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PERSPECTIVES on Voice and Voice Disorders

AMERICAN SPEECH-LANGUAGE-HEARING ASSOCIATION **DIVISION 3**

Mary J. Sandage

Coordinator's Corner

Greetings from the Division 3 Steering Committee (SC)! We are very pleased to bring the third and final issue of our 2007 *Perspectives* to you as a professional resource and a means to gather a few extra continuing education hours at the close of this calendar year. The quality of this publication has improved in the last few years, and we have our outgoing Editor, Bari Hoffman Ruddy, PhD, to thank for her tireless hours of planning, soliciting manuscripts, and editing. We are in your debt, Dr. Ruddy!

At the end of this year, Susan E. Baker, PhD, will take over as Managing Editor of *Perspectives,* and Tanya Edie, PhD, will join us in the role of Associate Editor. We greatly appreciate the contributions of all the authors of this issue and extend particular thanks extended to Drs. Diane Bless and Charles Ford who so expertly discuss scope of practice issues of the otolaryngologist and the speech language pathologist when assessing voice. Also, take note of the second installment of our new column Dollars $$ Sense, written by Dee Nikjeh, PhD.

Detailed plans have already been made for our 2008 *Perspectives,* the topics of which will include coding and reimbursement, management of tracheostomy and ventilator dependent patients, and research to clinical/bench to bedside research update. All promise to be substantial and current.

Going Green

Perspectives will go online *only* in 2008. During recent years, the dramatic growth in Division membership in company with increased printing and mailing costs for *Perspectives* meant devoting additional affiliate membership funds toward the production of this publication. Going online will re-align our budget, freeing up funds to devote to additional affiliate benefits (e.g., scholarship efforts, the development of assessment guidelines, etc.).

Perspectives will be published by HighWire Press, a division of the Stanford University Libraries, currently responsible for publishing the ASHA journals. Affiliates will have full-text access to current and archived content. Cross referencing and other features available for ASHA journals will also be available for *Perspectives.* **Please activate your HighWire account; *Perspectives* content can be accessed only through that account.** Go to http://journals.asha.org/cgi/activate/basic and use your ASHA ID (the number on your card and on your journal) to activate. Then, when your first issue of *Perspectives* appears in 2008, you'll have immediate access!

Where's the Money?

As this issue goes to press, the Division Reimbursement committee, chaired by Edie Hapner, PhD, is finalizing an ASHA seminar addressing best coding and billing practices for voice assessment.

As an important follow-up to the many affiliate questions regarding billing practices, documentation, and the appeals process, the entire March 2008 *Perspectives* issue will be devoted to reimbursement. Each state and service delivery setting may differ on best practice for reimbursement and unraveling the details can be confusing. Dr. Hapner and her committee, which includes Dee Nikjeh, PhD, Sandy Schwartz, and Mark Kander, ask that affiliates with coding questions seek answers from the reimbursement committee or from the ASHA staff directly (reimbursement@asha.org).

Assessment Guidelines

The Division 3 SC is thrilled to announce that a resolution has been submitted for approval to form a committee that will develop guidelines for voice assessment! These guidelines should be of use for any clinical setting, whether you have expensive di-

In This Issue. . .

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Use of Aerodynamic Measures in Clinical Voice Assessment

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Aerodynamic forces play a major role in the production of voice, so it seems reasonable that a complete clinical voice evaluation would include assessment of aerodynamic parameters. But a recent survey of voice therapists indicates that many do not have access to aerodynamic instrumentation and, even when equipment is available, aerodynamic assessment is not uniformly applied in the voice assessment process (Behrman, 2005). At our Center, aerodynamic assessment is a routine part of a complete voice evaluation.

The purpose of this article is to provide our perspective on the appropriate utilization of current approaches for the clinical assessment of vocal aerodynamics. Members of our group originally expressed their views on this topic as part of a publication entitled "Appropriate Use of Objective Measures of Vocal Function in the Multidisciplinary Management of Voice Disorders" (Hillman, Montgomery, & Zeitels, 1997). The current article essentially represents an updated and greatly expanded version of the sections in our original 1997 publication that were pertinent to aerodynamic assessment. This is very much a "nuts and bolts" description of how we clinically employ aerodynamic measures in a busy Voice Center. We conclude the present piece with a brief discussion of potential future developments/improvements in clinical methods for the aerodynamic assessment of vocal function. Readers seeking more complete information about the general topic of aerodynamic measurement of voice are directed to previous publications devoted entirely to a more comprehensive review of this area (Hillman, 2004; Hillman & Kobler, 2000).

General Philosophy of Objective Measurement

Aerodynamic measures can be used in the objective clinical assessment of how the larynx is functioning to produce voice (i.e., *vocal function*). Other common objective voice measures are derived from acoustic and electroglottographic assessments. The general concept of objective measurement of vocal function stems from a long-standing desire in the field to develop measures that would be less subjective and provide more reliable insights into vocal function than judgments that rely heavily on auditory perception (i.e., the clinician's impression that the voice "sounds" better or worse following treatment).

Given their current state of development, objective measures in general, and aerodynamic measures in particular, should not be viewed as primary diagnostic procedures. Instead, they are supplemental "tools" that are used as part of a comprehensive, integrated evaluation to enhance the quality of diagnosis and treatment. As such, objective measures are used to support and validate clinical judgments, not replace them.

Objective test results should be integrated into the evaluation report, where they are used as evidence to support clinical impressions, diagnoses, and treatment recommendations. When used and interpreted appropriately, objective measures provide quantitative documentation of vocal function as well as additional insights into underlying vocal mechanisms. By their very nature, such measures fill the growing need for objective outcome data to assist in the assessment of treatment efficacy.

Using Aerodynamic Measures

Voice is produced when the positive *subglottal air pressure* generated by an exhaled *volume of pulmonary air* exceeds the resistance of the adducted vocal folds, causing the folds to be blown into *airflow-induced* oscillation. As the vocal folds oscillate, pulses of air are emitted from the glottis (the glottal volume velocity waveform) to generate the acoustic energy that is perceived as the voice. This very brief description of the phonation process illustrates that *air volumes, air pressures,* and *airflows* all play a role in voice production.

While there are a number of methods that can be used to measure these aerodynamic parameters at various locations in the phonatory system (see Hillman & Kobler, 2000), current clinical voice assessment approaches, and associated instrumentation, are typically designed to obtain indirect estimates of average glottal airflow rates (L/sec) and average subglottal air pressures (cm H_20), along with simultaneous acoustic measures of vocal fundamental frequency (F_0) and sound pressure level (SPL).

These parameters are then often used as a basis for deriving additional vocal function measures, such as glottal resistance (a ratio of subglottal air pressure to glottal airflow) and vocal efficiency (a ratio of aerodynamic power at the larynx to the acoustic output power at the lips, with aerodynamic power being the product of subglottal air pressure and glottal air flow).

Estimates of glottal airflow and subglottal air pressure are derived using a long-established approach (Smitheran & Hixon, 1981) in which subjects produce a simple, well-controlled utterance (e.g., strings of /pi/ syllables at constant pitch and loudness levels) and noninvasive measurements of oral airflow (pneumotachograph and facemask) during vowels, and intraoral air pressures (catheter and pressure transducer) during bilabial stop consonants are used to estimate glottal airflows and subglottal air pressures respectively. The clinical systems that are used to obtain these measures also typically have a small microphone located down stream from the airflow sensing pneumotachograph to record the acoustic signal for F_0 and SPL extraction.

In our center, we have patients produce three strings of five /pae/ or /pi/ syllables at comfortable pitch and loudness, and then again using "louder" voice (the target is approximately a 6 dB increase). Measures are performed on the middle three syllables in each string to avoid voice initiation and termination effects (Holmberg, Perkell, & Hillman, 1984), yielding a total of nine sets of measurements per loudness condition. The nine data points are then used to obtain an average and standard deviation for each parameter for both comfortable and loud voice.

For the approach described above, to produce valid indirect estimates of laryngeal aerodynamic parameters, clinicians must closely monitor the airflow and air pressure signals during recording to ensure that the basic assumptions underlying the method are sufficiently satisfied. For both the airflow and pressure measures, the basic criteria for meeting underlying methodological assumptions is that signals must approximate a steady state (i.e., the flow signal should "level-off" during the mid portion of the vowel) and the pressure signal should display a "flat top" during lip closure for the /p/. These criteria ensure that airflows and pressures have equilibrated throughout the entire vocal tract, and, under these conditions, oral measurements can be used to estimate laryngeal aerodynamic parameters.

We have found that a few relatively simple specifications/instructions tend to facilitate elicitation of the desired airflow and pressure signals (Holmberg et al., 1984):

- An optimal target speech rate for facilitating the desired signals is approximately 1.5 syllables per second (approximately 3.5 seconds per syllable string).
- Each string of five syllables should be produced in a continuous fashion with no breaks between syllables ("choppy" productions with breaks between syllables tend to produce peaky pressure signals); we often instruct patients to "think about prolonging the vowel and simply insert the p-sounds."
- Pitch and loudness must be held as constant as possible to ensure that average glottal conditions are remaining as stable as possible during the utterance; it is common for patients to quickly fall into a "sing-song" type of pattern with associated up and down fluctuations in F_0 and/or SPL across the syllable string; such fluctuations are typically reflected in a flow signal that does not attain the required steady-state during vowel production.

Admittedly, for a few patients, no amount of instruction or practice produces the desired signals. In such cases, we are less likely to accept an unstable (non-steady state) airflow estimate, but are usually more willing to use elevated estimates of air pressure as evidence of abnormality since we have previously shown that failure to meet the signal criteria (usually appears as a "peaky" pressure signal with no flat portions at the peaks) generally results in underestimation of parameter values (Holmberg et al., 1984).

One additional clinical hint is: Be very wary of abnormally low average airflow values, particularly in cases where the patient can produce normal vocal intensity levels. In these situations, make certain that the airflow facemask is sealed tightly around the patient's nose and mouth, because even very small leaks can significantly reduce the rate of airflow that is registered.

Normative Data

As is the case for most measures of vocal function, there is not currently a set of normative data for aerodynamic measures that is universally accepted and/or applied in research and clinical work. Methods for collecting such data have not been standardized, and study samples have generally not been of sufficient size and/or appropriately stratified in terms of age and sex to ensure unbiased estimates of underlying aerodynamic phonatory parameters in the normal population.

However, there are several sources in the literature that provide estimates of normative values for selected aerodynamic measures (Baken, 1987; Colton, Casper, & Leonard, 2005; Holmberg, Hillman, & Perkell, 1988; Keilmann & Bader, 1995; Kent, 1994; Melcon, Hoit, & Hixon, 1989; Netsell, Lotz, Peters, & Schulte, 1994; Stathopoulos, 1986; Stathopoulos & Weismer, 1985; Tang & Stathopoulos, 1995). In our center, we use data from several of these sources in order create normative ranges that are as representative as possible of sex- and age-based difference in parameters. This is necessary since there can be significant differences in what is considered normal for a parameter depending on the age and sex of the speaker.

Clinical Interpretation

It is relatively intuitive and commonly accepted that, during phonation, incomplete closure of the membranous glottis tends to produce increased average airflow rates and that anything which impedes normal vocal fold vibration (e.g., incomplete glottal closure, damage, and/or loss of superficial lamina propria) will result in elevated average subglottal air pressures. Successful treatments to correct such deficits should produce airflow and pressure values that more closely approximate normal.

However, there are some additional nuances to the clinical use of aerodynamic measures that we would like to share, because we believe these observations/recommendations increase the utility of the measurements.

It has been shown that average glottal airflow rates can display a relatively high degree of variation across repeated recordings of normal speakers, which cannot easily be corrected for (Holmberg, Hillman, Perkell, & Gress, 1994). A likely source of this normal variation is changes in the unmodulated (DC) component of the glottal flow, which result from variance in the extent to which the posterior glottis closes across repeated phonations (i.e., variation in posterior glottal opening size; Holmberg et al., 1988). Such normal variations in DC flow do not appear to have a significant impact on voice quality as long as the posterior glottal opening does not extend into the membranous glottis.

Thus, we find average airflow rate to be most useful and reliable as an indicator of relatively large changes in vocal function (e.g., comparing vocal function before and after medialization for vocal fold paralysis), but that it tends not to be sensitive enough for tracking relatively small changes in the phonatory function of the vocal folds. Unfortunately, the high normal variation in average airflow rates also has the potential to limit the sensitivity of additional derived measures that include average airflow as a component, including glottal resistance and vocal efficiency (Hillman, Holmberg, Perkell, Walsh, & Vaughan, 1989).

Subglottal air pressure is highly correlated with the sound pressure level of the voice. Thus, the sensitivity and usefulness of subglottal pressure estimates can be greatly increased if interpreted relative to simultaneously-measured vocal sound pressure levels (Holmberg et al., 1994). In our center, we use age- and gender-specific normative data as a basis for calculating simple ratios which directly characterize the expected normal relationships between vocal sound pressure level and subglottal air pressure in dB SPL and cm H_2O, respectively. In this way, we can determine whether a patient is using excessive subglottal driving pressure to produce a given SPL output, even if the absolute air pressure value is within normal limits.

Such a scenario, in combination with other observations, can often be interpreted as evidence of vocal hyperfunction (Hillman et al., 1989; Hillman, Holmberg, Perkell, Walsh, & Vaughan, 1990). There is even some evidence that the SPL-pressure relationship may be more sensitive to the presence of vocal pathology than are some common acoustic measures (Holmberg, Doyle, Perkell, Hammarberg, & Hillman, 2003). Along the same lines, we have found that examining the SPL-pressure relationship for the increased loudness condition is particularly useful in reflecting the increased difficulties that some patients associate with trying to project their voices for lecturing, trying to talk above background noise, etc., all of which can also be associated with vocal fatigue. In such cases, the SPL-pressure ratio tends to become much more abnormal during the attempt to increase vocal loudness as compared to the comfortable loudness condition.

The commonly-used method of estimating subglottal air pressure from the intraoral air pressure during bilabial stop consonant production (i.e., /pi/ syllable strings) assumes that laryngeal conditions such as muscle tension do not vary significantly across the test utterance. While this approach has been validated via tracheal puncture in normal subjects (Lofqvist, Carlborg, & Kitzing, 1982), there is concern that absolute pressure value estimates need to be viewed cautiously when obtained from patients with laryngeal conditions that vary significantly across the test utterance (e.g., spasmodic dysphonia). However, in such cases, the finding of abnormally high pressures and the monitoring of the relative change in pressure with treatment are still useful and valid.

Future Directions

While the aerodynamic measures that we currently employ in clinical voice assessment are quite useful to us, there is clearly an interest in further developing and improving aerodynamic methods for clinical use. We conclude this article with a brief discussion of three possibilities for future developments in this area

1. The aerodynamic measurement methods that we currently use in the clinic produce only averaged values. This particularly limits our ability to more accurately assess glottal airflow since we can not separate out the contributions of the modulated (AC) versus unmodulated (DC) components of the flow (see discussion above about the assumed impact of DC flow on normal variation in the average flow), and we cannot estimate AC flow parameters that are directly related to the acoustic properties of the voicing source. Methods for estimating the detailed pattern of airflow at the glottis (e.g., inverse filtering of the oral airflow to estimate the glottal volume velocity waveform) have been used in studies of normal and disordered voice production for some time [see (Hillman et al., 1989; Holmberg et al., 1988)]. However, these approaches have not been adopted in the clinic due largely to persistent technical challenges associated with clinical implementation. Recently, there has been some renewed interest in implementing measures of glottal volume velocity on more user-friendly systems, raising the hope that these measures will gain larger clinical application.
2. It has also been suggested for some time that measuring the minimal aerodynamic forces that are required to initiate phonation would provide a more sensitive assessment of the impact of vocal pathology on vocal function than current approaches (Chan, Titze, & Titze, 1997; Jiang & Tao, 2007; Titze, 1992; Verdolini et al., 2002). We expect measures such as *phonation threshold pressure* and/or *phonation threshold flow* to eventually gain wider use in clinical voice assessment.
3. The recent increase in attempts to apply aeroacoustic principals to the study of voice and speech production (McGowan & Howe, 2007) holds the promise of elucidating higher-order, nonlinear processes at the laryngeal level that may be particularly significant to developing a better understanding of the mechanisms underlying disordered voice production. These efforts are in their relative infancy, and it will most likely be quite some time before any clinical applications can be considered.

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Clinical Applications and Use of the Voice Range Profile

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Quantifying perceptual measures of normal, disordered, and exceptional voices has become more tangible through the use of Voice Range Profiles (VRP). Specifically, VRP graphic representation of a patient's physiologic vocal capabilities by plotting frequency (x-axis) by intensity (y-axis) provides the voice clinician with another viable tool for measuring change and therapeutic efficacy. Taking into account both the source (vocal folds) and filter (vocal tract), the VRP (Figure 1) provides clinicians and researchers with a quantitative representation of a given persons maximal and minimal vocal output. Obtaining a VRP manually (pitch reference and sound level meter) or via an automated computer program has made the VRP an easily accessible and functional for most voice clinicians and researchers. This paper will focus on the history of the VRP, its clinical utility, methodology in obtaining a VRP, and relevant clinical research.

Historical Background

As early as the 1930s, voice researchers became interested in the ability to plot acoustic vocal output at various intensities and frequencies (Stout, 1938; Wolfe, Stanley, & Sette, 1935). Initial research specifically investigated the singing voice and its relation to pitch and intensity. A second wave of interest was generated in 1952 with Calvet and Malhiac's published paper on "Vocal curves and mutations" (*courbes vocals et muedela voix*). However, it was not until the 1970s and 80s when the use of the VRP began to