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MEASUREMENT OF A VOICE RANGE PROFILE WITH A SEMI-OCCLUDED VOCAL TRACT

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Abstract

Semi-occlusion of the vocal tract with a thin straw provides some advantages for assessing the physiological ranges of intensity and fundamental frequency in a voice. Signals can be obtained without concern about room noise, mouth-to-microphone distance, or vocal injury caused by excessive loudness produced by a patient or client. We show that differences between loud and soft phonation into the straw are clearly measureable and reflect the soft-loud differences measured from airborne sound radiating from an open mouth. Using this technique to acquire a traditional voice range profile, the range of fundamental frequency is not limited and risk for injury seems to be less than for traditional methods. In the lower portion of the fundamental frequency range, the steady pressures measured at the mouth constitute a range profile for subglottal (lung) pressure.

INTRODUCTION

A voice range profile, also known as a phonetogram, is a display of intensity range in a voice (in dB) over a range of fundamental frequencies (Damsté, 1970; Schutte and Seidner, 1983; Gramming, 1988). The voice range profile (VRP) has two boundaries. The low intensity boundary is the threshold of voicing, which corresponds to the threshold of hearing in an audiogram. The high intensity boundary is the (self-perceived) maximum safe vocal intensity, which corresponds to the threshold of feeling (or pain) in an audiogram. However, in order not to inflict injury upon a vocalist, the upper boundary is often not rigorously pursued. Further, in the studio or the examination room, clinicians generally do not push a client to reach the absolute maximum intensity level with repeated attempts.

One variation of the VRP (for singers) has been to plot the dynamic range in musical notation, labeling the lower boundary as *pp* (pianissimo) and the upper boundary as *ff* (fortissimo), where only artistically acceptable soft and loud productions are used (Cleveland and Sundberg, 1988). Another variation is to plot the *voice use profile* (VUP), where only the naturally occurring ranges of intensity and frequency are obtained from running speech rather than from isolated (and prompted) vowel phonations (Hunter and Titze, 2007).

The VRP is an internationally accepted tool of voice assessment (Schutte and Seidner, 1983; Ikeda et al., 1999). It is often obtained as the “first look” into vocal capability of an individual in the acoustic domain (Hacki, 1999; Sihvo et al., 2000; Wuyts et al., 2003). Standardization of mouth to microphone distance, as well as frequency weighting for sound pressure level (SPL) settings, have been suggested (Schutte and Seidner, 1983). The VRP has become particularly valuable for documenting changes in voice characteristics over time (De Bodt et al., 1998; van Mersbergen et al., 1999). Several attempts have been made to show VRP changes as a function of voice therapy and other forms of intervention

(Holmberg et al., 2007; DeJonckere et al., 2003; Schneider and Bigenzahn, 2005; Speyer et al., 2003). In addition to mapping out the two most important control variables in the voice, pitch and loudness, the VRP can be designed to display some elements of irregularity (or alternatively, spectral balance) as a third variable (Pabon and Plomp, 1988). A vocalist's own perception of voice quality can also be the third variable (Lamarche et al., 2008).

Shortcomings of the traditional VRP are (1) the potential inconsistency in mouth opening, even when a vowel is specified, which can affect the vocal intensity radiated from the mouth, (2) contamination of the airborne signal by reflections from the body of the vocalist, room reverberation, and environmental noise, (3) difficulty in keeping the mouth-microphone distance constant, (4) injury to the vocal folds with multiple attempts to elicit maximum vocal output, (5) uncertainty about voice registration to be used, especially by males, and (6) lack of knowledge of the lung pressures (the primary physiologic variable) used to produce the sounds.

This paper presents the results of an alternate method of eliciting the VRP in an attempt to remedy some of these shortcomings. We address the following questions: By using a semi-occluded vocal tract with a known mouth opening and an oral pressure measurement, (1) can a physiologic range of vocal intensity and F_0 be obtained, (2) can the likelihood of injury to the vocal folds be reduced when maximum effort phonation is elicited, (3) can the uncertainty of voice registration be reduced, and (4) can the range of lung pressure be determined or inferred?

METHODS

Four male volunteers and five female volunteers participated in the study. They were participants in the Summer Vocology Institute, an intensive vocology training program for graduate students, speech-language pathologists, voice coaches, and physicians in Denver, Colorado. Informed consent was obtained. All were adults of various ages, and they had various backgrounds in vocal training (Table 1). Only one had a medical history related to voice, a thyroid surgery (subject M04). For professional reasons, not all disclosed their exact age. We used a non-homogenous population, with a large proportion of singers, because we wanted subjects who were maximally reflective of their voice in this exploratory study. Later studies will be designed for populations who are less reflective and knowledgeable about their vocal capabilities. Parallel studies with school teachers are ongoing, but specific voice disordered populations have not yet been targeted.

Each volunteer produced three variations of a VRP, the first two in the conventional way by producing the vowels / α / and / u /, with the experimenter measuring the airborne signal with a sound level meter. The third VRP was produced by phonating into a thin straw, with an oral pressure transducer placed in the corner of the mouth (Figure 1). Henceforth, we will refer to the first two data sets as the VRP (with vowel specified) and the third data set as the SVRP. The latter abbreviation can be thought of as "semi-occluded tract voice range profile" or "straw voice range profile." Pitch was prompted with Casio® MT-35 keyboard synthesizer.

The more traditional VRP recordings were made in a single-wall sound isolation booth (Industrial Acoustics Company, Bronx, NY), 2.2 m wide by 2.3 m high by 2.3 m deep. The subject wore a head-mounted microphone (Countryman Associates omnidirectional B3 Lavalier) mounted on a wire boom attached to a plastic frame, worn like a pair of eyeglasses. The microphone element was about 5 cm from the mouth and slightly to the side, out of the airstream. A Type I sound level meter (Brüel & Kjaer 2238 Mediator) set at linear frequency weighting was mounted on a stand with a 30 cm string attached for quick

measurements during initial calibration of the head-mounted microphone (see Svec et al., 2003, for details). After the calibration procedure, the sound level meter was retracted and the recording channel was used as a chatter channel (discussion between the investigator and subject) during the recording. With the calibrated head-mounted microphone setup (Svec et al. 2003), the subject was allowed some freedom of movement without affecting the results.

The head-mounted microphone and sound level meter were connected to a Millennia HV-3D 8 channel microphone pre-amp (Millennia Media). The pre-amp delivered the signal to an RME ADI-8 DS AD/DA Converter and an RME Multiface II 36 channel digital audio interface (RME, Germany). The digital interface to the recording computer was via a proprietary PCI expansion card on the motherboard. All signals were recorded on a PC at a 44.1 kHz sampling rate and 24-bit accuracy using CUBASE SE software (version 3.0.3) as the software interface.

For the SVRP, the straw had a 2.6 mm inside diameter, a 13 cm length, and was placed centrally between the lips (Figure 1). In addition, the receiving element of an electronic pressure transducer, which was a 1.5 mm (inside diameter) steel catheter, was placed between the lips near the corner of the subject's mouth. The lips were sealed around both tubes. The oral pressure transducer (Glottal Enterprises® PTL-1) had a 0 – 2500 Hz frequency response. Hence, both steady and oscillatory pressure could be obtained with the same instrument. In addition to the pressure transducer, a microphone (Countryman Associates omnidirectional B3 Lavalier) was clipped on the lapel of the subject to capture general experimental chatter. As both the steady and the acoustic component of the pressure was desired, the oral pressure and microphone were digitized with Computerized Speech Lab (model 4400, Kay Elemetrics) with the direct current (DC) input option for the pressure, at 44.1 kHz sampling and 16-bit accuracy. For better experimental control and real time monitoring of the experiment, CUBASE SE software (version 3.0.3) was used as the software interface to the Kay Elemetrics device. To demonstrate the independence of the measure to ambient noise, recording was done in a classroom with other people (and resulting noises) present. Such room noises had negligible effect on the oral pressure measures.

Figure 2A shows a sample of the raw data as collected with the electronic pressure transducer for a soft production followed by a loud production. For every F_0 tested, the subject produced such a succession of the lowest (threshold) phonation followed by a maximum loudness phonation through the straw. The mean pressures $\bar{P}_1$ and $\bar{P}_2$, as well as the peak-to-peak (and the corresponding root-mean-squared, or RMS) acoustic pressures $\tilde{P}_1$ and $\tilde{P}_2$ were extracted for both loudness conditions as illustrated in the figure.

In Figure 2B, a pressure recording from another subject is shown, where the “steady” $\bar{P}_1$ component varies between about 0.35 and 0.5 kPa throughout the production with increased effort. Figure 2C illustrates the corresponding $\tilde{P}_2$, the peak-to-peak and RMS (outlined by a second envelope) after the $\bar{P}_1$ component was removed.

Care was taken during measurement to avoid clipping in these signals. Two of the subjects were able to produce lung pressures with the straw that exceeded the pressure transducer's range during maximum loudness at high frequency. While these renditions were repeated using a U-tube manometer (with a rubber tube placed in the corner of the mouth), they were not included in the current results because they were without the acoustic pressure components ($\tilde{P}_1$ and $\tilde{P}_2$). In all, each subject produced on the order of 40 phonations for each of the three voice range profiles. Extractions of the mean and acoustic pressures, as well as pressure and acoustic calibrations, were carried out with custom made MATLAB scripts.

RESULTS

Figure 3 shows steady pressure SVRPs (in kPa) plotted as a function of F_0 for the nine subjects. The first four are for males and the last five for females. Steady pressures ranged between 0 and 3 kPa, a normal range for lung pressure in humans. For the small straw diameter used here, it has been shown that the oral steady pressure is a good approximation to lung pressure (Titze, in press). The differences between steady pressures for loud and soft phonations were on the order of 1 – 2 kPa.

As a direct comparison, Figure 4 shows the traditional VRP on the vowel / α / for each of the subjects in the same order. The F_0 ranges are similar, suggesting that the semi-occlusion did not restrict the F_0 range. Furthermore, except for subjects M03 and M04, the soft-loud differences in pressure for the SVRP mirror the soft-loud differences in dB SPL for the VRP. Subject M03 stated that he felt uncomfortable with straw use because he had never heard of it in his native (Korean) culture, and subject M04 stated that he needed to restrict his lung pressure because of his previous thyroid injury. None of the remaining volunteers were concerned that they would injure themselves by phonating loudly into the straw.

Figure 5 shows the VRPs for the vowel / u /. Subject M03, who was uncomfortable with the straw, was also uncomfortable with the production of / u / vowels at high pitches and declined to produce the VRP on / u /. His voice was grounded in modal (chest) register. Likewise, subject M04 declined to produce a VRP on / u / because it required more lung pressure than for the / α / VRP on high pitches. For subjects M02, F03, F04, and F05, the frequency range was limited to values below about 700 Hz for / u / , while F_0 values above 1000 Hz were obtainable with / α /. Only for subjects M01, F01, and F02 was there a strong similarity between the / u / and the / α / VRP. This confirmed the known fact that vowel selection is important in producing a conventional VRP (Gramming, 1988).

A final data set was produced for the root-mean-squared (RMS) acoustic pressure measured in the mouth. This is shown in Figure 6. Interestingly, the major separation between the upper (loud) boundary and the lower (soft) boundary occurred only for F_0 values below about 500 Hz. The preliminary explanation is that the glottal resistance becomes comparable to (or larger than) the acoustic straw resistance at high F_0 , which diminishes the pressure drop across the straw and makes both high effort and low effort pressures go to zero. For a theoretical analysis of this effect, see Titze (in press).

There was also a peculiar peak around 250 – 300 Hz in the acoustic pressure SVRP. Aside from M03, who made a poor attempt at straw use, the only subject who did not show this was F02. All others showed the largest difference between the loud and soft boundary to be between 200 and 300 Hz. The preliminary explanation for this is that the straw-vocal tract combination has a resonance in this frequency region that increases the pressure at the straw input. This is an important observation that needs to be further investigated when straw lengths and diameters are optimized for SVRP use.

DISCUSSION AND CONCLUSIONS

Returning to the original questions posed in the Introduction, the results showed that phonation with a semi-occlusion at the mouth does not prevent a measurable range of intensity to be achieved over a wide (physiologic) range of F_0 . Nevertheless, at this stage of our exploration, only the steady pressures behind the occlusion (straw) retained wide pressure differences at high F_0 .

At low F_0 (below about 300 Hz), steady pressures at the mouth approximate lung pressures because the straw impedance is much greater than the glottal impedance. But unless the

straw diameter is reduced for the high part of the F_0 range, the steady oral pressure no longer reflects the lung pressure. Different diameter straws should be used in the future to maintain a straw impedance that is a factor of 10 greater than the glottal impedance. Until this condition is known to be satisfied, it is risky to call the steady pressure SVRP a lung pressure profile, although it is a good approximation of such in the lower half of the F_0 range.

Differences between the upper and lower (soft and loud) curves are on the order of 1 – 2 kPa, but vary with F_0 . For males, upper and lower curves showed an upward trend with F_0 , suggesting that increased lung pressure was needed to produce higher F_0 values. For females, the trend was mixed. For two individuals, both the absolute pressures and the pressure differences between loud and soft phonation decreased in the higher part of the F_0 range. Loud phonation around 1000 Hz showed a pressure below 1.0 kPa. For two other females, the trend was similar to that for males.

It does not appear likely that subjects would injure themselves by targeting maximum effort (loudness) when phonating through a thin straw. Only one subject felt uncomfortable but no more than with an / u / vowel. One additional subject limited his exploration because of a previous thyroid surgery. The remaining subjects explored (informally) with maximum possible lung pressure. Although some indicated that their sound was “bottled up” and they felt pressure in the head, none indicated a strain on the larynx. This topic deserves further investigation.

Regarding voice registration, the straw limits vocal fold collision (Titze et al., 2002; Titze, in press), which reduces registration. Subjects never queried the investigators about which register to use. But it is known that registration can be triggered by formant-harmonic interaction. A detailed analysis of spectral content in straw phonation, as well as changes in formant frequencies resulting from a straw-elongated vocal tract, is forthcoming.

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References

- Cleveland, T.; Sundberg, J. Acoustic analysis of three male voices of different quality. In: Askenfel, A.; Felicetti, S.; Jansson, E.; Sundberg, J., editors. Proceedings of the Stockholm Music Acoustics Conference. Stockholm: Royal Swedish Academy of Music; 1988. p. 143-156.
- Damsté PH. The phonetogram. *Practica Otology-Rhinology-Laryngologica*. 1970; 32:185–187.
- De Bodt MS, Wuyts FL, Van de Heyning PH, Lambrechts L, Vanden Abeele D. Predicting vocal outcome by means of a vocal endurance test: a 5-year follow-up study in female teachers. *Laryngoscope*. 1998; 108(9):1363–1367. [PubMed: 9738758]
- DeJonckere PH, van Wijck I, Speyer R. Efficacy of voice therapy assessed with the Voice Range Profile (Phonetogram). *Revue de laryngologie-otologie-rhinologie*. 2003; 124(5):285–289. [PubMed: 15144023]
- Gramming, P. The phonetogram: An experimental and clinical study. Malmö, Sweden: Department of Otolaryngology, University of Lund; 1988.
- Hacki T. Vocal capabilities of nonprofessional singers evaluated by measurement and superimposition of their speaking, shouting and singing voice range profiles. *HNO*. 1999; 47(9):809–815. [PubMed: 10525610]
- Holmberg EB, Ihre E, Södersten M. Phonetograms as a tool in the voice clinic: changes across therapy for patients with vocal fatigue. *Logopedics Phoniatrics Vocology*. 2007; 32(3):113–127.

- Hunter, EJ.; Titze, IR. The Voice Use Profile: Illustrating Actual Voice Use from Long Term Monitoring Using the NCVS Dosimeter. Salt Lake City, UT: Acoustical Society of America Meeting; 2007 Jun.
- Ikeda Y, Masuda T, Manako H, Yamashita H, Yamamoto T, Komiyama S. Quantitative evaluation of the voice range profile in patients with voice disorder. *European Archives of Otorhinolaryngology*. 1999; 256(Suppl 1):SS1–SS5.
- Lamarche A, Ternström S, Hertegård S. Not just sound: Supplementing the voice range profile with the singer's own perceptions of vocal challenges. *Logopedics Phoniatrics Vocology*. 2008; 13:1–8.
- Pabon JP, Plomp R. Automatic phonetogram recording supplemented with acoustical voice-quality parameters. *Journal of Speech and Hearing Research*. 1988; 31(4):710–722. [PubMed: 3230899]
- Schneider B, Bigenzahn W. Vocal risk factors for occupational voice disorders in female teaching students. *European Archives of Otorhinolaryngology*. 2005; 262(4):272–276. [PubMed: 15133684]
- Schutte HK, Seidner W. Recommendation by the Union of European Phoniatricians (UEP): Standardizing voice area measurement/phonetography. *Folia Phoniatrica*. 1983; 35:286–288. [PubMed: 6654278]
- Sihvo M, Laippala P, Sala E. A study of repeated measures of softest and loudest phonations. *J. Voice*. 2000; 14(2):161–169. [PubMed: 10875567]
- Speyer R, Wieneke GH, van Wijck-Warnaar I, DeJonckere PH. Effects of voice therapy on the voice range profiles of dysphonic patients. *Journal of Voice*. 2003; 17(4):544–556. [PubMed: 14740935]
- Svec JG, Popolo PS, Titze IR. Measurement of vocal doses in speech: experimental procedure and signal processing. *Logoped Phoniatr Vocol*. 2003; 28(4):181–192. [PubMed: 14686546]
- Titze IR. Phonation threshold pressure measurement with a semi-occluded vocal tract. *Journal of Speech Language Hearing Research*. (in press).
- Titze IR, Laukkanen AM, Finnegan EM, Jaiswal S. Raising lung pressure and pitch in vocal warm-ups: the use of flow-resistant straws. *Journal of Singing*. 2002; 58(4):329–338.
- van Mersbergen MR, Verdolini K, Titze IR. Time-of-day effects on voice range profile performance in young, vocally untrained adult females. *Journal of Voice*. 1999; 13(4):518–528. [PubMed: 10622518]
- Wuyts FL, Heylen L, Mertens F, Du Caju M, Rooman R, Van de Heyning PH, De Bodt M. Effects of age, sex, and disorder on voice range profile characteristics of 230 children. *Annals of Otology, Rhinology, Laryngology*. 2003; 112(6):540–548.

Figure 1.
Sketch of straw and pressure transducer placement into the mouth.

Figure 2.

(A) Uncalibrated oral pressure from a female subject's soft and loud rendition at 250 Hz. (B) male subject loud rendition zoomed into phonation portion. (C) same male subject as in (B) where only the AC component of the pressure is shown.

Figure 3.
Steady pressure profiles obtained with a straw and a pressure transducer for nine subjects,
four males followed by five females.

Figure 4.

Conventional VRPs obtained with a sound level meter on the vowel /ɑ/ at 30 cm mouth-to-microphone distance. The first four are for males and the last five for females.

Figure 5.

Conventional VRPs obtained with a sound level meter on the vowel / u / at 30 cm mouth-to-microphone distance. The first four are for males and the last five for females.

Figure 6. Acoustic RMS pressure profiles obtained with a straw and pressure transducer for nine subjects, four males and five females.

Table 1

Information About Volunteers

Subject	Gender	Age	Vocal Training	Category/Style
M01	Male	40	More than 10 years	baritone
M02	Male	27	One year, amateur	baritone
M03	Male	>40	More than 10 years	baritone
M04	Male	>55	40 years classical	tenor/baritone
F01	Female	<30	Voice graduate student	soprano
F02	Female	30 – 40	Six years	theatre
F03	Female		More than 10 years	mixed styles
F04	Female	30 – 40	More than 10 years classical	mezzo-soprano
F05	Female	30	More than 10 years	coloratura