to the USA Standard pitch notational system described in the introduction of this document.

Table 1. Frequency in Hertz
(C4=middle C)

Octave ⇨ Note ⇩	0	1	2	3	4	5	6	7	8
C	16.352	32.703	65.406	130.81	261.63	523.25	1046.5	2093.0	4186.0
C♯/D♭	17.324	34.648	69.296	138.59	277.18	554.37	1108.7	2217.5	4434.9
D	18.354	36.708	73.416	146.83	293.66	587.33	1174.7	2349.3	4698.6
E♭/D♯	19.445	38.891	77.782	155.56	311.13	622.25	1244.5	2489.0	4978.0
E	20.602	41.203	82.407	164.81	329.63	659.26	1318.5	2637.0	5274.0
F	21.827	43.654	87.307	174.61	349.23	698.46	1396.9	2793.8	5587.7
F♯/G♭	23.125	46.249	92.499	185.00	369.99	739.99	1480.0	2960.0	5919.9
G	24.500	48.999	97.999	196.00	392.00	783.99	1568.0	3136.0	6271.9
A♭/G♯	25.957	51.913	103.83	207.65	415.30	830.61	1661.2	3322.4	6644.9
A	27.500	55.000	110.00	220.00	440.00	880.00	1760.0	3520.0	7040.0
B♭/A♯	29.135	58.270	116.54	233.08	466.16	932.33	1864.7	3729.3	7458.6
B	30.868	61.735	123.47	246.94	493.88	987.77	1975.5	3951.1	7902.1

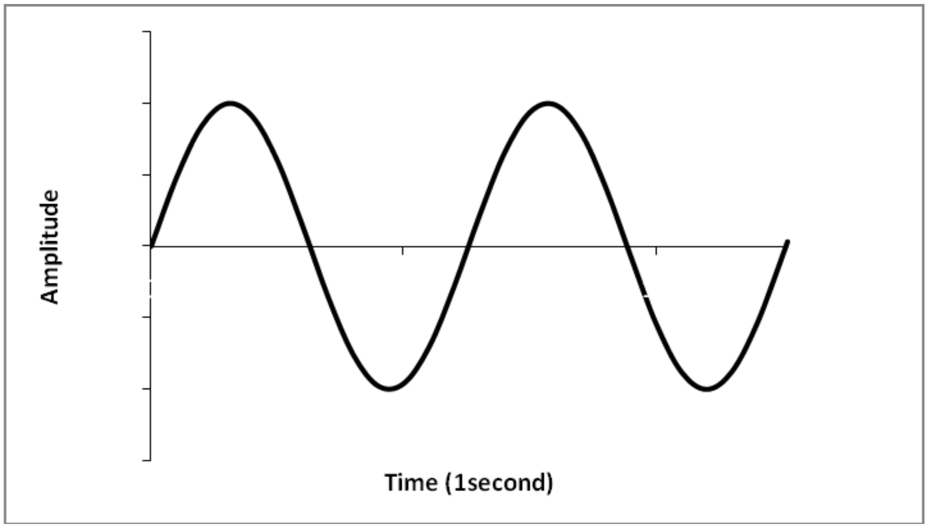
Source: Adapted from Titze 2000, 386-387.

Amplitude

As stated above, amplitude can be described as how far the molecules are displaced when they are disturbed. Two sound waves can have the same frequency but different amplitudes or have different frequencies with the same amplitude. Figures 4 and 5 illustrate this concept. A change in amplitude is detected by our ears and roughly corresponds to what we hear as loudness (Ware 1998, 130). Increasing amplitudes indicate increasing loudness. Decreasing amplitudes indicate decreasing loudness.

Figure 4. Two Sound Waves with the Same Frequency and Differing Amplitudes

a. Frequency = 2Hz; Amplitude = 2dB



b. Frequency = 2Hz; Amplitude = 0.5dB

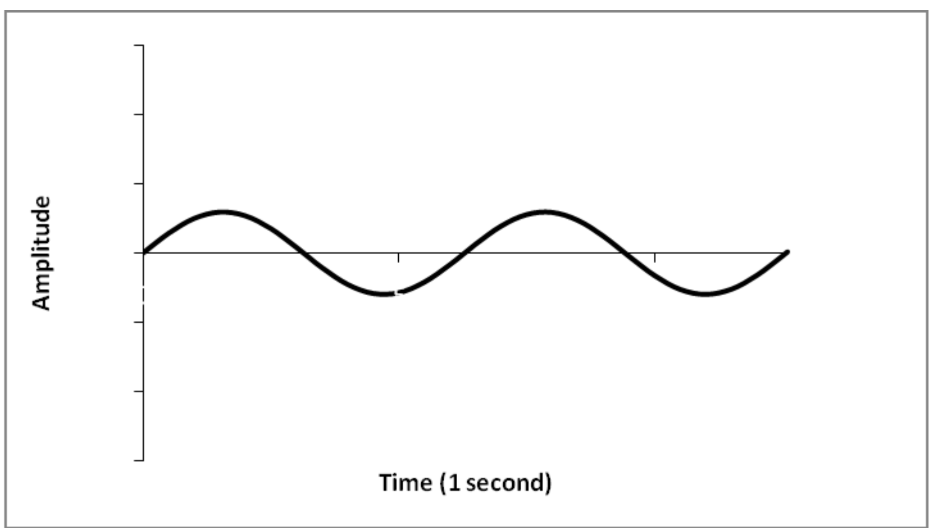
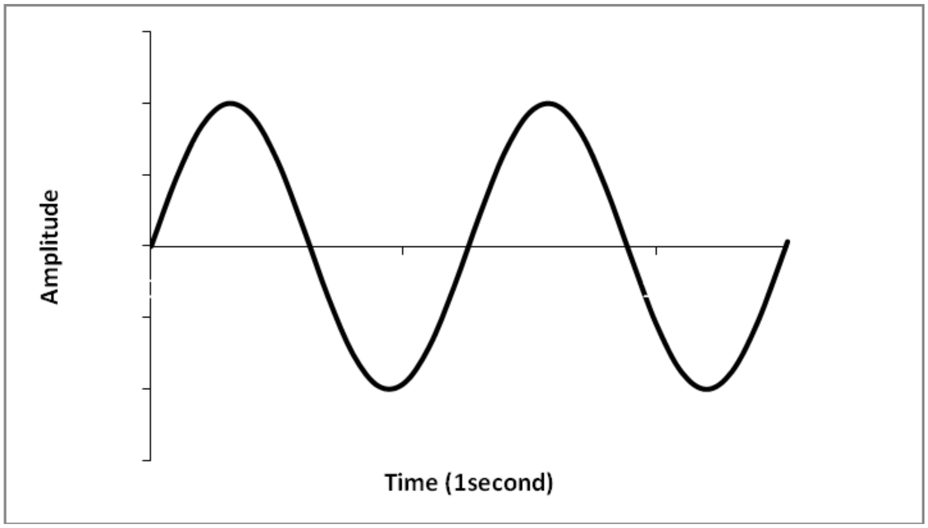
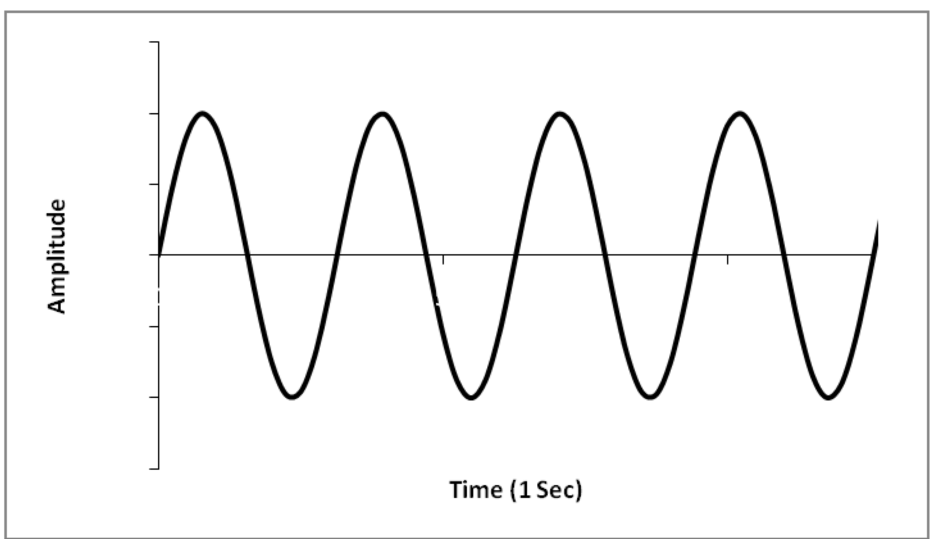


Figure 5. Two Sound Waves with the Same Amplitude and Different Frequencies

a. Frequency = 2Hz; Amplitude = 2dB



b. Frequency = 4Hz; Amplitude = 2dB



Acoustic Parameters

There are many acoustic parameters that can be assessed. Software programs have a large number of parameters that can be evaluated with a single voice sample. Below are definitions of the most common and helpful acoustic parameters that are used to evaluate the voice.

Speaking Fundamental Frequency (SFF)

When measured, the speaking fundamental frequency (SFF) gives insight into how a person uses his or her voice on a regular basis (Baken and Orlikoff 2000, 185). The average ranges for SFF are variable by age and gender. Table A4 in appendix A gives normative data for the mean SFF by gender and age. Keep in mind that these normative values are the mean frequencies, not exact pitches. As one speaks, one has normal inflections that hover around a cluster of pitches and this must be taken into consideration. Often the fundamental frequencies are converted into approximate pitches. Therefore, if a student's mean SFF is 220 Hz, his or her speaking pitch averages around A3.

The term, 'habitual pitch' can cause some confusion due to various definitions found in the scientific literature. Some researchers state that it corresponds to the most frequently used or occurring pitch (Prater and Swift 1984, 46; Boone and Mcfarlane 2000, 151) and others indicate that is the same as the average pitch level (Case 1996, 71). When looking at normative data, one must be careful to understand precisely what is meant by this term in the data presented.

Maximum Phonational Frequency Range (MPFR)

The maximum phonational frequency range (MPFR) measures the highest and lowest pitch a person can produce (Stemple 1995, 130). It is a way to evaluate basic vocal ability (Baken and Orlikoff 2000, 185). This is an especially important parameter to evaluate for singers as vocal distress is often accompanied (or even defined by) a loss of range. When evaluating MPFR, pulse register (glottal fry) is not included (Baken and Orlikoff 2000, 188). Both the SFF and the MPFR can be assessed using computer hardware and software designed for voice analysis. See table A5 in appendix A for normative values of MPFR.

Vocal Intensity

Vocal intensity is the correlate parameter to amplitude. It is measured in decibels (dB) and the mean intensity value correlates with how we perceive vocal loudness (Coltan and Casper 1996, 210). Ware states that, “Although amplitude is the actual attribute of vibration, it is more typically measured as intensity, which is the amount of pressure exerted by the sound wave upon the tympanic membrane” (1998, 130). We call this the sound pressure level (SPL) and measure it in decibels (dB). The SPL offers an idea as to the intensity of the vocal fold vibration. As the number of decibels increases, the louder the sound is perceived by the listener (Colton and Casper 1996, 25). The human threshold of audibility has been set at 0dB. An SPL above 140 dB causes pain. Conversational SPLs are around 70 to 80 dB (Baken and Orlikoff 2000, 109). We can measure mean intensity as well as intensity range using a sound level meter (older method) or using computer hardware and software programs designed for voice analysis. Table A6 in appendix A gives some normative values for vocal intensity.

Voice Range Profile (VRP)

The voice range profile (VRP) is an evaluation often done in European clinics, and is gaining some popularity in the United States. This is an evaluation of the total range of an individual as well as the intensity capabilities. So, for each pitch sounded, the subject is asked to sound it as softly as possible and as loudly as possible. Usually the subject is able to produce the greatest range of intensity in the middle of the frequency range and there can be a 20 to 30dB range in a typical subject There are special software programs that can evaluate this or it can be done using a keyboard or pitch pipe and a sound level meter. This is a time-consuming process, but if the software and time is available, it can be quite useful to compare baseline VRPs to VRPs during vocal distress (Sataloff 2005, 283).

Perturbation

In an ideal sound wave forms are periodic. This means that each wave form repeats over and over again with the same motion, keeping the same period, fundamental frequency, and amplitude. In reality, no two waveforms are alike. Variability in mass, tension, and biomechanical characteristics of the vocal mechanism, and neural control all contribute to changes in period and amplitude (Baer 1979). Jitter, shimmer, tremor and vibrato are all terms which can refer to perturbations, or disturbances in the waveform and thus the sound. Below are discussions of these terms.

Jitter and Shimmer

Jitter refers to short-term (cycle-to-cycle) variability in the fundamental frequency, that is, there is variation in the pitch over time. Shimmer refers to short-term variability in the amplitude, or loudness, over time (Titze 2000, 313). Titze offers the following insight into these parameters:

> A problem has arisen in trying to make a precise mathematical definition stick for jitter and shimmer. What is meant by short term, for example, and what kind of variability measure should be adopted? . . . There are many kinds of ways of quantifying a deviation from an expected pattern or trend. This has led to a proliferation of mathematical definitions for jitter and shimmer. I believe that it is best to believe the terms as they are (as generic descriptions of fundamental frequency and amplitude variability) and use more standard terminology of engineering and statistics for precise definitions of error measurements (Titze 2000, 314).

Normal speakers have some variation in frequency, or jitter, in their speech Instability of the vocal folds during phonation can be caused by biomechanical, aerodynamic, neurological and other issues. These can vary with age, physical health, and perhaps gender (Coltan and Casper 1996, 353-354). It is when the instability is greater than normal that jitter moves out of normal boundaries. In measuring the perturbation, the key is to note sudden, involuntary changes. These are the ones that may indicate pathology (Baken and Orlikoff 2000, 204).

One of the more important fundamental frequency perturbation measurements is the Relative Average Perturbation (RAP). This parameter measures jitter over three cycles, and expresses the value in percent (Radionoff 1996, 7). Normative values for RAP can be found in table A7 in appendix A.

Often when singing teachers talk about shimmer in the studio, they are describing a beautiful, clear sound and this definition is most different than that of shimmer in the scientific context. Titze states that "As a short term amplitude perturbation . . . shimmer is not particularly pleasing. It is usually perceived as a crackling or buzzing, and in extreme cases, it can become very unpleasant and rough. It is important to communicate, therefore, the context in which the term shimmer is used" (Titze 2000, 314). Some typical shimmer in dB values can be found in appendix A, table A9.

Jitter and shimmer can be analyzed several different ways. Currently they are most commonly evaluated with a program called the Multi-Dimensional Voice Program™ (MDVP™), offered by KayPENTAX™. This software is able to analyze many parameters of the voice. In the next chapter, more information is provided about MDVP™. Below, find definitions of some of the jitter and shimmer parameters analyzed by MDVP™ that are most commonly referenced by SLPs. These definitions were adapted from Radionoff's *Objective Measures of Vocal Production During the Course of Singing Study* (1996, 6-8) and the *Multi-Dimensional Voice Program (MDVP) Model 5015 Instruction Manual* (1999, 15). For a list of many other parameters measured by MDVP™, see appendix C.

1. Jita (Absolute Jitter): This is a measure of cycle-to-cycle variation of the pitch periods. It is measured in microseconds (usec). Jita is dependent on the

fundamental frequency of the voicing sample. As pitch increases, Jita decreases. Normative data is thus different for men and women. Absolute jitter is significantly altered by pitch extraction errors (Radionoff 1996, 7).

2. JITT (Jitter Percent): This is a cycle-to-cycle variation of the pitch periods expressed in percent. Because this is a relative measure, the "influence of the average fundamental frequency is significantly reduced" (Radionoff 1996, 7). This parameter is quite sensitive to pitch variations, so if the voice is unstable JITT will be affected.

3. RAP (Relative Average Perturbation): This is a relative evaluation of cycle-to-cycle variability within the voice sample with a smoothing factor of 3 periods. It is a percentage value. Basically it is JITT with the smoothing factor of three periods. A smoothing factor evaluates Jitter by averaging the three periods together. The smoothing factor reduces the measure's sensitivity to changes in pitch.

4. ShdB (Shimmer in dB): This is an evaluation of the very short-term cycle-to-cycle variability of peak-to-peak amplitude. Hoarseness is almost certainly a factor but it is still not clear how or if it is indicative of other vocal pathologies.

5. Shim (Shimmer percent): This is the short term evaluation of the cycle-to-cycle variability of the peak-to-peak amplitude, measured in percent.

6. SAPQ (Smoothed Amplitude Perturbation Quotient): Expressed as a percent, this compensates for long-term changes by applying smoothing. The smoothing factor set up by the factory is 55 periods, but this can be changed by the user.

Tremor and Vibrato

Another term which is often associated with perturbations in the voice is **tremor**. The term can be confusing, as it often used to generically describe any fluctuations in the voice which could be a manifestation of a number of issues including inherent laryngeal pathology manifesting in abnormal jitter, shimmer, or several neurological conditions such as Parkinson's disease or muscle tension dysphonia (Case 2002, 196). In Parkinson's disease, the body is subject to what is called "essential tremor" and can affect areas such as the hands, feet, head and larynx. Coltan and Casper define characteristics of tremor as "relatively regular, involuntary movements of the distal or proximal muscles" (1996, 146). In all people there is an inherent amount of tremor in the body with a frequency from 6 to 12 Hz. Outside of this range, variability in tremor may or may not indicate pathology. Larger amplitudes may also indicate pathology (Coltan and Casper 1996, 146). Misunderstandings about tremor also exist in that sometimes it is confused or used synonymously with the term **vibrato**. Johann Sundberg gives the following insight regarding this matter:

> Vibrato has also been compared to vocal tremor (Ramig & Shipp, 1987). The vibrato characteristics of nine opera singers were compared with the tremor characteristics of six patients of different diagnoses suffering from vocal tremor. Surprisingly, the results revealed only minor physical differences. The rate was 5.5 Hz for the singers and 6.8 Hz for the vocal tremor patients, and the regularity

> of the fundamental frequency variations appeared to be greater in singing. However, none of these differences reached statistical significance in their investigation. In any event, it is fair to conclude that there are similarities between vocal tremor and vibrato (Sundberg 1995, 40).

This brings the discussion to the manifestation of vibrato in vocal tone. A steady modulation in the range of 4-6 Hz above and below the fundamental frequency is commonly considered a healthy vibrato. This modulation is usually smaller than a semitone above and below the fundamental frequency and is approximately 5-7 undulations per second (Sundberg 1995, 39, 43). There is also amplitude variation inherent in vibrato. This variation can result from acoustic or aerodynamic sources or even from glottal adjustment (Sundberg 1995, 46). There is much mystery surrounding the origin of vibrato and further study is needed in this area of voice research.

When the voice is evaluated by an SLP, usually the client is asked to produce tone without vibrato. This is because in voice analysis programs such as MDVP™, any modulation in the sound is perceived as pathologic. According to the *Multi-Dimensional Voice Program (MDVP) Model 5015 Instruction Manual,* "in MDVP™, the goal is to voice a steady-state flat tone voice. Modulations [vibrato], therefore, are assumed to be undesirable and may be characteristic of [abnormal] tremors" (1999, 19). The indication is that if a subject cannot hold a "steady-state flat tone," that there is likely some type of pathology. This may or may not be true in the case of a trained singer. After all, classical singers are especially trained to use vibrato all the time. Usually when asked, singers can produce a speech level tone with no vibrato, but asking them to 'take it out' can sometimes be difficult. A singing teacher or SLP should, however, be able to differentiate between a student who simply has trouble with this, and one who has pathology and cannot hold a steady tone. Case states that "Vocal pathological tremor . . . [has] greater variability and intensity [than] musical vibrato" (2002, 196-197).

Videostroboscopy

When a student is experiencing serious vocal problems one of the first sources of information can be looking at the vocal folds in action using videostroboscopy. This is commonly referred to as "being scoped." A laryngologist or an SLP will use either a rigid or flexible endoscope to look at the vocal folds. This is called endoscopy and will provide an image of the vocal folds for evaluation. Stroboscopy is not synonymous with endoscopy. An endoscope is the instrument used to see the vocal folds and endoscopy is the procedure of doing so. Stroboscopy is the technique used to observe motion in cases in which the movement is so quick that the human eye cannot perceive the image.

One of the more difficult obstacles to overcome as a singer is learning to work with a musical instrument that cannot be seen. Not only is the larynx in a difficult viewing position, the vocal folds move so rapidly that it is virtually impossible to evaluate their movement (vibratory cycles) in real time with the naked eye. The introduction of videostroboscopy has greatly enhanced the clinician's ability to see the vibratory cycles of the vocal folds during phonation and also provides a bigger, brighter, and longer look at the larynx. It is important to remember, however, that videostroboscopy is not video of the vocal folds in real time. Instead, in very broad terms, it is a compilation of many pictures of the vocal folds taken at different times during many vibratory cycles.

Obviously, most voice teachers are not able to perform laryngoscopies on students. However, it behooves them to understand what exactly the doctor or SLP is looking at and reporting back to the student. This imaging is some of the best baseline data that can be collected and recorded. Information on glottal and supraglottal appearance as well as adductory and abductory function is all available through videostroboscopy. If the voice department can overcome the economical obstacles involved in scoping students, it is recommended that each student have a stroboscopic evaluation as part of the baseline information collected. This procedure would most likely need to be done by an SLP or laryngologist. Sometimes SLP departments have this equipment available on campus.

CHAPTER III

INSTRUMENTATION

Voice teachers are sometimes wary of instrumentation. Although perceptual evaluation is an important part of the evaluative process, it alone may not deliver the most complete picture of the voice. Awan mentions three important reasons for the inadequacy of perceptual judgments alone:

> 1. Variability in training and experience between [evaluators] inevitably leads to a lack of reliability and validity in the perceptual judgments that are made. Discussions with colleagues will often reveal that even such commonly used severity terminology such as mild, moderate, and severe may have very different meanings for different therapists.
>
> 2. Perceptual judgments alone do not allow for objective comparison with normative groups. One of the fundamental diagnostic decisions made in any evaluation is one of "normal" vs. "abnormal." One of the valuable aids we have in making this decision is a measure of the average performance for a target group in conjunction with a measure of the average deviation. Unfortunately, perceptions cannot be compared with measurable norms in any valid manner.
>
> 3. Progress in therapy sessions [or changes in the mechanism] may not be gauged effectively with perceptions alone. Perceptual judgments may not detect relatively small but significant changes in voice characteristics that may indicate that a treatment procedure is having a positive effect on the patient. In addition, perceptual judgments alone may not provide the data required to justify continuation of therapy and reimbursement for the treatment (Awan 2001, 3).

While not all of these reasons relate directly to the voice teacher and students, indirectly they do apply. And, although the array of equipment and instruments available in the world of voice science is vast, it is not an insurmountable obstacle.

Basic Equipment

The basic equipment needed to set up a station for taking baseline vocal measurements is outlined below.

1. A quiet space, comfortable chairs, calm environment
2. Spirometer
3. Stopwatch
4. A good quality microphone
5. A computer and monitor (IBM compatible)
6. Microphone power/preamplifier/converter
7. Acoustic analysis software (MDVP™)
8. Sound Level Meter (optional)
9. Keyboard or Pitch Pipe (optional)

Following is a brief discussion of the basic pieces of equipment recommended in this document. For more specific information regarding the equipment needed for setting up a voice laboratory, the reader is directed to the large body of speech pathology literature available as well as the *National Center for Voice and Speech Website* (www.ncvs.org). Within this website is an insightful memo entitled, "Recommendations for the Creation of a Voice Acoustics Laboratory" by Jennifer Spielman et al. (2007), which contains detailed descriptions of the acoustics equipment.

A quiet space, comfortable chairs, calm environment

It is imperative that a space be created where the student and evaluator are comfortable, will not be interrupted, and is quiet. Disturbances may create anxiety in the student and outside noise may contaminate data. A safe environment, both physically and mentally, is of utmost importance as this will produce the most accurate assessment of the voice.

Spirometer

Hand-held spirometers measure aerodynamic parameters of the voice and can be purchased fairly inexpensively. A student or patient blows into the device. Vital capacity can be measured with this device.

Stopwatch

Any decent stopwatch with microseconds will do. Something that is easy to use and uncomplicated to read is ideal. This would be used to measure such parameters as MPT or the s/z ratio.

A good quality microphone

Microphones come in many varieties. For MDVP™ to work best, a good quality microphone that is unidirectional dynamic or condenser is needed. It should have a frequency response between 50 Hz and 15 kHz (kilohertz) (Awan 2001, 6).

A Computer and Monitor

This should be a Pentium® level computer, and currently must be IBM® compatible in order for the acoustic software analysis systems recommended by this paper to function. Usually the computer should be multimedia with at least a 16-bit sound card and speakers. These are required for the recording and the playback of the voice samples (Awan 2001, 6).

Microphone power/preamplifier/converter

A good quality dynamic or condenser microphone can produce decent recordings but the output is very quiet. Microphone preamplifiers increase the volume of an incoming audio source to a level that is suitable for audio recording. The converter is needed to convert the analog signals from the microphone to digital so that they can be analyzed by the computer software.

Acoustic Analysis Hardware and Software

For the purposes of ease and availability, it is the recommendation of this author that a voice department choose one of three available computerized systems for acoustic analysis. Visipitch™, Multispeech™, and Computerized Speech Lab™ (CSL™) are all products offered by KayPENTAX™. These are the most widely used systems by SLP's and they are all-inclusive packages of acoustic analysis equipment. Visipitch™ and CSL™ both include hardware and software options, while Multispeech™ is software only. They all include or have options to include the Multi-Dimensional Voice Program™ (MDVP™) which is a robust software program that can analyze many different parameters with just a single sample of vocal production. The most important features of these computer systems for baseline evaluations are the MDVP™ program and the Voice Range Profile Program. These are both options available for the CSL™ and Visipitch™. Multispeech™ does not have the option for the Voice Range Profile program, but it does for MDVP™. Brief descriptions of the MDVP™ program and the Voice Range Profile program follow later in this chapter.

Sound Level Meter (Optional)

Sound level meters are used to measure intensity. Using a microphone, they measure intensity in decibels. Sound level meters can be purchased fairly inexpensively. This device would be used in the absence of a computerized program for acoustic analysis.

Keyboard or Pitch Pipe (Optional)

In the absence of acoustic analysis software to determine acoustic measurements, a keyboard or pitch pipe may be used to evaluate parameters such as the phonational range or voice range profile (in conjunction with a sound level meter).

Acoustic Analysis Software

Multi-Dimensional Voice Program (MDVP™)

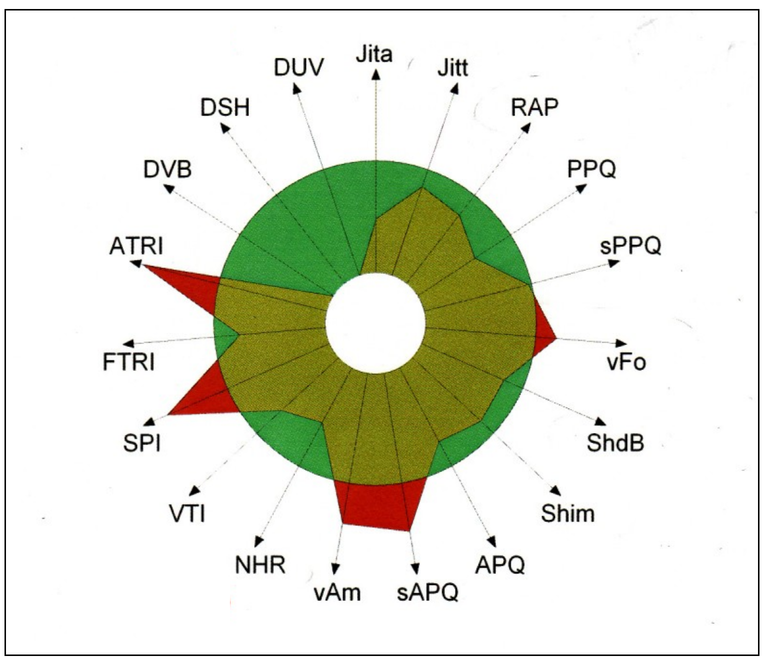
MDVP™ is the most widely-used software program for acoustical evaluation by SLPs and is "often found cited in professional literature" (*Multi-Dimensional Voice Program (MDVP) Model 5015 Instruction Manual* 1999, 1). This program is used for acoustic assessment of vocal quality. It is included in the CSL™ and Visipitch™ packages, and is an option for Multispeech™. According to the *KayPENTAX™ Website:*

> The Multi-Dimensional Voice Program™ (MDVP™) is the gold standard software tool for quantitative acoustic assessment of voice quality, calculating more than 22 parameters on a single vocalization. Based on extensive field testing with normal and disordered voices, MDVP™ is unique in its ability to work accurately over a wide range of pathological voices. Its normative references are based on an extensive database of normal and disordered voices; and results are graphically and numerically compared to these normative threshold values.

> MDVP™ quickly and easily provides a revealing snapshot of voice quality (*KayPENTAX Website*. "Multi-Dimensional Voice Program (MDVP) Model 5015," n.d.).

A useful feature of this program is that it represents the results graphically. This provides a way to efficiently see areas of the voice that are abnormal and illustrates a 'snapshot' of voice quality. Figure 6 shows a sample radial graph from MDVP™. The norms are represented by the green circle. The olive green portion represents the vocal parameters of the subject that are within the norms. The red portions of the graph indicate where the vocal parameters were out of the normal range.

Figure 6. MDVP™ Radial Graph



Note: This graph was generated by the MDVP™ manufactured by KayPENTAX™ from a voice sample by the author.

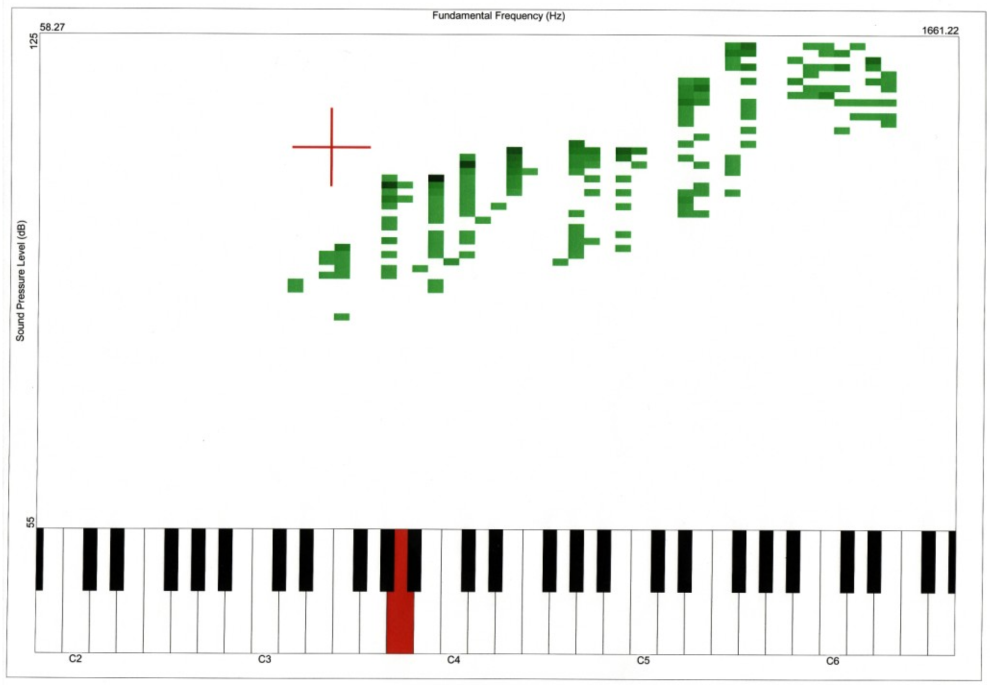
Voice Range Profile (VRP)

The voice range profile is a way of evaluating the student's range of frequencies and amplitudes. That is, the entire vocal range of a student as well as the student's capability within the range of dynamic change. The program offered by KayPENTAX™ plots a graph with the fundamental frequency on the x-axis and the sound pressure level (intensity) on the y-axis. See figure 7 for an example. The program also offers a detailed table of the statistics of the voice sample with numerical data for all data represented graphically. Although this is one of the more time-consuming evaluations, it is an important one, especially for professional singers. According to the *KayPENTAX™ Website*:

> VRP is unique in its ability to detect subtle changes in vocal function. Professional singers, who as "vocal gymnasts" often appear normal in other vocal function protocols, may find that the VRP reveals an altered voice range profile. The same is often true of other patients who complain that something feels wrong with their voices, but, at normal fundamental frequencies and levels, show no discernible abnormality (*KayPENTAX™ Website*, "Voice Range Profile, Model 4326," n.d.).

Figure 7

Voice Range Profile



Note: This graph was generated from the Voice Range Profile Program manufactured by KayPENTAX™ from a voice sample by the author.

CHAPTER IV

PROCEDURES AND PROTOCOL

Consistency is the key to taking vocal measurements that are valid and reliable (repeatable). It is imperative that the same protocol and procedures are used for each student, each time the measurements are taken. Whenever possible, it is recommended that the analysis take place in the same room, with the same equipment, with the same person taking the measurements. At the very least, there should be a manuscript detailing everything from what room is used, to what equipment was used, to the evaluator. Obviously, a record of the values measured should also be included.

For each test taken, it is recommended that it be repeated three times. This will establish reliability, that is, repeatability of the data. The validity of the data is determined by the quality of the equipment as well as the procedure for taking the measurement. This can also be reliant upon the health of the student that particular day. Of course, it is imperative that the student is well, physically and vocally, lest the baseline measurements be skewed.

A strict system of record keeping must be implemented in order to preserve the data collected from each student. Prepared forms for each student should be used for recording all data. The forms should be the same for all students. An example of a prepared form can be found in appendix D. Each student should have a designated file with a record of all evaluations including all forms, graphs, and other information deemed appropriate by the department or institution.

Baseline vocal measurements will, of course, change to a certain degree over time. A variety of factors might change the student's vocal state including age, vocal technical changes and environmental considerations. It would be important, then, to implement a system in which measurements were taken two to three times during an individual's course of study. This would provide the most accurate view of the student's voice. Should the student run into vocal trouble, he or she would have relatively current documentation of his or her healthy vocal parameters.

Protocol for Aerodynamic Measurements

In this section suggestions are made as to proper protocol for measuring aerodynamic parameters. Procedures and protocol are adapted from *Manual of Voice Therapy* by Prater and Swift (1984), *The Voice Diagnostic Protocol: A Practical Guide to the Diagnosis of Voice Disorders* by Awan (2001), and *Understanding Voice Problems: A Physiological Perspective for Diagnosis and Treatment* by Colton and Casper (1996).

Maximum Phonation Time (MPT)

Maximum phonation time is measured by recording the amount of time a subject can sustain the vowel sound /a/ without taking a breath. The measurement is taken using a stopwatch and is recorded in seconds. It may be helpful in soliciting the MPT for the evaluator to verbally encourage the student to "keep going" as he or she is sustaining the vowel (Awan 2001, 130). This procedure is repeated three times.

Sample procedure for obtaining MPT

1. The student is sitting comfortably in a chair.
2. Explain the task to the student. "When you are ready, sustain the vowel /a/ at a comfortable pitch and loudness for as long as you can without breathing. We will repeat this three times."
3. When the student starts, immediately start the stopwatch. As the student sustains the pitch, maintain a calm composure, but encourage him or her to keep going for as long as possible. When the student is finished, stop the timer.
4. Record the time in seconds on a prepared form.
5. Repeat two more times. Be sure to record all measurements.

Vital Capacity (VC)

Vital capacity is recorded using a handheld spirometer. The student is asked to take a deep breath and then blow into the mouthpiece for as long as possible, keeping a steady stream of air going. The evaluator should encourage the student verbally in order to obtain the maximal VC measurement. This is repeated three times.

Sample procedure for obtaining VC

1. The student is sitting comfortably in a chair.
2. Turn on the spirometer and show the instrument to the student, explain that he or she will blow into the mouthpiece.
3. Explain the task to the student. "When you are ready, take a deep breath and blow into the mouthpiece for as long and as steadily as possible. We will repeat this three times." The evaluator should watch the student for signals that he or she is getting a deep inhalation and verbally encourage the student as he or she blows into the mouthpiece.
4. Record the VC in liters or milliliters on a prepared form.
5. Repeat two more times. Be sure to record all measurements.

S/Z Ratio

The s/z ratio is obtained by asking the student to sustain the sound /s/ for as long as possible and the sound /z/ for as long as possible and timing each one. Each sound is sustained and recorded three times. The calculation is done using the maximum times for each sound.

Sample procedure for obtaining s/z ratio

1. The student is sitting comfortably in a chair.
2. Explain the task to the student. "When you are ready, take an expansive breath and sustain the sound /s/ for as long as possible

without breathing." The evaluator may example this if he or she deems it helpful.

3. When the student begins, start the stopwatch. When the student can no longer sustain the sound, stop the stopwatch.
4. Record the measurement in seconds on a prepared form.
5. Ask the student to now sustain the sound /z/ for as long as possible without taking a breath.
6. When the student begins, start the stopwatch. When the student can no longer sustain the sound, stop the stopwatch.
7. Record the measurement in seconds on a prepared form.
8. Repeat the entire process two more times.
9. Calculate the s/z ratio using the longest /s/ trial and the longest /z/ trial. Record the ratio on a prepared form.

Protocol for Acoustic Measurements

Acoustic measurements are most efficiently taken using computer hardware and software designed for vocal analysis. Visipitch™, Multispeech™, and CSL™ can all be used for acoustic analysis. Because there are several different ways within the aforementioned systems to take acoustic measurements, this paper will outline only the most basic procedures. It would be impractical within the scope of this paper to try to give step by step actions in terms of what to do within the software programs, as these programs are frequently updated and the information is readily available in the instructional manuals for the software. The basic procedures and protocol for this section are adapted from *Professional Voice: the Science and Art of Clinical Care* by Robert Thayer Sataloff (2005). For all of the acoustic analysis procedures performed with acoustic analysis software, it is important to use a high-quality microphone that is always at the same distance from the mouth (Sataloff 2005, 379).

Speaking Fundamental Frequency

The speaking fundamental frequency can be obtained through sustained reading or speaking of about thirty seconds. The student speaks into the microphone for that length of time and the computer program will assess the average fundamental frequency.

Sample procedure for obtaining SFF

1. The student is sitting comfortably.
2. Ask the student to hold the microphone up to his or her mouth. Use a wood craft stick attached to the microphone to ensure that the same distance is used for all trials.[1] See figure 8 for an illustration of this.

[1] It should be noted that this is not the only system for controlling microphone-to-mouth distance recommended by clinicians, scientists or doctors. Sataloff suggests using a microphone holder fashioned from a harmonica holder or a headband with a microphone attached (2005, 379). For the purposes of ease, availability, and cost-efficiency, the author recommends the microphone/wood craft stick arrangement, as it also will allow for a fixed distance between the mouth and microphone. This system is also used at some voice clinics. Sataloff also suggests that the microphone be placed 4 inches from the mouth (2005, 379). While this may work for some microphones and recording systems, it should be noted that the ideal distance may vary depending on the type of microphone used. In general, the system of microphone placement needs to be tailored to the resources available for collection.

3. Explain the task to the student. For example: "When you are ready, hold the microphone up to your mouth, and read this passage (or talk to me about what you did yesterday)."
4. When the student is ready, the evaluator will set up the software program and begin recording when the student begins speaking.
5. When the student is finished, the evaluator records the information on a prepared form.
6. Repeat two more times.

Figure 8. Microphone with Wood Craft Stick Attached

Note: Photograph by the author

Phonational Range

The phonational range may be evaluated using computer software or simply with a keyboard or pitch pipe. Both consist of the student singing from the middle of the range down to the lowest pitch and then from the middle up to the highest pitch. Pulse register (glottal fry) is not included. The evaluator should try to encourage the student to go as high and low as possible, as many times students will stop before they have reached maximal capabilities.

Sample procedure for obtaining phonational range using computerized programs

1. The student is sitting or standing comfortably.
2. Ask the student to hold the microphone up to their mouths. Use a wood craft stick attached to the microphone to ensure that the same distance is used for all trials.
3. Explain the task to the student. "When you are ready, take a deep breath and starting at a comfortable pitch sing down to your lowest pitch. Do not go into vocal fry. You may use any vowel that is comfortable. You may breathe at any time you feel the need."
4. When the student is ready, the evaluator will start recording. When the student finishes, record the lowest frequency and vowel on a prepared form.
5. Repeat two more times.
6. If the evaluator deems it appropriate, he or she may ask the student to switch vowels to obtain a higher or lower pitch
7. Make sure all trials are recorded.

8. Explain the next part of the task to the student. “When you are ready, take a deep breath and starting at a comfortable pitch sing up the highest pitch possible. You may use any vowel that is comfortable. You may breathe at any time you feel the need.”
9. When the student is ready, the evaluator will start recording. When the student finishes, record the highest frequency and vowel on a prepared form.
10. Repeat two more times.
11. Make sure all trials are recorded.

Sample procedure for obtaining phonational range using a keyboard or pitch pipe

1. The student is sitting or standing comfortably.
2. Explain the task to the student. “When you are ready, take a deep breath and starting at a comfortable pitch sing down to your lowest pitch. Do not go into vocal fry. You may use any vowel that is comfortable. You may breathe at any time you feel the need.”
3. As the student sings, the evaluator will match the lowest pitch to the pitch on a keyboard or pitch pipe. The evaluator must listen carefully to ensure the correct pitch is found. Record the pitch and vowel on a prepared form.

4. If the evaluator deems it appropriate, he or she may ask the student to switch vowels to obtain a higher or lower pitch.
5. Repeat two more times.
6. Make sure all trials are recorded on a prepared form
7. Explain the next part of the task to the student. “When you are ready, take a deep breath and starting at a comfortable pitch sing up the highest pitch possible. You may use any vowel that is comfortable. You may breathe at any time you feel the need.”
8. When the student is ready, the evaluator will listen and match the highest frequency to the keyboard or pitch pipe. Record the pitch and vowel on a prepared form.
9. Repeat two more times.
10. Make sure all trials are recorded.

Voice Range Profile (VRP)

The voice range profile can be assessed using computerized software or using a keyboard (or pitch pipe) and a sound level meter. According to Sataloff, “the vocalist produces the softest and loudest notes on pitches C,E G, and A, respectively, until the entire range is sampled” (Sataloff 2005, 383).

Sample procedure for obtaining VRP using computerized VRP program

1. The student is sitting or standing comfortably.
2. Ask the student to hold the microphone up to their mouths. Use a wood craft stick attached to the microphone to ensure that the same distance is used for all trials.
3. Explain the task to the student. "You will hear a pitch sounded. Sing the pitch back as softly as possible and then as loudly as possible."
4. When the student is ready, the evaluator will playing the pitches and the evaluation will begin.
5. Make sure all trials were recorded.

Sample procedure for obtaining VRP using a keyboard and sound level meter

1. The student is sitting or standing comfortably.
2. Explain the task to the student. "You will hear a pitch sounded. Sing the pitch back as softly as possible and then as loudly as possible."
3. When the student is ready, the evaluator will playing the pitches and the evaluation will begin.
4. The evaluator records the pitch and corresponding intensity as measured by the sound level meter.
5. Make sure all trials were recorded.

Perturbations and Other Acoustic Parameters Measured by MDVP™

As previously discussed, MDVP™ can measure a large number of acoustic parameters. This software is efficient and accurate. A single voice sample is needed to measure all the parameters, but it is suggested that this is repeated two to three times to ensure accuracy.

Sample procedure for obtaining perturbation measures as well as other acoustic parameters using MDVP™

1. The student is sitting comfortably
2. As the student to hold the microphone up to their mouths. Use a wood craft stick attached to the microphone to ensure that the same distance is used for all trials.
3. Explain the task to the student. For example: "When you are ready, hold the microphone up to your mouth, take an expansive breath and sustain the sound /a/ at a comfortable pitch and loudness for approximately 5 seconds.
4. Prepare the computer for analysis. When you are ready to record, indicate to the student that they may start at any time. Start the recording as soon as they start.
5. Stop the recording when the student stops.
6. Repeat 2 more times.
7. Save the data and print the graph(s).

CHAPTER V

CONCLUSION

The fact that scientific measurements and evaluations are being discussed in the world of the vocal arts is a leap into a realm many people thought would never happen. Due to the increased information available to the voice teachers and singers, it is not impossible anymore that those voice professionals outside the research and medical fields understand scientific and medical information about the voice and expect to be able to understand his or her own voice, and students' voices scientifically as well as artistically. The fact is that access to this kind of information is readily available. Anyone can purchase the equipment to perform the vocal acoustic or aerodynamic assessments suggested in this document. This is an extraordinary opportunity and invites voice departments to explore and enjoy the availability of the information and encourages voice departments to collaborate with other departments on campus. Consequently, increased learning and comprehension among several disciplines ensues and discussions amongst voice professionals, teachers, clinicians and medical professionals are promoted.

Further Considerations

The idea of incorporating measurements and data into a discipline traditionally based mainly on perceptual and subjective assessments creates new quandaries and dilemmas. Aside from the obvious and increasingly-debated "art versus science" debate, evaluating baseline measurements and recording them in a university setting can lead to ethical and legal questions. Who is qualified to evaluate the student? What kind of privacy laws must be considered? Should the student be informed of the 'results' of the evaluation? Should the voice teacher be privy to the evaluations? The following section addresses these issues in order to prompt further thoughts and discussion, rather than to draw sweeping conclusions about such matters and makes no attempts to fully exploit the various legal or ethical matters involved.

Privacy Issues

Privacy laws both in the medical profession and at universities must be considered any time one is evaluating a student and recording the results. For example, results of a laryngoscopy would certainly fall under medical privacy law. Each institution must research and adhere to university, local, state and federal legal issues when it comes to taking baseline measurements and keeping the records. This would include such acts as the Family Education Rights and Privacy Act (FERPA), The Health Insurance Portability and Accountability Act (HIPAA), and any other legal privacy laws that the university must follow. Research involving who would be able to evaluate the student and who was privy to the information must happen before beginning any type of system for collection and record keeping. If the SLP department were involved, it would probably be easiest to have an SLP perform all of the evaluations, as they would already have a system in place that considers the legal issues at hand. The student could then sign a release form to give their teacher access to the results, should the teacher need the information. This procedure is already followed at many voice clinics. If teachers are doing the evaluating, there must be an investigation into legal issues concerning such matters, but it is likely that the non-invasive evaluations suggested in this document may be done legally by anyone.

Considerations Concerning Disclosure of Information to the Student and Teacher

According to FERPA, a student has the right to see his or her academic records (*U.S. Department of Education Website*, "Family Education Rights and Privacy Act (FERPA)," n.d.). HIPAA allows individuals to have access to his or her medical records (*U.S. Department of Health and Human Services Website,* "What Rights Does This Law Give Me Over My Health Information," n.d.). Thus, a department cannot prohibit a student from seeing his or her own vocal evaluations. That being said, it is the opinion of this writer that the student's evaluations not be a focal point of the student's vocal study. Extreme emphasis on numerical assessments of the voice could have a negative impact on the student. It can cause undue worry in the student about whether or not his or her voice is "normal" or "good." Young singers are especially vulnerable to this kind of speculation and resulting anxiety. An intense fear of singing or speaking incorrectly can certainly cause stress upon the student which would be likely to negatively impact his or her performances, practice sessions, lessons, and the like. An alarmist attitude for a student can be emotionally destructive and vocally inhibiting.

This brings up the question of whether or not the applied teacher should see the student's assessment before or during study. Because it is not necessary for vocal technical and artistic development, it is the opinion of this writer that teachers use the information provided to them sparingly unless the student is experiencing vocal distress. Unless they are medical doctors, under no circumstances are teachers qualified to diagnose vocal health problems. The information gathered for baseline assessments is meant to be used as a comparative tool, not to diagnose. Its usefulness is in comparing vocal measurements when healthy to those when vocally ill and is meant to be used by medical professionals (i.e. medical doctors and SLPs). After medical diagnosis, teachers can then be helpful to students in interpreting the information given to them by the medical professionals. Furthermore, singing teachers need not fret over baseline or other assessments that are out of the norm (just as students need not), unless there is some additional reason for concern. In the end, there is no substitute for the human ear in evaluating vocal quality and as most voice teachers are trained to listen for the subtlest of aberrations, they should be able to tell when things have gone awry. If a student is not experiencing vocal trouble and the teacher is not hearing it, there is probably no reason for undue stress and worry. A myriad of negative implications could result from a teacher's overreaction to a possibly innocuous situation.

Conclusions

Baseline vocal measurements are an excellent way to record singers' states of vocal health and are an extremely useful tool in evaluating and diagnosing vocal health concerns and problems. Published normative values are not sufficient comparison tools for singers because they do not take into consideration the vocal training which may change a singer's personal norms nor do they account for a singer's heighted sensitivity to changes in the vocal mechanism. To a student in vocal distress, it is paramount that issues concerning his or her assessment, diagnosis, and treatment be addressed efficiently and effectively. Time is a major concern to a voice student as performances, auditions, and required singing curriculum for their degree insist upon use of the voice not only for the required event, but also for practice time in preparation for the event. The more individualized information available to professionals assisting a student faced with vocal health issues, the more efficiently and specifically those issues can be addressed. Baseline vocal measurements provide specificity and a point of reference for the evaluator and can assist in proper diagnosis and treatment of vocal health issues.

In a recent article in the *Journal of Singing* Heman-Ackah et al. speak to the importance of a baseline laryngeal evaluation:

> Early during one's career, every vocal performer should have a baseline laryngeal evaluation. . . . If asymptomatic abnormalities are present, it is important to be aware of them. Otherwise, if they are recognized first during a period of vocal problems, they may be diagnosed incorrectly as the cause of the complaint. . . . Some individuals function well even in the presence of mild vocal fold weakness, small vocal fold polyps, nodules, or cysts and are unaware that these lesions exist unless they have had a baseline examination. If a new vocal difficulty arises, particularly after an illness, it is helpful to know that these conditions were preexisting and likely not contributing significantly to the current vocal problem. Such knowledge even can help prevent the performance of unnecessary vocal fold surgery on benign lesions when vocal difficulties do arise. (Herman-Ackah et al. 2008a, 471).

And although the above citation is speaking to endoscopic evaluation of the vocal folds themselves, it is logical to include acoustic and aerodynamic evaluations when devising a baseline 'portfolio' of a singer's vocal mechanism.

The university setting provides a wonderful place to set up a system and program for taking baseline measurements. Teachers and students both benefit from this kind of information and collaboration between departments and disciplines is encouraged. The main benefit for a student is that a record of his or her baseline vocal measurements is available for use when and if it is ever needed. Teachers and students will both be able to expand their breadth of knowledge of voice science, speech pathology, and vocal medicine. Teachers will be able to acquaint themselves with some of the procedures, protocol, and equipment used by medical professionals and this may assist them in fostering students through a vocal health dilemma.

As research and development in the area of voice science continues to grow, singing teachers must learn and grow with it. Students will be confronted with clinical information about their voices and it is the responsibility of the voice teacher to know how to work with each student and the SLP, laryngologist or singing voice specialist in order to promote the student's vocal health. At the very least singing teachers should be prepared to interpret information from these professionals. The system thus described provides a basic tool for getting a voice department started in setting up a program for taking and recording baseline measurements for students. These measurements may prove to be an invaluable tool for a student when he or she is encountering vocal problems. It is also hoped that this type of program will help singing teachers and students to become more knowledgeable about vocal health assessment and promote vocal health awareness to all individuals involved.

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APPENDIX A

NORMATIVE VALUES

Normative Data: Aerodynamic Parameters

Table A1. Maximum Phonation Time (MPT)

Males:

Age (years)	Mean (s)	Standard Deviation
3-4	8.95	2.16
5-12	17.74	4.14
13-65	25.89	7.41
65+	14.68	5.7

Females:

Age (years)	Mean (s)	Standard Deviation
3-4	7.5	1.8
5-12	14.97	3.87
13-65	21.34	5.66
65+	13.55	5.7

Source: Coltan and Casper 1996, 358.

Note: The above data are taken from tables in Raymond Colton and Janina K. Casper, *Understanding Voice Problems: a Physiological Perspective for Diagnosis and Treatment,* 2nd ed. (Baltimore: Williams and Wilkins, 1996). According to Colton and Casper, “Our purpose is not to present all the available data, much of which is incomplete and confusing, but rather to provide the most meaningful data against which patient data may be compared clinically…The data reported here were gathered from a variety of sources.” (Coltan and Casper, 1996, 352). The data presented in the above tables “presents a summary of the data reported on maximum phonation duration from many studies” (Coltan and Casper, 1996, 356).

Table A2. Vital Capacity (VC)

Males

Author	Number of Subjects	Age (years)	Mean (L)	Standard Deviation	Range (L)
Ptacek et al. (1966)	31	18-39	4.80	0.60	3.40-6.00
	27	68-89	3.10	0.70	1.10-2.90
Yanagihara et al. (1966)	11	30-43	4.73	0.65	3.86-5.76
Ramig and Ringel (1983)[a]	8 (Y,G)	26-35	5.16	N/A	4.52-6.47
	8 (Y,P)	25-38	5.04	N/A	3.77-6.25
	8 (M,G)	46-56	5.02	N/A	4.16-7.30
	8 (M,P)	42-59	4.26	N/A	3.23-6.00
	8 (O,G)	62-75	3.97	N/A	2.68-5.05
	8 (O,P)	64-74	3.41	N/A	2.03-4.26
Rau and Becket (1984)	10	19-28	4.18	0.87	3.10-6.15
Trullinger and Emanuel (1989)	5	8.1-8.11	1.82	0.38	1.22-2.38
	5	9.0-9.11	2.22	0.57	1.50-2.93
	5	10.1-10.9	2.42	0.57	1.55-2.73

[a]Y=young subjects, M=middle age subjects, O=old age subjects; G=good condition, P=poor condition
Source: Awan 2001, 129.

Females

Author	Number of subjects	Age (years)	Mean (L)	Standard Deviation	Range (L)
Ptacek et al. (1966)	31	18-38	3.50	0.60	2.40-4.60
	35	66-93	1.90	0.40	1.10-2.90
Yanigihara et al. (1966)	11	21-41	3.63	0.38	3.10-4.30
Rau and Beckett (1984)	9	21-29	3.02	0.32	2.42-3.37

Trullinger and Emanuel (1989)	5	8.1-8.11	1.79	0.23	1.56-2.16
	5	9.0-9.10	1.88	0.12	1.50-2.93
	5	10.1-10.9	1.96	0.24	1.55-2.73
Sperry and Klich (1992)[b]	9 (Y)	20-28	3.36	0.62	N/A
	9 (O)	62-70	2.46	0.58	N/A
Awan and Ziminsky-Ammon (1996)	10	18-30	3.45	0.40	2.95-4.00
	10	40-49	3.10	0.42	2.50-3.75
	10	50-59	2.64	0.35	2.25-3.20
	10	60-69	2.33	0.30	1.70-2.65
	10	70-79	1.92	0.48	1.10-2.80

[b]Y=Younger subjects, O=Older subjects
Source: Awan 2001, 129.

Table A3. S/Z Ratio

Males

Author	Number of subjects	Age (years)	Mean	Range
Tait et al. (1980)	6	5	0.92	0.82-1.08
	6	7	0.70	0.52-0.97
	15	9	0.92	0.66-1.50
Fendler and Shearer (1988)	N/A	1st Grade	1.42	0.51-2.66
		2nd Grade	1.13	0.53-2.13
Mueller (1993)	20	20-30	1.10	0.56-1.81
	22	65-87	0.85	0.46-1.78

Females

Author	Number of subjects	Age (years)	Mean	Range
Tait et al. (1980)	9	5	0.83	0.50-1.14
	8	7	0.78	0.51-1.10
	8	9	0.91	0.75-1.26
Fendler and Shearer (1988)	N/A	1st Grade	1.31	0.48-2.02
		2nd Grade	1.13	0.52-2.34
Mueller (1993)	20	20-30	1.05	0.66-1.50
	22	65-92	0.89	0.56-1.44

Males and Females:

Author	Number of Subjects	Age (years)	Mean	Range
Eckel and Boone (1981)	86	8-88	0.99	0.41-2.67
Larson et al. (1991)	22	19-41	1.18	N/A
Mueller et al (1991)	54	5-6	0.89	N/A
	22	19-41	1.13	N/A
Sorenson and Parker (1992)	11	5.1-9.11	0.97	0.84-1.27

Source: Awan 2001, 138.

Normative Data: Acoustic Parameters

Table A4. Mean Fundamental Frequency
(Read passages)

Males:

Author	Age Range (years)	Mean Fundamental Frequency (Hz)
Fairbanks, Wiley, and Lassman (1949)	7	294
	8	297
	10	270
	14	242
Fitch and Holbrook (1970)	19	117
Snidecor (1943)	Adults	132
Hollien and Shipp(1972); Shipp and Hollien (1969)	20-29	120
	30-39	112
	40-49	107
	50-59	118
	60-69	112
	70-79	132
	80-89	146

Females:

Author	Age Range	Mean Fundamental Frequency (Hz)
Fairbanks, Herbert, and Hammond. (1949)	7	281
	8	288
Horii (1983)	11	238
Fitch and Holbrook (1970)	19	217
Stoicheff (1981)	20-29	224

Saxman and Burk (1967)	30-40 40-50	196 189
Stoicheff (1981)	60-69 70+	200 202
McGlone and Hollien (1963)	80-94	200

Source: Coltan and Casper 1996, 353.

Table A5. Maximum Phonational Frequency Range (MPFR)

Males

Author	Age Range (years)	Number of Subjects	Lowest F_0[e] Mean (Hz)	Lowest F_0 Range (Hz)	Highest F_0 Mean (Hz)	Highest F_0 Range (Hz)	MPFR (Mean) (Hz)
Hollien and Jackson (1973)	17.9-25.8	157	79.5	62.0-110.0	763.6	292.0-1568.0	864.1
Hollien, Dew and Phillips (1971)	18-36	332	80.1	61.7-123.5	674.6	220.0-1567.8	594.5
Shipp and McGlone (1971)	Young adult	14	87	69-110	571	440-698	484
Gelfer, 1989[f]	23-33	10	84.8	61.7-123.5	752.8	493.8-932.2	N/A
Ptacek, Sander, Maloney and Jackson (1966)	18-39 68-89	31 27	77.3 85.3	N/A N/A	567.3 394.2	490 308.9	N/A N/A

[e] F_0= Fundamental Frequency
[f] "Data is means of three trials on each of two days, 1 to 2 months apart" (Baken and Orlikoff 2000, 188).
Note: Data does not include pulse register.

Females

Author	Age Range (years)	Number of Subjects	Lowest F_0[e] Mean (Hz)	Lowest F_0 Range (Hz)	Highest F_0 Mean (Hz)	Highest F_0 Range (Hz)	MPFR (Mean) (Hz)
Kim, Oates, Phyland and Campbell (1998)	18-33	44	141.4	93.8-190.1	884.1	334.1-1917.4	743.4
Hollien, Dew and Phillips (1971)	18-36	202	140.2	98-196	1121.5	587.3-2092.8	981.3
Gelfer (1989)	23-33	10	127.1	98.0-164.8	1102.2	830.5-1666.1	N/A
Ptacek, Sander, Maloney, and Jackson (1966)	66-93	36	133.8	N/A	570.6	N/A	436.8

Source: Baken and Orlikoff 2000, 188.

Table A6. Vocal Intensity

Males

Author	Utterance Type	Loudness Level	Number of subjects	Age (years)	Mean Intensity (dB)	Standard Deviation (dB)
Statholopoulos and Sapienza (1993)	/pa/	Soft	10	20-30	70.42	3.19
		Comfortable	10	20-30	74.69	3.08
		Loud	10	20-30	80.72	3.51
Holmberg, Hillman and Perkell (1988)	/pœ/	Soft	25	17-30	75.00	2.50
		Comfortable	25	17-30	79.50	3.30
		Loud	25	17-30	86.00	4.30
Ryan and Gelfer (1993)	Rainbow Passage	N/A	N/A	20-30	70.42	N/A

Females

Author	Utterance Type	Loudness Level	Number of Subjects	Age (years)	Mean Intensity (dB)	Standard deviation (dB)
Stathopoulos and Sapienza (1993)	/pa/	Soft	10	20-30	65.35	1.84
		Comfortable	10	20-30	70.44	1.88
		Loud	10	20-30	76.75	3.38
Holmberg, Hillman and Perkell (1988)	/pœ/	Soft	20	18-36	83.30[c]	3.20
		Comfortable	20	18-36	76.40	4.00
		Loud	20	18-36	71.50	4.90
Ryan and Gelfer (1993)	Rainbow Passage[d]	N/A	N/A	20-30	68.15	N/A

[c] Averaged over 15 syllable repetitions
[d] The Rainbow Passage is one of the most common reading passages used to test an individual's speech ability. It was designed to contain almost all of the English phonemes and is used by many speech pathologists and researchers.
Source: Coltan and Casper 1996, 356.

Table A7. Relative Average Perturbation (RAP) for Normal Adults

Males

Author	Group	Age (years)	Number of subjects	Vowel	Mean F_0 (Hz)	RAP x 100 (Mean)
Dwire and McCauley (1995)[g]	American	18-25	24	/a/	117.8	0.38
	American	18-25	24	/i/	128.1	0.42
	American	18-25	24	/u/	137.2	0.58
Till, Jafari, Crumley, and Law-Till (1992)	American	30	5	/a/	112.1	0.21
	American	30	5	/pa/	112.1	0.25
Takahashi and Koike (1975)	Japanese	27.7	7	/a/	108.1	0.57

Walton and Orlikoff (1994)	European-American African-American	30 29	50 50	/a/ N/A	107.5 108.8	0.28 0.40

[g] "Data are means of 2 test sessions, separated by 1 to 2 weeks. Measurement by Kay Elemetrics [*sic*] 'Visipitch'" (Baken and Orlikoff 2000, 208).

Females

Author	Group	Age (years)	Number of subjects	Vowel	Mean F_0 (Hz)	RAP x 100 (Mean)
Dwire and McCauley (1995)	American	18-25	25	/a/	222.9	0.89
	American	18-25	25	/i/	234.7	0.54
	American	18-25	25	/u/	241.8	0.84
Till, Jafari, Crumley, and Law-Till (1992)	American	27.4	5	/a/	221.2	0.28
	American	27.4	5	/pa/	221.2	0.303
Takahashi and Koike (1975)	Japanese	29.5	2	/a/	206	0.61

Source: Baken and Orlikoff 2000, 208.

Table A8. Typical Shimmer in dB for Normal Adults

Males

Vowel	Mean (dB)	Standard Deviation
/a/	0.47	0.34
/i/	0.37	0.28
/u/	0.33	0.31
Mean	0.33	0.31

Females

Vowel	Mean (dB)	Standard Deviation
/a/	0.33	0.22

/i/	0.23	0.08
/u/	0.19	0.04
Mean	0.25	0.11

Source: Coltan and Casper 1996, 357.

APPENDIX B

INTERNATIONAL PHONETIC ALPHABET

Table A9. IPA- Consonants

IPA	Examples
p	**p**en, s**p**in, ti**p**
b	**b**ut, we**b**
t	**t**wo, s**t**ing, be**t**
D	**d**o, o**dd**
tʃ	**ch**air, na**t**ure, tea**ch**
dʒ	**g**in, **j**oy, e**dge**
k	**c**at, **k**ill, s**k**in, **q**ueen, uni**que**, thi**ck**
g	**g**o, **g**et, be**g**
f	**f**ool, enou**gh**, lea**f**, o**ff**, **ph**oto
v	**v**oice, ha**ve**, o**f**
θ	**th**ing, tee**th**
ð	**th**is, brea**the**, fa**th**er
s	**s**ee, **c**ity, pa**ss**
z	**z**oo, ro**s**e
ʃ	**sh**e, **s**ure, emo**ti**on, lea**sh**
ʒ	plea**s**ure, bei**ge**, sei**z**ure
x	Scottish lo**ch**
h	**h**am
m	**m**an, ha**m**
n	**n**o, ti**n**
ŋ	ri**ng**er, si**ng**, fi**n**ger, dri**n**k
l	**l**eft, be**ll**
ɹ	**r**un, ve**r**y
w	**w**e, q**u**een
j	**y**es
ʍ	**wh**at

Source: Adapted from *Wikipedia,* *"*IPA Chart for English Dialects,*"* n.d.

Table A10. IPA- Select Vowels
AuE = Australian English
GA = General American English
RP = Received Pronounciation (England)

AuE	GA	RP	Examples
æ, æː	æ	æ	lad, bad, cat
aː	ɑ	ɑː	father
ɔ		ɒ	not, wasp
oː	ɔ	ɔː	law, caught, all, halt, talk
ə	ə	ə	about
	ɨ	ɪ	English
ɪ	ɪ	ɪ	sit
i	i	i	city
iː		iː	see
			meat
æɪ	eɪ	eɪ	date
			day, pain, whey, rein
e	ɛ	ɛ	bed
ɜː(ɹ)	ɝ/ɹ̩	ɜː(ɹ)	burn
			herd, earth
			bird
aː(ɹ)	ɑɹ	ɑː(ɹ)	arm, car
a	ʌ	ʌ	run, won, flood
ʊ	ʊ	ʊ	put
			hood
ʉː	u	uː	soon, through
ə(ɹ)	ɚ/ɹ̩	ə(ɹ)	winner

Source: Adapted from *Wikipedia, "*IPA Chart for English Dialects,*"* n.d.

APPENDIX C

SELECT PARAMETERS EVALUATED BY THE MULTI-DIMENSIONAL VOICE PROGRAM™

Extracted Parameters on Radial Graph

APQ (Amplitude Perturbation Quotient)
Jita (Absolute Jitter)
Jitt (Jitter Percent)
PPQ (Pitch Period Perturbation Quotient)
RAP (Relative Average Perturbation)
SAPQ (Smoothed Amplitude Perturbation Quotient)
ShdB (Shimmer in dB)
Shim (Shimmer Percent)
SPPQ (Smoothed Pitch Period Perturbation Quotient)
VTI (Voice Turbulence Index)
SPI (Soft Phonation Index)
NHR (Noise-to-Harmonic Ratio)
ATRI (Amplitude Tremor Intensity Index)
Fatr (Amplitude-Tremor Frequency)
Fftr (Fo-Tremor Frequency)
FTRI (Frequency Tremor Intensity Index)

Extracted Parameters Not on Radial Graph

DSH (Degree of Sub-Harmonics)
DUV (Degree of Voiceless)
DVB (Degree of Voice Breaks)
Fhi (Highest Fundamental Frequency)
Flo (Lowest Fundamental Frequency)
Fo (Average Fundamental Frequency)
Mfo (Mean Fundamental Frequency)
NSH (Number of Sub-Harmonic Segments)
NUV (Number of Unvoiced Segments)
NVB (Number of Voice Breaks)
PER (Pitch Periods)
PFR (Phonatory Fundamental Frequency Range)
SEG (Total Number of Segments)
STD (Standard Deviation of the Fundamental Frequency
To (Average Pitch Period)
Tsam (Length of Analyzed Data Sample)
vAm (Peak Amplitude Variation)
vFo (Fundamental Frequency Variation.

Source: *Multi Dimensional Voice Program Model 5105: Software Instruction Manuel*, 1999, 15-19.
Note: For complete information concerning these parameters, see *Multi Dimensional Voice Program Model 5105: Software Instruction Manuel*, (Lincoln Park, NJ: Kay Elemetrics Corp., 1999), 15-19.

APPENDIX D

SAMPLE FORM FOR DATA COLLECTION

Name____Age_____Sex____

Name of Evaluator______________________________ Date of Evaluation__________

Location of Evaluation___________________________

Equipment used for evaluation
(specify exact brand, model, for all equipment including microphone, computer, keyboard, spirometer, stopwatch, etc.)

Maximum Phonation Time (MPT)

Trial 1.__________(s)
2.__________(s)
3.__________(s)

Vital Capacity (VC)

Trial 1.__________(ml)
2.__________(ml)
3.__________(ml)

S/Z ratio

/s/

Trial 1.__________(s)
2.__________(s)
3.__________(s)

Maximum phonational duration of /s/__________(s)

/z/

Trial 1.__________(s)
2.__________(s)
3.__________(s)

Maximum phonational duration of /z/__________(s)

Maximum /s/________(s)
-------------------------------- = _____________ = s/z ratio
Maximum /z/________(s)

Speaking Fundamental Frequency (SFF)

Reading passage used (e.g. the Rainbow Passage): ____________________

Average SFF__________(Hz) ___________(pitch)

Phonational Range

Vowel__________

Lowest Frequency____________(Hz) ___________(pitch)

Highest Frequency____________(Hz) ___________(pitch)

Voice Range Profile

Pitch Sounded	Frequency sounded (Hz)	Soft phonation SPL (dB)	Loud phonation SPL (dB)	Vowel used
Ex) B4	246.94	89	105	/a/

Note: Remaining acoustic data from MDVP™ or another computerized program should be attached to this form.