# Phonation Quotient in Women: A Measure of Vocal Efficiency Using Three Aerodynamic Instruments

*Ashwini Joshi and †Christopher R. Watts, *Houston and †Fort Worth, Texas

**Summary: Objective.** The purpose of this study was to examine measures of vital capacity and phonation quotient across three age groups in women using three different aerodynamic instruments representing low-tech and high-tech options.
**Study Design.** This study has a prospective, repeated measures design.
**Methods.** Fifteen women in each age group of 25–39 years, 40–59 years, and 60–79 years were assessed using maximum phonation time and vital capacity obtained from three aerodynamic instruments: a handheld analog windmill type spirometer, a handheld digital spirometer, and the Phonatory Aerodynamic System (PAS), Model 6600. Phonation quotient was calculated using vital capacity from each instrument. Analyses of variance were performed to test for main effects of the instruments and age on vital capacity and derived phonation quotient. Pearson product moment correlation was performed to assess measurement reliability (parallel forms) between the instruments. Regression equations, scatterplots, and coefficients of determination were also calculated.
**Results.** Statistically significant differences were found in vital capacity measures for the digital spirometer compared with the windmill-type spirometer and PAS across age groups. Strong positive correlations were present between all three instruments for both vital capacity and derived phonation quotient measurements.
**Conclusions.** Measurement precision for the digital spirometer was lower than the windmill spirometer compared with the PAS. However, all three instruments had strong measurement reliability. Additionally, age did not have an effect on the measurement across instruments. These results are consistent with previous literature reporting data from male speakers and support the use of low-tech options for measurement of basic aerodynamic variables associated with voice production.
**Key Words:** vocal efficiency–spirometer–aerodynamics–vital capacity–phonation quotient.

## INTRODUCTION

Aerodynamic assessment forms one of the main domains of voice evaluation. Assessment of airflow, air pressure, lung volume, phonation efficiency, and associated measurements has been recommended as part of a comprehensive voice evaluation by the Special Interest Group 3 of the American Speech-Language-Hearing Association in addition to the European Laryngological Society.[1,2] Subtle changes in the laryngeal anatomy and function can alter the balance between the respiratory and the phonatory systems and impair the process of voice production. Assessment of aerodynamics in disordered voice contributes to clinical understanding of the pathophysiology underlying a voice disorder, developing a treatment plan to rehabilitate vocal function, and obtaining baseline measurements to which change with treatment can be compared.[3] Among the aerodynamic measurements available to clinicians, vital capacity (VC) and transglottal airflow rate provide information about the volume of air available to power vocal fold vibration and how efficiently the vocal folds valve that air, respectively. Although acquisition of these measurements requires instrumentation, there is a wide range of instruments available for clinical application. Unfortunately, there is little research evidence available to inform our knowledge of measurement reliability between different instruments used for aerodynamic analyses.

For clinicians working in settings ranging from private practice, schools, hospitals, nursing homes, and home health, cost of the assessment tools plays a major role in deciding the assessment protocol. A complete aerodynamic assessment using a precision high-tech pneumotachograph-based system to obtain aerodynamic measurements may not be possible for a large number of clinicians who do not have the necessary resources, or cannot justify purchasing equipment costing thousands of dollars. In the absence of high-tech equipment, clinicians do have other viable options in the form of low-tech spirometers combined with physiological measurements such as maximum sustained phonation.[4,5] Although low-tech options do not allow for measurements of air pressure, spirometers can be used to measure VC and a stopwatch or timer can be used to measure maximum phonation time (MPT). These measurements provide important clinical information regarding lung capacity and phonation efficiency, respectively. Together they can be used to calculate an indirect estimate of transglottal airflow rate. The ratio of VC to MPT (VC/MPT) will provide the measurement of phonation quotient (PQ) in milliliters per second (mL/s), an indirect measure of airflow rate that can also be used to infer voicing efficiency. PQ has been used in comparative studies of normal aging and sex differences; disordered phonation secondary to neurologic, benign, and malignant lesions; and to document treatment outcomes.[3,5–11]

Hirano et al[12] in 1968 were the first to use and assess the reliability of PQ as a measure, without a pneumotachograph, to quantify air usage during phonation. Measurements of mean flow rate (MFR) obtained from pneumotachograph-based instruments tend to be lower than PQ derived from VC and MPT, because the latter are obtained from productions of maximum performance.[9,13,14] Although absolute values were different, Hirano et al[12] found a strong correlation between MFR obtained with

Accepted for publication June 15, 2016.
From the *Department of Communication Sciences and Disorders, University of Houston, 4455 Cullen Blvd, Houston, Texas; and the †Harris College of Nursing & Health Sciences, TCU Box 297450, Fort Worth, TX 76129.
Address correspondence and reprint requests to Ashwini Joshi, Department of Communication Sciences and Disorders, University of Houston, 4455 Cullen Blvd, Houston, TX 77204. E-mail: ajoshi4@uh.edu
Journal of Voice, Vol. 31, No. 2, pp. 161–167
0892-1997

http://dx.doi.org/10.1016/j.jvoice.2016.06.007

a high-tech instrument and PQ obtained with low-tech instruments for both men and women, demonstrating the feasibility of using PQ in the absence of a pneumotachograph. PQ has been used in other diagnostic studies of disordered voice in patients with vocal fold inflammation, benign and malignant tumors, unilateral and bilateral vocal fold paralysis, spasmodic dysphonia, and functional voice disorders.[10–12] PQ values in disordered voices are typically higher[7] owing to reduced MPT in the context of VC remaining within normal limits. Although PQ does not distinguish between different pathologies, it does provide information specific to how pathology influences airflow through the glottis during phonation. As such, PQ has been used in treatment studies to monitor change in patients with vocal fold paralysis,[15–17] Parkinson disease,[18] and early glottic cancer.[19,20]

Rau and Beckett[5] used three different spirometers to measure PQ in healthy adults to assess feasibility of the equipment. They used data from a high-tech wet respirometer as a reference to compare the data they obtained with their handheld spirometers. The values obtained with the spirometers corroborated with those in the initial Hirano et al study,[12] leading them to the conclusion that low-tech handheld spirometers can be reliably used for aerodynamic assessment. In a recent study using two handheld spirometers (a digital spirometer and an analog spirometer) and a pneumotachograph in men, we found PQ values derived from all three instruments were consistent with the results found by Joshi and Watts[4] and Rau and Beckett.[5] More importantly, although there were strong correlations between the three instruments for VC and PQ, there was no statistically significant difference in the data obtained with the analog handheld spirometer and the pneumotachograph-based system.

Differences between male and female values on aerodynamic measures are well documented secondary to physiological differences in the respiratory and phonatory systems.[21,22] Adults in the age group of 18–40 years have been shown to have the highest values for MFR, MPT, and VC as compared with children and older adults (over 65 years).[23,24] However, Awan[6] did not find significant differences in PQ across age groups in women. This could be attributed to consistent changes in the components of the PQ measurement—MPT and VC—with age. The purpose of the present study was to extend our previous investigation by replicating the methodology in women. In addition, we recruited women representing three different age ranges to determine if VC and PQ obtained from low-tech and high-tech systems were affected by age. A major purpose of this line of investigation is to determine the extent of parallel forms reliability between low-tech, relatively inexpensive equipment and high-tech equipment used for aerodynamic analyses.[25] To accomplish this, a pneumotachograph-based system was used as the standard for comparison of VC and PQ measures with lower cost analog and digital spirometers.

## METHODS

### Participants

Forty-five nondysphonic women were recruited for this study. Participants were recruited into three different groups comprising 15 women each within the ages of 25–39 years, 40–59 years, and 60–79 years. All participants were self-reported nonsmokers with no complaints of hearing loss, pulmonary, neurological, previous, or current voice disorder. The study was approved by the Committee for Protection of Human Subjects at the authors' respective universities.

### Instruments

VC and derived PQ values were obtained using three instruments (Figures 1–3). The two low-tech (cost < $300) handheld spirometers chosen were an analog windmill-type (Baseline Measurement Instruments, Fabrication Enterprises, Inc., White Plains, NY) and a digital spirometer (SP10, Contec Medical, China). Both were handheld devices placed by the participants to their mouth. Airflow through a mouthpiece on the windmill spirometer moves an analog dial around a measurement window on the face piece of the spirometer. The body of the spirometer is lightweight with an internal resistance screen. The digital spirometer converts the analog signal to a digital signal using an internal circuit board. This device also requires air to be blown through a mouthpiece against the resistance of internal metal blades. The

**FIGURE 1.** Baseline windmill-type spirometer. (Baseline Measurement Instruments, Fabrication Enterprises, Inc., White Plains, NY.)


**FIGURE 2.** SP10 Digital Spirometer. (Contec Medical, China.)

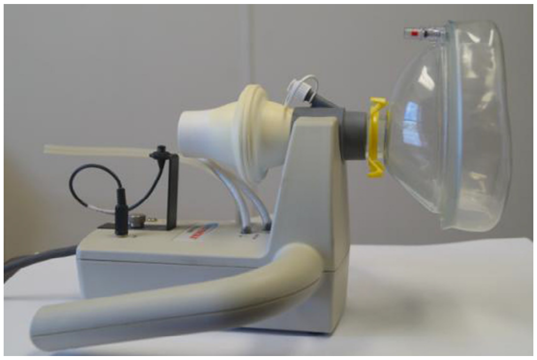

**FIGURE 3.** Phonatory Aerodynamic System (PAS), Model 6600. (KayPENTAX Corp, Lincoln Park, NJ.)

liquid crystal display provides the measured values. The high-tech pneumotachograph-based system (cost >$1000) used as the standard for comparison was the Phonatory Aerodynamic System (PAS) Model 6600 (KayPENTAX Corp, Lincoln Park, NJ). The pneumotachograph provides a line input to a desktop personal computer. Custom software is used to digitize and process the aerodynamic signal for recording, playback, and analysis.

### Calibration protocol

Instrument calibration was completed before each measurement session. The windmill and digital spirometer were calibrated with the same 1.0 L calibration syringe used in the calibration of the PAS. A mouthpiece of the spirometer was attached to the syringe with a suitable adaptor. The plunger was fully withdrawn and then completely depressed. The measured volume was displayed on the screen of the spirometer and was accepted if it was within 1% of the 1.0 L volume. Calibration of the PAS airflow head was performed as described in the PAS instruction manual[26].

### Procedure

Each testing session began with three trials of MPT followed by obtaining VC measures on the spirometers and PAS. The order of the instruments for VC was counterbalanced between participants. The method of measurement for MPT and VC mirrored typical clinical practice. For the MPT task, the participant was given instructions to take a deep breath, sustain the vowel /a/ for as long as possible until she completely ran out of air while the investigator manually operated a stopwatch to calculate MPT. The participants were given a 1-minute rest period between trials.

The participants received the same instructions to complete VC measures on all three instruments. They were asked to breathe in maximally, place their mouth around the mouthpiece of the spirometer or in the face mask of the PAS, and blow out all their air until they have nothing left to expire. Participants used a nose clip to prevent nasal air escape and were instructed to ensure a good lip seal around the mouthpieces for the spirometers. For the PAS, they were asked to place the face mask firmly against their face to prevent any air escape. Three trials of VC were completed on each instrument, with 1-minute rest periods between trials. The display showed the VC value for the spirometers. The VC protocol was used when capturing data with the PAS.

### Analyses

PQ was calculated using the VC trial with the largest volume (in milliliters) on each instrument and divided by the longest MPT trial (in seconds). Statistical analyses were performed using *SPSS Statistics 23.0* (IBM Corp, Armonk, NY).[27] A univariate analysis of variance (ANOVA) was calculated to test the main effects of instrument and age on measures of VC and PQ, respectively. *Post hoc* analyses using Fisher least significant difference (LSD) were performed for further investigation of significant differences in the ANOVA. A Pearson product moment correlation was applied to the VC and PQ data from the three different instruments to investigate the degree of measurement reliability. Scatterplots and regression equations for the two spirometers and the PAS were also computed.

## RESULTS

Means, standard deviation, and age range for each of the age groups is provided in Table 1. Analysis of the data for normality revealed normal distributions for all three groups (Table 1). Mean and standard deviation for the longest MPT trial for the age groups of 25–39 years (25.27 seconds, SD = 5.16) and 40–59 years (24 seconds, SD = 5.52) were similar, whereas the older group (60–79 years) had a lower mean of 18.73 seconds (SD = 4.73). Means, standard deviation, range, and standard error for VC and PQ for each instrument by age group are provided in Table 2.

### Vital capacity

A one-way ANOVA for VC revealed main effects for both instruments (F = 10.05, df = 2, $P < 0.001$) and group (F = 7.98, df = 2, $P < 0.001$). There was no interaction effect of group and instrument. *Post hoc* analyses using Fisher LSD for the main effect of instrument revealed significant difference between windmill and digital spirometers ($P = 0.003$) and the digital spirometer and PAS ($P < 0.001$). There was no significant difference between the windmill spirometer and the PAS ($P < 0.1$). *Post hoc* analyses for the main effect of age group revealed no significant difference between 25–39 years and 40–59 years ($P = 0.127$) but a significant difference between 25–39 years and 60–79 years ($P < 0.001$), and 40–59 years and 60–79 years ($P < 0.001$).

### Phonation quotient

A one-way ANOVA for PQ revealed a main effect of instrument (F = 3.43, df = 2, $P = 0.035$) but not for group (F = 0148, df = 2, $P = 0.863$). There was no interaction effect of group and instrument for PQ. *Post hoc* analyses using Fisher LSD for the main effect of instrument revealed significant differences between

**TABLE 1.**
**Means, Standard Deviation (SD), Range, and Skewness of Distribution for Each Age Group (Years)**

| Age Group | Mean | SD | Range | Skewness |
|---|---|---|---|---|
| 25–39 | 31.20 | 4.28 | 13 | –0.266 |
| 40–59 | 48.93 | 5.52 | 18 | 0.554 |
| 60–79 | 65.73 | 4.75 | 15 | –0.285 |

**TABLE 2.**
**Means, Standard Deviations (SD), Ranges, and Standard Errors (SE) for VC (mL) and PQ (mL/s) for Each Age Group (Years)**

| Age Group | Measure | | Windmill | Digital | PAS |
|---|---|---|---|---|---|
| 25–39 | Vital capacity | Mean | 3333 | 3015 | 3494 |
| | | SD | 483 | 220 | 451 |
| | | Range | 1600 | 680 | 1510 |
| | | SE | 137 | 137 | 137 |
| | Phonation quotient | Mean | 137.22 | 124.61 | 143.62 |
| | | SD | 34.51 | 29.29 | 33.51 |
| | | Range | 98.4 | 91.94 | 117.52 |
| | | SE | 10.61 | 10.61 | 10.61 |
| 40–59 | Vital capacity | Mean | 3140 | 2789 | 3396 |
| | | SD | 658 | 450 | 667 |
| | | Range | 2200 | 1420 | 2000 |
| | | SE | 137 | 137 | 137 |
| | Phonation quotient | Mean | 138.99 | 123.18 | 149.24 |
| | | SD | 45.67 | 37.69 | 45.20 |
| | | Range | 154.54 | 140.84 | 154.76 |
| | | SE | 10.61 | 10.61 | 10.61 |
| 60–79 | Vital capacity | Mean | 2577 | 2236 | 2627 |
| | | SD | 604 | 472 | 626 |
| | | Range | 2100 | 1630 | 2110 |
| | | SE | 137 | 137 | 137 |
| | Phonation quotient | Mean | 145.18 | 126.63 | 147.72 |
| | | SD | 48.01 | 41.93 | 49.05 |
| | | Range | 183.33 | 141.67 | 189.04 |
| | | SE | 10.61 | 10.61 | 10.61 |

the digital spirometer and the PAS at $P < 0.05$ ($P = 0.012$) and between windmill and digital spirometer at $P < 0.1$ ($P = 0.073$). These differences mirrored those from the VC measurements.

## Parallel forms reliability

A Pearson product moment correlation was used to examine parallel forms reliability between instruments. Results of this analysis are provided in Table 3. All correlations were significant at the $P < 0.01$ level (two-tailed). Moderately strong positive correlations observed for VC for both spirometers with the PAS in the 25- to 39-year-old group (r = 0.570 to 0.636). Stronger correlations were present for PQ between all three instruments for this group along with VC and PQ correlations for the other two groups (correlation coefficients ranged from r = 0.864 to 0.960). These

**TABLE 3.**
**Intercorrelation Matrix for VC and PQ**

| Group | | | Windmill | SP10 | PAS |
|---|---|---|---|---|---|
| 25–39 years | Vital capacity | Windmill | 1.00 | .570 | .636 |
| | | SP10 | | 1.00 | .596 |
| | | PAS | | | 1.00 |
| | Phonation quotient | Windmill | 1.00 | .896 | .882 |
| | | SP10 | | 1.00 | .874 |
| | | PAS | | | 1.00 |
| 40–59 years | Vital capacity | Windmill | 1.00 | .928 | .900 |
| | | SP10 | | 1.00 | .949 |
| | | PAS | | | 1.00 |
| | Phonation quotient | Windmill | 1.00 | .965 | .964 |
| | | SP10 | | 1.00 | .973 |
| | | PAS | | | 1.00 |
| 60–79 years | Vital capacity | Windmill | 1.00 | .864 | .925 |
| | | SP10 | | 1.00 | .910 |
| | | PAS | | | 1.00 |
| | Phonation quotient | Windmill | 1.00 | .944 | .960 |
| | | SP10 | | 1.00 | .942 |
| | | PAS | | | 1.00 |

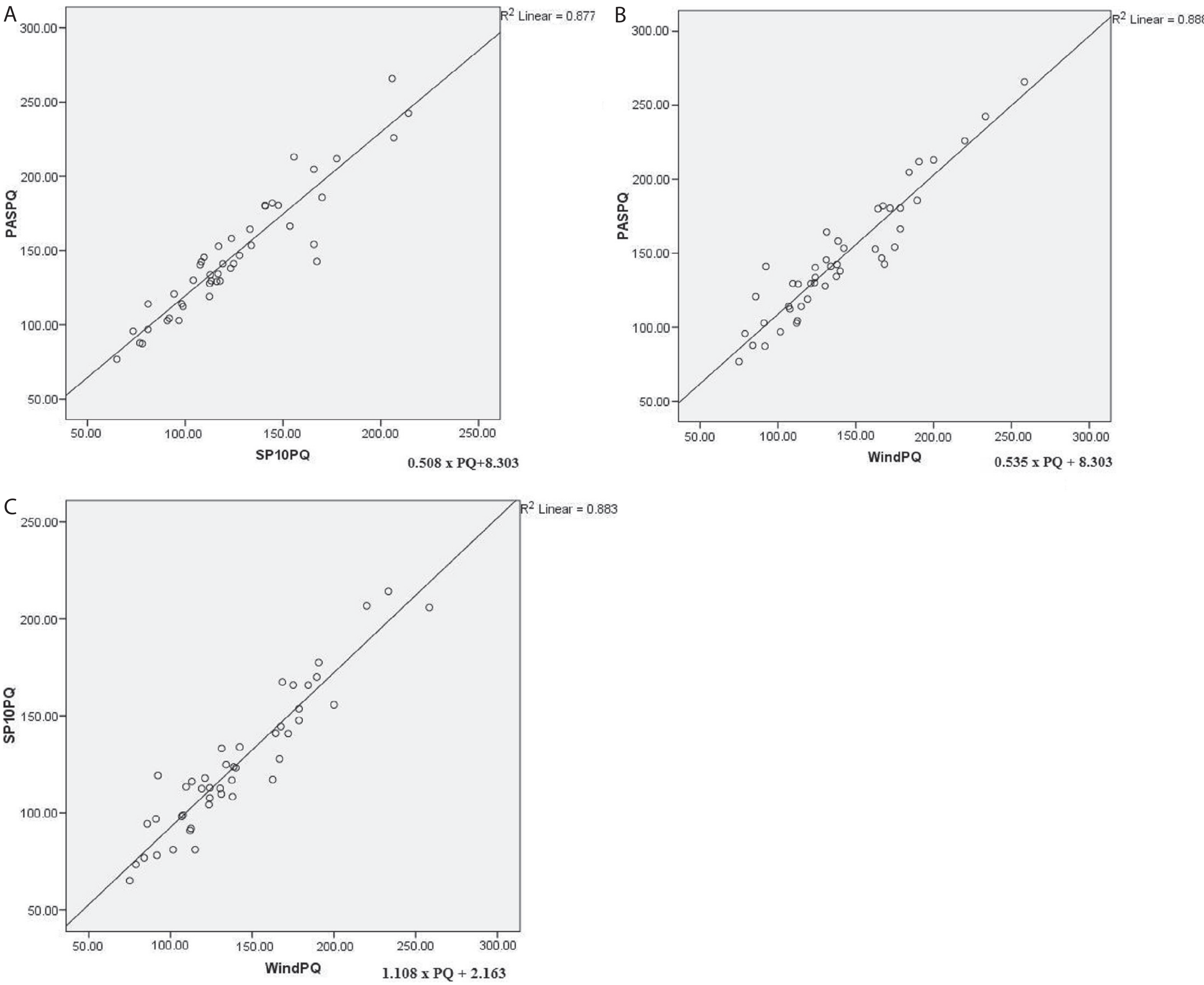


**FIGURE 4.** **(A–C)** Scatterplots, coefficients of determination ($r^2$), and regression equations for vital capacity measurements illustrating relationships between each instrument type.

relationships between instruments for VC and PQ are similar to those found by Rau and Beckett[5] and our previous study on male participants.[4]

Scatterplots of PQ data comparing the three instruments along with coefficients of determination ($r^2$) and regression equations are shown in Figure 4A–C. The graphs demonstrate strong positive relationships among the three instruments, with the windmill and digital spirometer slightly overestimating VC from the PAS, and the digital spirometer underestimating VC from the windmill spirometer. The PAS was used as a standard for comparison given its increased precision from calibration values. The regression equations in Figure 4A–B can be used as a means of correcting measurements obtained from the handheld spirometers used in this study to account for the absolute error associated with them.

## DISCUSSION

The purpose of this study was to examine parallel forms reliability for VC and PQ measures between two spirometers and a pneumotachograph-based system, and to investigate the effect of age on these measurements in female speakers. The two low-tech handheld spirometers used in this study were an analog windmill spirometer and a digital spirometer, and the PAS served as the high-tech pneumotachograph-based system. Whereas our previous study[4] looked at these data in men, the present study investigated women across three age groups ranging from 25 to 79 years. Results of the ANOVA and correlational analyses demonstrated differences for VC and PQ results based on the instrument used. Specifically, the digital spirometer had lower mean VC and PQ values across age groups as compared with the windmill spirometer and PAS values. Differences between measurements derived from the PAS and windmill spirometer were nonsignificant.

It is possible that measurement differences inherent in the digital spirometer arose from multiple sources, among which include reduced measurement precision for lower airflow, such as that at the end of the breath stream (because of the construction of the internal turbine), and loss of fidelity through the process of analog-to-digital conversion. This could explain the significantly lower VC and PQ measurements observed between the digital spirometer and other two instruments. Although absolute values of VC and derived PQ varied across the three systems, the correlational coefficients substantiated good measurement reliability, and supported the interpretation that measurements obtained from all three instruments demonstrated acceptable parallel-forms measurement reliability. This means that an increase in VC measured from one instrument would also be reflected in an increased value from the other two instruments.

Age group differences were seen for VC but not for PQ values. VC values and MPT values were lower for the oldest age group of 60–79 years than the 25–39 years and 40–59 years groups. There were no significant differences in the VC values of the younger two groups. This lowering in VC and MPT values is consistent with aging changes that affect lung volumes.[23,24] PQ being a ratio of VC and MPT, the values remained comparable with that of the younger age groups, consistent with the findings in the Awan study.[6] This finding reflects the fact that PQ is a product of the ratio between VC and MPT, both of which decrease with age and offset the changes in either individual measurement. Although further investigation is needed to better understand the effect of age on PQ, the current study suggests this measurement can be validly applied to compare phonation efficiency across different age groups.

Commercial pneumotachograph-based systems will likely continue to be the preferred instrument option for aerodynamic measurements obtained in clinical practice and research. There are multiple reasons for this supposition, including the ease of calibration, the sensitivity to low degrees of airflow, and the linearity of the output within the testing range that allows for better measurement precision.[28–30] In addition, systems such as the PAS used in this study come with the added benefit of knowledgeable customer support, which was unavailable for the low-tech instruments used. This fact could be important for practicing clinicians who rely on these instruments during routine clinical practice.

Measurement precision as reflected in the absolute VC values was likely greater with the PAS in part owing to the use of a face mask *versus* a flow tube. The handheld spirometers use a flow tube around which the speakers place their lips. This requires a good seal between the lips and the tube to prevent air escape. Although each VC production was monitored and participants wore nose clips, we were not able to measure potential air loss when participants were measured with the handheld spirometers. The use of a face mask eliminated the need for lip seal around the flow tube, the need of a nose clip, and provided more freedom for oral posturing during expiration. Despite these advantages, based on the results of this study, low-tech handheld spirometers demonstrated moderate-to-strong measurement reliability compared with the PAS when using VC to derive calculations of PQ. This finding supports their clinical application as viable and less expensive options for speech-language pathologists who acquire aerodynamic measurements during voice evaluation or over the course of voice treatment. This finding is consistent across sexes and age groups in adults.[4]

### Limitations

This study did not include a disordered population. Based on the consistency of results in men and women, and knowing MPT values can be decreased in disordered populations,[9,10,19] it is likely that larger PQ values will be obtained across instruments in populations with dysphonia. This hypothesis will need to be investigated in subsequent studies. Although the instructions for eliciting VC and PQ were kept consistent, inter-rater reliability was not assessed. At this time, only two handheld spirometers have been compared with one commonly used pneumotachograph-based system in this study. We cannot generalize the findings of this study to other instruments because results are specific to the instrumentation used. Future studies should test for differences across examiners and instruments. Finally, subglottal pressure and laryngeal resistance are an important part of aerodynamic assessment. These measures cannot be obtained with a spirometer, which limits assessment to calculations of lung volume and derived phonation efficiency through measurement of PQ.

## CONCLUSIONS

The consistency of measurements (parallel forms reliability) was assessed for VC and derived PQ measures using three aerodynamic instruments across three different age groups of women. Measurement precision was lower for the digital spirometer than for the analog spirometer when compared with the PAS, but strong correlations demonstrated good measurement reliability of the three instruments. The pneumotachograph-based system is more comprehensive (eg, allows measurement of airflow and air pressure) and offers greater measurement precision than some low-tech options, but is also expensive. In the absence of such a system, a spirometer can provide information on respiratory and phonatory function in the form of VC and derived PQ measures at a significantly lower cost. The clinician must exercise caution if using a spirometer different from the two used in this study, but the data from this and previous investigations[5,6] provide strong support for the valid use of spirometers to obtain aerodynamic measurements in men and women across age groups.

## REFERENCES

1. Dejonckere PH, Bradley P, Clemente P, et al. A basic protocol for functional assessment of voice pathology, especially for investigating the efficacy of (phonosurgical) treatments and evaluating new assessment techniques. *Eur Arch Otorhinolaryngol*. 2001;258:77–82.
2. ASHA committee on Instrumental Voice Assessment Protocols (IVAP).Recommended Protocols for Instrumental Assessment of Voice: Draft Summary of Recommendations, 2015.
3. Dejonckere PH. Assessment of Voice and Respiratory Function. In: Remacle M, Eckel HE, eds. *Surgery of Larynx and Trachea*. Berlin Heidelberg: Springer-Verlag; 2010.

4. Joshi A, Watts CR. Measurement reliability of phonation quotient derived from three aerodynamic instruments. *J Voice*. 2015;doi:10.1016/j.jvoice.2015.11.015.
5. Rau D, Beckett RL. Aerodynamic assessment of vocal function using hand-held spirometers. *J Speech Hear Disord*. 1984;49:183–188.
6. Awan SN. The aging female voice: acoustic and respiratory data. *Clin Linguist Phon*. 2006;20:171–180.
7. Raes JP, Clement PA. Aerodynamic measurements of voice production. *Acta Otorhinolaryngol Belg*. 1996;50:293–298.
8. Tanaka S, Hirano M, Terasawa R. Examination of air usage during phonation: correlations among test parameters. *J Voice*. 1991;5:106–112.
9. Yumoto E. Aerodynamics, voice quality, and laryngeal image analysis of normal and pathologic voices. *Curr Opin Otolaryngol Head Neck Surg*. 2004;12:166–173.
10. Iwata S, von Leden H. Phonation quotient in patients with laryngeal diseases. *Folia Phoniatr Logop*. 1970;22:117–128.
11. Wang C-C, Chang M-H, Jiang R-S, et al. Laryngeal electromyography-guided hyaluronic acid vocal fold injection for unilateral vocal fold paralysis: a prospective long-term follow-up outcome report. *JAMA Otolaryngol Head Neck Surg*. 2015;141:264–271.
12. Hirano M, Koike Y, von Leden H. Maximum phonation time and air usage during phonation. *Folia Phoniatr Logop*. 1968;20:185–201.
13. Awan SN. *The Voice Diagnostic Protocol. A Practical Guide to the Diagnoses of Voice Disorders*. Frederick, MD: Aspen Publishers Inc.; 2001.
14. Yanagihara N, Koike Y, von Leden H. Phonation and respiration. *Folia Phoniatr Logop*. 1966;18:323–340.
15. Choi J-N, Kim H, Nam CM, et al. Characteristics of glottal area waveform and phonation in patients with unilateral vocal fold palsy or sulcus vocalis. *Commun Sci Disord.* 2007;12:487–507.
16. Hertegård S, Hallén L, Laurent C, et al. Cross-linked hyaluronan versus collagen for injection treatment of glottal insufficiency: 2-year follow-up. *Acta Otolaryngol*. 2004;124:1208–1214.
17. Remacle M, Mayné A, Lawson G, et al. Subtotal carbon dioxide laser arytenoidectomy by endoscopic approach for treatment of bilateral cord immobility in adduction. *Ann Otol Rhinol Laryngol.* 1996;105:438–445.
18. Remacle M, Lawson G. Results with collagen injection into the vocal folds for medialization. *Curr Opin Otolaryngol Head Neck Surg.* 2007;15:148–152.
19. Sjögren EV, van Rossum MA, Langeveld TM, et al. Voice outcome in T1a midcord glottic carcinoma: laser surgery vs radiotherapy. *Arch Otolaryngol Head Neck Surg*. 2008;134:965–972.
20. Verdonck-De Leeuw IM, Hilgers FJM, Keus RB, et al. Multidimensional assessment of voice characteristics after radiotherapy for early glottic cancer. *Laryngoscope*. 1999;109:241–248.
21. Goozée JV, Murdoch BE, Theodoros DG, et al. The effects of age and gender on laryngeal aerodynamics. *Int J Lang Commun Disord.* 1998;33:221–238.
22. Zraick RI, Smith-Olinde L, Shotts LL. Adult normative data for the KayPENTAX phonatory aerodynamic system model 6600. *J Voice*. 2012;26:164–176.
23. Ptacek PH, Sander EK, Maloney WH, et al. Phonatory and related changes with advanced age. *J Speech Lang Hear Res*. 1966;9:353–360.
24. Netsell R, Lotz WK, Peters JE, et al. Developmental patterns of laryngeal and respiratory function for speech production. *J Voice*. 1994;8:123–131.
25. DeVon HA, Block ME, Moyle-Wright P, et al. A psychometric toolbox for testing validity and reliability. *J Nurs Scholarsh*. 2007;39:155–164.
26. KayPENTAX Corp LP, NJ. Instruction Manual, Phonatory Aerodynamic System (PAS), Model 6600. March 2009.
27. IBM Corp. *IBM SPSS Statistics for Windows* [computer program]. Version 22.0. Armonk, NY: IBM Corp. Released 2013.
28. Awan SN, Novaleski CK, Yingling JR. Test-retest reliability for aerodynamic measures of voice. *J Voice*. 2013;27:674–684.
29. Baken R, Orlikoff R. *Clinical Measurement of Speech and Voice*. 2nd ed. Clifton Park, NJ: Thompson Learning; 2000.
30. van den Berg J. Modern research in experimental phoniatrics. *Folia Phoniatr Logop*. 1962;14:81–149.