ECHO

A COMPARISON OF NASALANCE VALUES IN TRACHEOESOPHAGEAL VOICE PROSTHESIS AND NORMAL LARYNGEAL SPEAKERS

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ABSTRACT

The purpose of this study was to compare nasalance values in tracheoesophageal (TE) voice prosthesis and laryngeal speakers. Nasalance measures were obtained from 10 age-matched male TE speakers and 10 healthy male laryngeal speakers reading the Zoo Passage and Nasal Sentences. All TE speakers were rated as good to excellent in terms of speech proficiency and intelligibility. Nasalance scores were compared across groups. The findings revealed there were no significant differences in average nasalance values between the two groups. Clinical implications and future research needs are discussed.

KEY WORDS: Nasalance values, Nasometry, Nasalization, Tracheoesophageal speech, Alaryngeal speech, Resonance

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INTRODUCTION

An estimated 12,500 new cases of cancer of the larynx are diagnosed annually in the United States with 3,500 to 3,700 deaths resulting from the disease (American Cancer Society, 2011). The age-adjusted incidence rates for laryngeal cancer, shown in Table 1, reveal that on an annual basis, more males acquire the disease than females and that African American men are one-and-a-half times more likely to be diagnosed with laryngeal carcinoma than white males (Howlader, Noone, Krapcho, Neyman, Aminou, et al. 2010). Smoking (cigarettes, cigars, marijuana) and heavy alcohol intake increase a person's risk for developing this form of cancer. Depending upon the location, type, and extent of the disease, treatment options for laryngeal carcinoma may consist of radiation therapy, chemotherapy, surgery, or combinations of these treatment modalities (Boone, McFarlane, Von Berg & Zraick, 2010; Casper & Colton, 1998). Larger and more extensive or late stage malignant tumors (i.e., T3 or T4) of the larynx are generally treated by total laryngectomy wherein the entire larynx is surgically removed (Wolf, 2010).

Table 1. Laryngeal Cancer Incidence Rates by Race/Ethnicity and Gender. Data are from Surveillance Epidemiology and End Result (SEER) Cancer Statistics Review 1975-2008 (Howlander et al. 2010).

Race/Ethnicity	Male	Female
All Races	6.0 per 100,000 men	1.3 per 100,000 women
White	6.0 per 100,000 men	1.3 per 100,000 women
Black	9.8 per 100,000 men	1.9 per 100,000 women
Asian/Pacific Islander	2.2 per 100,000 men	0.3 per 100,000 women
American Indian/Alaska Native	2.8 per 100,000 men	NA
Hispanic	4.6 per 100,000 men	0.6 per 100,000 women

Several functional alterations in respiration and speech production occur following total laryngectomy. As shown in Figure 1, the trachea is redirected to create a stoma in the front of the individual's neck just above the sternal notch and the excised vocal folds are no longer available as a sound source (Sapienza & Hoffman-Ruddy, 2009). Moreover, post-laryngectomy, respiration occurs through the neck stoma and pulmonic air can no longer be directed into the upper airway areas (i.e., the pharynx, oral cavity, and nasal cavity) for voice and speech production.

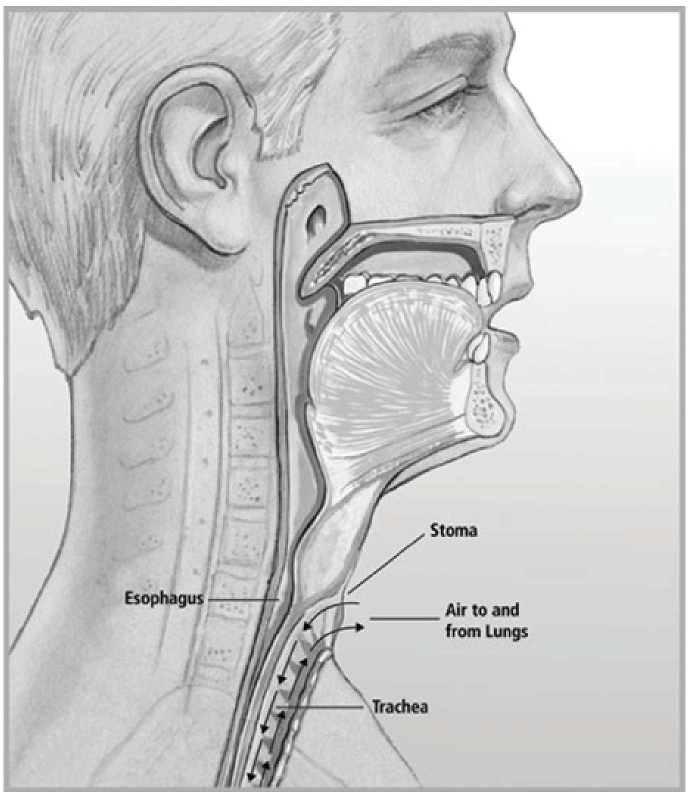

Figure 1. Illustration of alterations in respiratory and speech production processes following total laryngectomy. In this illustration, laryngeal speech is no longer possible due to surgical removal of the larynx. Figure used with permission of InHealth Technologies, Carperteria, CA.

Total laryngectomy and the resultant loss of the respiratory support and sound source required for oral-verbal communication, can have a significant impact on the quality of life of the laryngectomized individual. It has been stated that the goal of rehabilitation for a laryngectomized person is to learn to communicate with whatever option is best to improve functional communication and quality of life (Sapienza & Hoffman-Ruddy, 2009). Presently, there are three primary alaryngeal communication options available to persons who have undergone total laryngectomy. These include electrolarynx/artificial larynx speech, esophageal speech, or tracheoesophageal prosthesis (TE) speech. The TE surgical voice restoration technique developed by Singer and Blom in 1980, dramatically improved functional voice and speech outcomes for total laryngectomees (Lewin, Evans & Blom, 2009; Oh, Meleca, Simpson & Dworkin, 2002; Singer & Blom, 1980). This procedure can be performed primarily at the time of the laryngectomy, or at a later date as a secondary surgical procedure. With its use of a one-way valve voice prosthesis (see Figure 2) that is inserted into a small surgically-created puncture through the upper posterior tracheal wall and into the esophagus, the TE procedure allows for airflow from the trachea into the area below the pharyngoesophageal (PE) segment or neoglottis thereby permitting pulmonary air to drive PE/neoglottic vibration for the production of speech (Knott & Lewin, 2012; Sapienza & Hoffman-Ruddy, 2009). In this regard, the TE prosthesis interacts with the neoglottis to create a new sound source for speech.

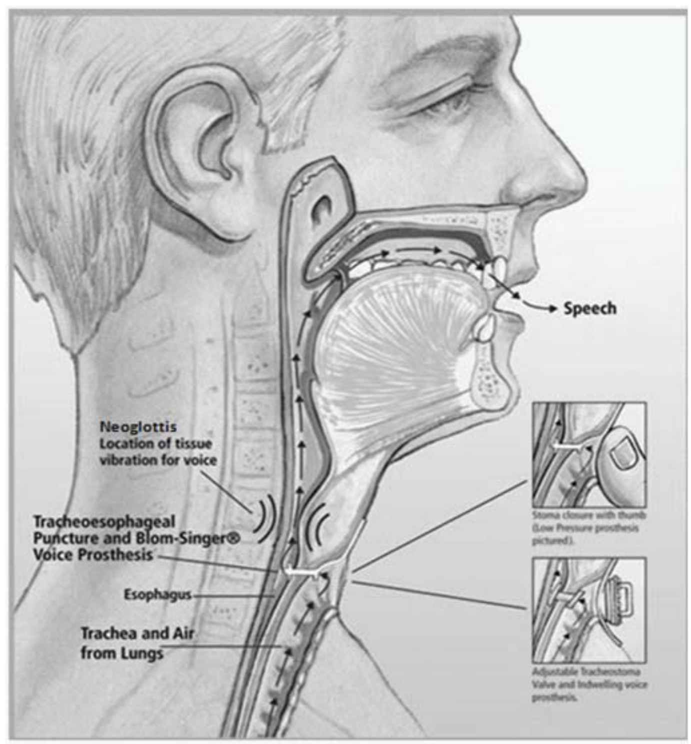

Figure 2. Illustration of tracheoesophageal voice prosthesis and speech production following total laryngectomy. Figure used with permission of InHealth Technologies, Carperteria, CA.

Studies which have compared the features of TE speech with those of laryngeal, electrolarynx/artificial larynx speech, and esophageal speech have focused on (1) perceptual characteristics such as intelligibility and acceptability (Tardy-Mitzell, Andrews, & Bowman, 1985; Blom, Singer, & Hamaker, 1986; Miralles & Cervera, 1995; Clements, Rassekh, Seikaly, Hokanson & Calhoun, 1997; Max, DeBruyn, & Steurs, 1997) and (2) acoustic parameters such as fundamental frequency, vocal intensity, voice onset time, frequency perturbation, and amplitude perturbation

(Robbins, Fisher, Blom, & Singer, 1984; Serle & Carpenter, 2001; Trudeau & Qi, 1990). Collectively, these investigations reveal that TE speakers are more intelligible than electrolarynx or esophageal speakers but not normal laryngeal speakers. Additionally, TE speakers show the least difference from laryngeal speakers in terms of fundamental frequency and vocal intensity.

While much of the acoustic research on tracheoesophageal speech has focused on the new sound source, i.e., the TE prosthesis and the PE segment, no studies have examined the acoustic characteristics of the supraneoglottic vocal tract in this population. Specifically, no studies have explored the acoustics of nasalization in TE speech. Nasalization involves the coupling of the nasal and oral cavities via the velopharyngeal (VP) mechanism during speech and is realized during the production of nasal consonants and for phonemes adjacent to nasal sounds. Acoustic events associated with VP function during speech involve the movement of sound pressure/vibrational energy through the vocal tract and the proper transmission of that energy through the oral and/or nasal cavities as required by the particular speech activity. If the nasal airway is sufficiently impaired or trans-nasal airflow and acoustic energy are reduced during the production of a nasal consonant, speech is generally perceived by the listener as hyponasal or denasal.

The perceptual significance of nasalization is better understood when one realizes that nasal consonants constitute 11 percent of the phonemic content of commonly spoken American English (Tobias, 1959). Since speech sounds typically are produced at a rate of 10/second, nasal consonants might be expected to occur at an average rate in excess of 1/second (Glenn & Kleiner, 1968). Thus, nasal consonants are significantly represented in the phonemic inventory of speakers, and any obstacle (structural or functional) to achieving nasalization might be expected to affect nasal resonance.

Instrumentally, nasalization can be measured by spectrography, accelerometry, or nasometry among other techniques (Moon, 2001; Krakow & Huffman, 1993). Nasometry is a method of measuring the acoustic correlates of resonance and velopharyngeal function and can be compared to standardized norms for interpretation (Kummer, 2008). The device most commonly used in nasometry is the Nasometer. With the Nasometer system, the relation of nasal and oral signals is computed as a ratio of nasal to nasal-plus-oral energy multiplied by a constant of 100 (Krakow and Huffman, 1993). The resulting quantity is expressed as a percentage *nasalance* score. Nasometric measures have been shown to be strongly correlated with aerodynamic and perceptual measures of velopharyngeal function (Dalston, Warren, & Dalston, 1991; Mayo & Mayo, 2011).

Colyar and Christensen's (1980) study of nasalance characteristics of eight esophageal speakers revealed that this group of alaryngeal communicators could achieve nasalization but at lower levels than laryngeal speakers of similar age. In explaining their findings, Colyar and Christensen (1980) postulated that perhaps esophageal speakers achieve VP opening more slowly than laryngeal speakers and may speak at a slower rate to achieve VP opening. An alternative explanation offered by Searl and Evitts (2004) citing the work of Struben and van Gelder (1958) and Diedrich and Youngstrom (1966) is that esophageal speakers "may not release air nasally on nasal consonants in an attempt to conserve the limited air supply available to them during speech production (i.e., the maximum would be the volume of the esophagus that is substantially less than the lungs)." (p. 558). Unlike esophageal speakers, TE speakers have available to them a pulmonary air supply and might not need to conserve that air source to produce nasal consonants. However, failure to achieve adequate levels of nasalization by TE users could result in listeners not being able to perceive nasal consonants produced by these speakers very well (Colyar & Christensen, 1980).

The purpose of this study was to compare nasalance values in tracheoesophageal voice prosthesis and normal laryngeal speakers. This investigation is seen as an important step in furthering our knowledge of how the TE prosthesis and subsequent acoustic energy generated via the device interacts with the supraneoglottic resonating cavities (oral and nasal) during speech. Such information may lead to improved alaryngeal speech rehabilitation service outcomes for this group of communicators.

METHOD

Speakers

Ten male TE speakers aged 54 to 69 years (mean = 60.9 yrs.) provided speech samples. Ten age-matched healthy male laryngeal speakers who did not smoke served as controls. All TE speakers had undergone total laryngectomy. Inclusion criteria for both groups were similar to those described by Searl and Evits (2004): (1) normal articulatory placement; (2) normal oral-motor movements; (3) negative history of velopharyngeal dysfunction, clefting, oral-nasal resonance problems, or surgeries affecting the palate or VP mechanism; (4) use of a common dialect (i.e., the South-Atlantic region version of Standard American English); (5) hearing level of at least 25 dB HTL or better in one ear for the frequencies between 500-2000 Hz; (6) normal or corrected vision; (7) ability to read at the eighth-grade level and (8) free of upper respiratory infection on the day of and two weeks prior to participating in the study. The TE speakers had used this method of alaryngeal communication for an average length of 3.9 years (range = 1.0 – 8.5 yrs). All TE speakers used Blom-Singer low-pressure TE puncture voice prostheses and manual/digital occlusion of the stoma. Most of the TE participants had undergone myotomy of the cricopharyngeus muscle of the upper esophageal sphincter to limit pharyngospasm or stricture of the PE segment. This procedure has long been advocated for the development of good alaryngeal speech (Henley & Souliere, 1986; Singer & Blom, 1981). Demographic characteristics of the TE speakers are shown in Table 2.

TE speech proficiency and intelligibility were determined based on ratings from three certified speech-language pathologists who listened to a two-minute monologue provided by the speakers. Using a five-point rating scale of speech proficiency and intelligibility (1 = poor and 5 = excellent), all TE speakers were judged to be ‘good’ to ‘excellent’.

Table 2. Demographic Characteristics of the Trachesophageal (TE) Speakers Who Participated in the Present Study.

TE Speaker	Age (years)	Race/ Ethnicity	Post-Operative Radiation Treatment	Primary Puncture	Myotomy	TE Speech Usage (years)	TE Speech Therapy
1	64	White	Yes	No	Yes	1.0	Yes
2	55	Af Am	Yes	Yes	Yes	2.0	Yes
3	57	White	Yes	Yes	Yes	2.5	Yes
4	63	White	Yes	Yes	No	4.0	No
5	64	White	No	Yes	Yes	3.5	Yes
6	69	White	Yes	Yes	No	7.6	No
7	54	White	Yes	Yes	Yes	1.5	Yes
8	65	White	Yes	Yes	Yes	6.0	Yes
9	57	White	No	Yes	No	2.5	Yes
10	61	White	Yes	Yes	Yes	8.5	No

Stimuli

The stimuli used in this study consisted of The Zoo Passage (Fletcher, 1972), a standardized reading passage containing all oral phonemes and The Nasal Sentences in which 35 percent of the sounds contained therein are nasal consonants (Fletcher, 1978). This is three times as many nasal phonemes as would be expected in Standard American English sentences. Both sets of stimuli have demonstrated clinical utility in identifying both hyper- and hyponasality (Dalston & Seaver, 1992) and have been used extensively in research on cleft palate and oral-nasal resonance balance (see Anderson, 1996; Cahill et al. 2003: Dalston et al. 1991a; 1991b; David et al. 1999; Dejonckere & van Wijngaarden, 2001; Gonzalez Landa et al. 1990; Kummer et al. 1993; Mayo et al. 1996; McHenry, 1999; Nieminen et al. 2000; Rieger et al. 2002; Roy et al. 2001; Soneghet et al. 2002; Tatchell et al. 1991; Van Lierde et al. 2002; Wenke et al. 2002; Zajac et al.1996).

Instrumentation and Data Acquisition Procedure

Nasalance data were acquired using a Nasometer Model 6200 (KayPENTAX, Lincoln Park, NJ) interfaced with an IBM-compatible computer. A computer based system, the Nasometer allows clinicians to determine the relative amount of oral and nasal energy in an individual’s speech (Dalston & Seaver, 1992; Kummer, 2008). With the device, nasal and oral acoustic components of a subject’s speech are sensed by microphones separated by a horizontal head set-mounted sound separator that rests on the upper lip. The signal from each of the microphones is filtered and digitized by custom electronic modules. The data can then be processed by a personal computer and displayed in real-time on a computer screen. The resultant signal is a ratio of nasal-plus-oral acoustic energy.

In interpreting nasalance scores for the Zoo Passage, a nasalance score of 28 percent obtained from a speaker of American English via the Nasometer 6200 would be the threshold for differentiating speakers with borderline velopharyngeal function from those who are normal speakers (Kummer, 2008, p. 396). Conversely, when nasal consonants are combined with oral consonants in connected speech as with the Nasal Sentences, the resulting nasalance score in normal populations is between 50 percent and 70 percent (Kummer, 2008, p. 396). Before the recordings, the Nasometer was calibrated according to the manufacturer’s instructions. Each participant read The Zoo Passage and The Nasal Sentences twice.

Data Analysis

Data analysis consisted of between-group comparisons of nasalance scores using t-tests for independent measures. An alpha level of 0.01 was used as an indication of statistical significance. Intermeasurement reliability for nasalance scores was determined by the authors who randomly selected and re-measured the data of half of the TE and laryngeal speakers. Reliability was high for nasalance scores as indicated by statistically significant Pearson correlation coefficients ($r = 0.96$, < 0.05 and $r = 0.92$, <0.05, respectively).

RESULTS

The mean nasalance scores of the TE and laryngeal speakers are shown in Table 2. Group comparisons of the data revealed no statistically significant differences between the TE and laryngeal speakers in Zoo Passage scores ($t = .721$; $df = 18$; $p = .480$) or Nasal Sentences scores ($t = 1.79$; $df = 18$; $p = .089$). Included in Table 2 for comparative purposes, are the Zoo Passage and Nasal Sentences nasalance data from the Seaver, Dalston, Leeper, and Adams (1991) study for normal laryngeal speakers of the same dialect region as the TE and laryngeal participants in the present study. Within-group analysis of the variables using a paired samples t-test revealed consistency of performance of the two speaker groups. That is, nasalance scores of speakers in each group were found to be consistent from reading to reading.

Table 2. Means, Standard Deviations and Ranges of Zoo Passage and Nasal Sentences Scores of Tracheoesophageal (TE) and Normal Laryngeal Speakers of the Present Study. Means and Standard Deviations of Zoo Passage and Nasal Sentences of Normal Male Laryngeal Speakers of the Mid-Atlantic Dialect from the Seaver et al. (1991) Study are Included.

Speaker Group	Zoo Passage Score in % (SD)	Nasal Sentences Score in % (SD)
TE	20.39 (6.97) Range: 10.5 – 32.16	56.75 (10.28) Range: 32.8 – 67.9
Normal Laryngeal	18.31 (5.94) Range: 11.2 – 30.5	63.74 (6.77) Range: 52.3 – 76.6
Normal Male Laryngeal Speakers of the Seaver et al. (1991) Study	21.00 (5.0) (Range values were not reported)	64.00 (4.0) (Range values were not reported)

DISCUSSION

The major finding of this study was that males who underwent total laryngectomy and who used tracheoesophageal prosthesis (TE) speech as their primary means of oral communication produced similar nasalance values during non-nasal (Zoo Passage) and predominantly nasal utterances (Nasal Sentences) when compared with normal laryngeal speakers.

Non-nasal utterances

The finding of similarity in nasalance values during production of non-nasal utterances among TE and laryngeal speakers confirms that, as measured acoustically, TE speakers are able to effectively utilize the velopharyngeal mechanism to achieve adequate levels of oral-nasal cavity separation for speech purposes. The finding also supports the observations of other researchers that despite the surgical restructuring of the vocal tract rendered by total laryngectomy, the velopharyngeal mechanism participates actively in alaryngeal speech given that the structures of the upper pharynx and soft palate are not involved in the surgery (Colyar & Christensen, 1980; Searl & Evitts, 2004). Thus, in the present study, TE speakers who were rated as good to excellent in terms of speech intelligibility and proficiency, produced nasalance values on non-nasal utterances that are typically seen in normal laryngeal speakers.

The results of one aerodynamic study (Searl & Evitts, 2004) suggest that for production of shorter non-nasal utterances, i.e., consonant-vowel (CV) tokens, TE speakers tend to use higher levels of intraoral pressure when compared to normal laryngeal speakers. Such intraoral pressure values would require rather air-tight closure of the VP mechanism. It is not known whether TE speakers generally utilize higher oral pressures in connected speech contexts or the extent to which such action could impact nasalance values in this population. While intraoral pressure values of the speakers were not examined in the present study, future investigations might look at the possible influence of this variable on nasalance values in the non-nasal connected speech of TE communicators.

Nasal utterances

The average Nasal Sentences values of the TE speakers were not significantly different from those of the normal laryngeal speakers. This finding reveals that TE speakers are able to achieve opening of the VP port for nasal utterances produced in connected speech contexts. While it was not studied directly in the present investigation, it is noteworthy that in normal speakers, it appears that the VP port opening for nasal consonants must be larger than 20 mm2 before there will be acoustic excitation of the air in the nasal cavities necessary for speech to be perceived as normal by listeners (Warren, Dalston, & Mayo, 1993; Krakow & Huffman, 1993). In contrast, acoustic studies of nasalization in esophageal speakers (Colyar & Christensen, 1980) found significantly reduced nasalance values for nasal utterances in this group of alaryngeal communicators compared to laryngeal talkers. As mentioned earlier, TE speakers use pulmonary air to support speech and have greater flexibility in terms of how the air is used (Searl & Evitts, 2004). By contrast, esophageal talkers must use much smaller volumes of air that are trapped in and expelled from the esophagus to vibrate the PE segment and produce voice. Thus, as Miller and Hamlet (1988) note, the esophageal speaker has a more difficult task, apportioning limited amounts of air trapped in the esophagus and coordinating its release with velar movement in order to nasalize a nasal consonant. Perhaps the esophageal speaker uses less oral-nasal coupling during production of nasals. As a consequence, the esophageal speaker may denasalize nasal consonants.

In the absence of significant nasal airway impairment (which might result from nasal congestion associated with upper respiratory infection, allergies; a deviated septum or a pharyngeal flap) most normal adult laryngeal speakers exhibit Nasal Sentences scores above 50 percent (Warren, Dalston & Mayo, 1993). None of our normal laryngeal speakers recorded Nasal Sentences scores under 50 percent. However, two of the TE speakers (#6 and #10) exhibited Nasal Sentences values that averaged below 50 percent (i.e., 32 and 46 percent, respectively). Neither of them displayed obvious nasal congestion. An explanation for this observation may lie in the finding that for some patients, total laryngectomy results in a significant and permanent contraction of the nasal cavity which is attributable to the fact that laryngectomy patients no longer use their noses for purposes of respiration (Ozgursoy & Dunsun, 2007). This structural change in the nasal cavity could increase nasal airway resistance and result in lower nasalance values for nasal utterances in some TE speakers (Williams, Eccles, & Hutchings, 1990; Birkent et al., 2009).

Limitations

As only ten TE speakers participated in this study, our findings should be viewed as preliminary. Additionally, no females participated in this investigation. As nasalance values have been shown to vary by gender in laryngeal speakers (Litzaw & Dalston, 1992), future studies should be conducted to determine if this phenomenon also occurs in female TE speakers. Additionally, in this initial study, we utilized only English-speaking participants who were, with the exception of one speaker, of the same cultural background. As African American males present with greater incidences of laryngeal cancer compared to other cultural groups, studies examining their treatment needs and rehabilitation outcomes must be conducted. Thus, future studies should include African Americans as well as other members of the non-majority population. Some studies have suggested that nasalance values may be influenced by the primary language of the speaker (Seaver et al. 1991; Leeper, Rochet, & MacKay, 1992). Therefore, TE speakers of languages other than English should be included in future investigations of nasalance values in this population. Finally, only good to excellent TE speakers were utilized in this investigation. Thus, future studies should examine nasalance values in TE speakers who are less proficient in their communication skills.

CONCLUSION

This study provides initial information on nasalance characteristics in TE speech. The TE speakers of this study produced similar nasalance values during non-nasal and predominantly nasal utterances in connected speech compared with normal laryngeal speakers. Additionally, the nasalance values produced by both groups of our speakers were similar to those reported previously for normal laryngeal speakers (Seaver et al. 1991). The acoustic findings offer indirect evidence that male TE speakers are able to effectively achieve separation of the oral and nasal cavities for production of oral speech and open the velopharyngeal port to realize nasalization of speech. This study also adds to the growing body of evidence that underscores the advantages of TE speech over other forms of alaryngeal communication such as use of the electrolarynx and esophageal speech. With its use of pulmonary air support, TE speech appears to offer speakers greater flexibility and efficiency in the areas of phonation and resonance than other alaryngeal speech modes.

In those TE speakers who have difficulty achieving nasalization and who are judged by listeners as sounding hyponasal, perhaps nasometry might be used in post-laryngectomy speech therapy, offering the individual useful and objective real-time visual feedback. The goal of such treatment would be to achieve perceptually salient changes in nasalization in those TE speakers requiring greater nasal resonance during connected speech production.

Future studies of nasalance values in TE speech will need larger participant groups that include females and individuals varying in speech proficiency. Investigations might also focus on the effects of different types of TE prostheses on nasalance characteristics. Finally, there is a dearth of studies examining the utility of nasometry in the treatment of TE speakers. Such studies might yield information which proves fruitful in enhancing the speech skills of this group of alaryngeal communicators.

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