SPECTROGRAPHS ANALYSIS

OF

OESOPHAGEAL, TRACHEO-ESOPHAGEAL SPEECH

Hariprasad (G.U.M)
Reg.No. M-9003

A Dissertation submitted in part fulfillment of Final year M.Sc. (Speech andHearing) to the University of Mysore.

TO

AMMA, NANNA
AND
PAPAI

WHOSE LOVE AND AfEECTION ARE
RESPONSIBLE FOR WHAT
I WAS,
I AM,
& I WILL BE..................

CERTIFICATE

This is to certify that the dissertation entitled "SPECTROGRAPHIC **ANALYSIS OF OESOPHAGEAL, TRACHEO-ESOPHAGEAL SPEECH"** *is the bonafide work in part fulfillment for the degree of Master of Science (speech and Hearing), of the student with Register Number* **M-9003.**

Dr.S.NIKAM
Director
AIISH,
Mysore - 570 006

CERTIFICATE

This is to certify that the dissertation entitled

"SPECTROGRAPHIC ANALYSIS OF OESOPHAGEAL,

& TRACHEO-ESOPHAGEAL SPEECH"

has been prepared under my supervision and guidance.

Dr.N.P.NATARAJA 29/10/91
(Guide)
Professor & Head
Dept. of Speech Sciences,
AIISH, Mysore.

DECLARATION

I hereby declare that this dissertation entitled "SPECTROGRAPHIC ANALYSIS OF OESOPHAGEAL, TRACHE-OESOPHAGEAL SPEECH" *is the result of my own study under the guidance of* Dr. N. P. Nataraja, *Professor and Head, Dept. of Speech Sciences, AIISH, Mysore and has not been submitted earlier at any University for any other diploma or degree.*

Reg.No. M-9003

ACKNOWLEDGEMENT

The Investigator is highly indebted to:

Dr.N.P.NATARAJA, Professor and HOD, Speech Sciences, AIISH, Mysore, for his valuable guidance and comments to conduct this study.

Dr. S. NIKAM, Director, AIISH, Mysore, for permitting me to conduct the study at the institute.

Mr.B. RAJASHEKHAR, for his timely help and encouragement, without whose help this study would not have been what it is.

Mr. VENKATESH and **Mr.B.N. KRISHNA MURTHY,** deserve a special mention for all the help, extended, in all the phases of the study and their valuable comments, without whose encouragement and support the study would not have been completed in such a short span.

Mr.G. SOWMYA NARAYANAN, for his invisible motivation encouragement, support and sharing my feelings of ups and downs all throughout the study.

Ms. RASHMI, Ms. PRAGNA, Ms. SUJATHA and **Ms. SUMA** who deserve a heartfelt thanks for their critical comments, moral support and encouragement at the right moments of the study.

Mr. RAJIV who helped me to cope with the demanding pace to complete the study and acts of kindness. **Mr. RAGHUNATH** and **Mr. GOKULA KRISHNA** for their moral support and encouragement.

The Staff of Library, AIISH, Mysore, for their kind untiring sense of duty and helping to locate various references.

All my class mates, Juniors and those who directly and indirectly stood by me at the hour of need.

The **MESS TRIO - BATRU, MAHADEVA & APPA** (Pandey) for their vital nutritional support during my stay at Mysore.

Last but not least **Mr. Ravishankar** for neatly preparing this manuscript.

ONCE AGAIN I THANK YOU ALL..........

INTRODUCTION

"It took man about five years to build the atom bomb after he started seriously. It took him about 10 years to hurl a couple of tons of metal into space after he decided he could do it. It has taken man and nature several million years to develop the human voice and speech to the current point of personal communication. Compared to the mechanism of human speech, the hard ware of an atom bomb or a space missile is simple engineering work".

Robert M DeuPree, 1971

"In nature, structure determines function, anatomy determines physiology and it changes only in response to physiological demands from one millenia to the next. Anatomical structures used in human oral communication are marvels of evolutionary development and selective physiological enrichment through the ages".

Robert M DeuPree, 1971

"All the structures whose original function was none more than for a primitive action have undergone change to make up the voice and speech mechanism for example vocal folds close the glottis air tight to enable abdominal muscle to contract and assist micturation and defecation, probably a far more "primitive" act in any species than phonation".

Robert M DeuPree, 1971

One attribute of man, probably the most important is the ability to communicate with fellow beings sets him apart from other species of animals. The ability to use the vocal apparatus to carry out interpersonal, intrapersonal and group communication is unique to human beings.

Voice being the basis for speech, is affected in various vocal fold pathologies. Cancer of vocal folds is one such condition which warrants the surgical excision of larynx leading to voicelessness. Restoration of voice is a challenging task for the speech pathologist and head & neck surgeon. Rehabilitation aims to restore voice by two methods (i) the oesophageal voice and (ii) the use of electronic devices (artificial larynx), which is not preferred for its mechanical and inferior voice quality. Various surgical procedures to restore voice have been tried but had to face with various disadvantages.

With the introduction of the tracheoesophageal puncture (TEP) technique and the Blom-Singer's (BS) voice prostheses (Singer and Blom, 1980), a third alternative is available, which uses the pulmonary air source to vibrate the PE segment.

Evaluating the factors affecting the intelligibility of the alaryngeal speech is important for the rehabilitation of the laryngectomees. Changes in the speech production mechanism occasioned by laryngectomy are reflected in the acoustic characteristics of alaryngeal speech in many ways (Hillman and Weinberg, 1982; Robbins, Fisher, Blom and Singer, 1984; Sisty and Weinberg, 1972; Weinberg, 1986; Weinberg and Bennett, 1972a and 1972b; Weinberg, Horii and Smith 1980).

Both TEP and oesophageal speech are characterized by altered fundamental frequency, speaking rate, duration and intensity characteristics. These altered characteristics highlight some of the differences between normal and alaryngeal speech, serve to identify parameters of speech important to clinical evaluation and management.

Comprehensive understanding of acoustic properties of alaryngeal speech, however, is for from complete. Most of the acoustic research on oesophageal speech has been concerned with the measurement of fundamental frequency. In general, the source function characteristics of oesophageal speech have been studied because investigations have assumed that the principle factors affected by laryngectomy are those of the vibratory source (Daraste, 1958; Nichols, 1968).

The literature on oesophageal speech presents different views in terms of the effects of laryngectomy on vocal-cavity transmission characteristics. Damste (1958) has suggested that "the rest of the vocal tract (pharyngeal and oral cavities) behaves substantially the same in both normal and oesophageal speech. For that reason phonetic, events in this region undergo no change". His conclusion were based on the studi es of German and Dutch speaking oesophageal speakers (Shiling and Binder, 1926; Beck, 1931; Luchsinger, 1952) which, according to Damste, showed little difference between the vowel formant frequencies of normal and oesophageal speakers.

In contrast, the reports of Rollin (1962) and Kytta (1964) suggest the removal of the larynx does result in altered vocal cavity transmission characteristics. Specially their data show that vowel formant frequencies for oesophageal speakers were generally higher than those of normal speakers.

The information about the formant frequencies of the oesophageal and TE speakers is important both in understanding the physiology of alaryngeal speech production and documenting changes in vocal tract function associated with laryngectomy. Studies dealing with the T.E. speech aided by B.S.prosthesis are limited. Robbins, Fisher, Blom and Singer (1984) indicated that oesophageal and T.E.speech are two distinct phenomena. Moon and Weinberg (1987) provided further evidence that the vibrating segment was - subjected to aerodynamic and myoelastic influences distinct from those in oesophageal speech. The improved aerodynamic driving force in T.E. speakers may have an influence on the temporal aspects (duration of vowels and voice-onset time in consonants). Hence the present study is planned with the objective of studying various acoustic parameters of speech in TE and oesophageal speakers and determine their contribution to intelligibility.

AIM OF THE STUDY:

The present study is undertaken to:

- Compare the speech of T.E. and oesophageal speakers, based on spectrographic analysis.

- To determine the differences between alaryngeal speakers and normals on various parameters.

- To relate the deviations in various parameters to reduced intelligibility in alaryngeal speakers.

Some of the temporal and spectral parameters used by Robbins et.al., (1984), Sisty and Weinberg (1982) have been used in the present study i.e.,

1) Formant frequencies (F1, F2 & F3) in vowel /a/, /e/, /o/, /u/, /i/.
2) Duration of vowels /a/, /e/ /o/, /u/, /i/.
3) Formant frequencies (F1, F2 & F3) in stop consonants /p/, /t/, /k/, /b/, /d/ and /g/.
4) VOT in stop consonants /p/, /t/, /k/, /b/, /d/ and /g/.

METHODOLOGY:

The speech samples of three groups (oesophageal, TEP and normal speakers) each containing five subjects were studied. The formant frequencies of vowels and consonants, the vowel duration, and voice onset time of various stop consonants were analysed using spectrograph. The data has been subjected to appropriate statistical analysis and results have been discussed.

HYPOTHESIS:

- There is no significant difference in terras of parameters studied between oesophageal and normal speakers i.e.,

1) Formant frequencies (F1, F2 & F3) in vowel /a/, /e/, /o/, /u/, /i/.
2) Duration of vowels /a/, /e/ /o/, /u/, /i/.
3) Formant frequencies (F1, F2 & F3) in stop consonants /p/, /t/, /k/, /b/, /d/ and /g/.
4) VOT in stop consonants /p/, /t/, /k/, /b/, /d/ and /g/.

- There is no significant difference in terras of parameters studied between T.E. speakers and normals i.e.,

1) Formant frequencies (Fl, F2 & F3) in vowel /a/, /e/, /o/, /u/, /i/.
2) Duration of vowels /a/, /e/ /o/, /u/, /i/.
3) Formant frequencies (F1, F2 & F3) in stop consonants /p/, /t/, /k/, /b/, /d/ and /g/.
4) VOT in stop consonants /p/, /t/, /k/, /b/, /d/ and /g/.

- There is no significant differences in terras of parameters studied between oesophageal and T.E. speakers i.e.,

1) Formant frequencies (F1, F2 & F3) in vowel /a/, /e/, /o/, /u/, /i/.
2) Duration of vowels /a/, /e/ /o/, /u/, /i/.
3) Formant frequencies (F1, F2 & F3) in stop consonants /p/, /t/, /k/, /b/, /d/ and /g/.
4) VOT in stop consonants /p/, /t/, /k/, /b/, /d/ and /g/.

IMPLICATIONS:

The analysis of B.S. prosthesis aided T.E. speech and oesophageal speech provides some of the characteristics of their speech, and also how the various parameters studied may affect the intelligibility of the alaryngeal speakers. This also provides information towards improving the intelligibility of alaryngeal speakers.

LIMITATIONS OF THE STUDY:

1) Only male speakers have been studied.
2) Only acoustic and temporal parameters were studied.
3) Small sample size.

REVIEW OF LITERATURE

Normal speech production is accomplished by generating sounds in the larynx or at various sites in the vocal tract and differentially modifying these sounds by acoustic filtering. (Weinberg, 1986).

The production of voice depends on the synchrony between the respiratory, the phonatory and the resonatory systems. Any anatomical, physiological or functional deviation in any of these systems would lead to a voice disorder. There are circumstances in which people must produce speech using a radically altered mechanical system. Patients who are affected by cancer of vocal folds, having undergone total laryngectomy are in such a situation. Alternate modes of speech or voice production in laryngectomees can be generally classified as oesophageal, artificial laryngeal and prosthetically aided tracheoesophageal.

Voice restoration in laryngectomees has been a challenging problem for both the Head and Neck Surgeon and Speech Pathologists. A total laryngectomy necessitates the removal of entire larynx, sometimes including the structures including the hyoid bone the strap muscles and the upper tracheal rings. As a result of such a surgical procedure there is an anatomical separation between the pulmonary air way and the digestive tract. As part of this surgical procedure, the trachea is rotated forward and sutured to the base of the neck to create a permanent respiratory stoma on the neck wall. Thus the total laryngectomy always results in a dissection of tissue essential for normal vocal function to such an extent that there is always a loss of ability to produce voice by conventional means.

Contemporary approaches to voice restoration following total removal of larynx include (1) assisting laryngectomised patients to produce voice for speech powered by some type of prosthetic artificial larynx, (2) assisting patients to produce oesophageal speech, (3) developing voice that is mediated, in part, on a surgical prosthetic basis.

An artificial larynx is a device meant to simulate an approximation to normal laryngeal tones. They have been developed mainly for individuals who have had their larynx surgically removed. The quality of sound, the ease of use, and other physical attributes vary greatly from device to device. Since this study is not concerned with the study of artificial larynx details have not been included.

The production of alaryngeal speech necessitates the use of non conventional air stream, phonatory and articulatory mechanisms. One of the most important implications is that the speech reacquisition and training involves far more than "getting the voice back" (Weinberg, 1981).

The laryngectomee can generate sound at three locations: (1) within the oral cavity, called "buccal speech" (2) within the pharyngeal cavity, termed as 'pharyngeal speech' (3) at the lumen of the oesophagus known as 'oesophageal speech'. Of the various methods of sound production available, oesophageal speech is the time honoured one. Aronson (1980) states that this mode of alaryngeal speech is based on the principle that when air is taken into the oesophagus, sound is produced on the release of the air by exciting the upper oesophageal tract into vibration, like 'belching'.

General requirements for oesophageal voicing

According to Diedirch and Youngstone (1966) "oesophageal speech is that in which the vicarious air chamber is located within the lumen of the oesophagus and the neoglottis is located above the air chamber.

Weinberg (1982) states that the production of oesophageal voice necessitates use of the oesophagus as an accessory lung and the pharyngoesophageal (P.E.) segment as the source of voice.

In explaining the anatomy and physiology of the oesophageal speech mechanism, Duguay (1977> considers the oesophagus as similar to a long, narrow collapsed balloon. At the top of the balloon is a rubber ring that, if closed tightly, would resemble the PE segment. To blow into the balloon one would have to build enough oral-pharyngeal pressure to override the natural resistance of the rubber ring. If one is successful, the balloon will inflate. When the top ring of the balloon is pinched off to allow air to pass upward through the fingers, the natural elasticity of the balloon wall will help force the air upwards. As it passes through the narrow opening at the top of the balloon, sound is produced. Such an analogy clarifies the idea that it is necessary to manipulate behaviours in three areas (1) the oral pharyngeal area, (2) the PE segment area, (3) the oesophagus.

Methods of air intake

Oesophageal speech is considered to be. achieved by two primary methods of air intake, which are based on two theories about the opening of the PE segment for air intake and expulsion. They are (1) inhalation technique and (2) injection technique.

The inhalation technique has also been termed insufflation or aspiration. At rest, in the laryngectomee, the lips are closed, nasal cavity coupled to the oro-pharynx and the P.E. segment shut. As air intake is attempted, a patent airway is established between the lips and P.E. segment, the nose and P.E. segment or the lips, nose and P.E. segment. The tongue is relaxed and does not occlude the airway during the air intake phase of inhalation. As the laryngectomee begins to take in a breath for pulmonary respiration using diaphragmatic intercoastal breathing, their is an immediate drop in the intrathoracic pressure. Being in the thoracic cavity the oesophagus too experiences the pressure drop from -4mm to -7mm Hg to around -15rara Hg. Considerable difference between the positive atmospheric pressure above the P.E. segment and the increased negative pressure below the P.E. segment causes the air to flow into the oesophagus. With the reduction in pressure difference, the P.E. segment snaps shut, leaving air contained within the inflated oesophagus ready for use for voice production (Edels, 1983).

In the injection technique the laryngectomee attempts to force air past the P.E. segment by increasing the pressure of the air within the oral/pharyngeal cavity, by shutting the escape routes for the air, and then reducing the size of the air chamber. The oral exit is shut, either by sealing the lips, or more commonly by tongue-tip alveolar ridge contact and the nasal exit by velopharyngeal closure. If the air is now subjected to sufficient increased pressure, it would enter the oesophagus via the P.E.segment.

Voice production using standard injection method has two distinct phases, i.e., an air intake phase and an air expulsion phase (Edels, 1983). Moolenaar - Bijl (1953), provided the description of consonant injection and was the first person to advance the notion that oesophageal insufflation can occur as a result of pressure build up associated with the production of certain types of consonants. The action of the tongue injecting the air into the oesophagus may also be :associated with the articulation of a voiceless consonant particularly a plosive, fricative or sibilant. The method is termed consonant or plosive injection and may be differentiated from standard injection in that the air intake and voice production phases either occur simultaneously or in an inseparable association with the articulation of the voiceless sound.

Air reservoir

The normal laryngeal speaker has an air reservoir within the lungs of between 3,500ml and 4,000ml of air, although not all of this is available for phonation. According to Greene (1964), about 1,500 to 2,000ml of air is inspired during respiration for phonation. In contrast, the total capacity of the oesophagus is between 60ml and 80ml of air when fully inflated (Vanden Berg and Moolenaar - Bijl, 1959). However, the oesophagus as reported by Edels (1983) is not fully inflated for phonation. Only the top one third to one half is inflated during air charging for voice production by good and superior oesophageal speakers which amounts to only about 15ml of air available for use after each air charge. The mean air flow rate values during continuous speech for voiced air expulsion in the laryngectomees is reported to range from 25ml/sec to 97ml/sec with a median of 61ml/sec (Snidecor and Isshiki, 1965). The mean flow rates in normal laryngeal speakers is about 219ml/sec. Research by Vanden Berg (1958) has shown that the two prime factors maintaining a constant flow of air from oesophagus are the intra-thoracic pressure and the elastic quality of the non-muscular components of the walls of oesophagus. With so little air available, it is essential that the patient develops good consistency for successive attempts at recharging his oesophagus, fast air intake, controlled sound production which are acceptable.

Not all laryngectomees are able to acquire oesophageal speech. Reported percentages range from 43% (King, Fowlks and Pierson, 1968) to 98% (Hunt, 1964) with an average of 64-69% (Snidecor, 1975). Gates, Ryan and Cooper (1982) reported that only 55% were considered to be successfully rehabilitated. Gates et.al., (1982) concluded that, "the rehabilitation needs of today's laryngectomees are not being met successfully with traditional methods". Hence there is a need for voice restoration techniques for laryngectomees which would ensure a higher success rate.

According to Singer (1983), a vocal rehabilitative method in laryngectomees should meet the following critical criterion:

A. No limitation on adequate cancer treatment, either surgical or radiation.

B. Normal and rapid postoperative deglutition.

C. Avoidance of prolonged hospitalization, convalescence, or excessive cost.

D. No dependance on complicated valves, cannulas, or external devices.

Keeping these issues in mind, Singer and Blom (1980) developed an endoscopic technique for voice restoration - Tracheo Esophageal Puncture (TEP), a surgical prosthetic approach. A high success rate in the acquisition of 'fluent' speech by this method has been reported (Mitzell, Andrews and Bowman, 1985; Wetmore, Krueger, Wesson and Blessing, 1985; Blom, Singer and Hamaker, 1986; Perry, 1988; Hazarika, Murthy, Rajashekhar and Kumar, 1990; Rajashekhar, Nataraja, Rajan, Hazarika, Murthy and Venkatesh, 1990).

TRACHEO-OESOPHAGEAL SPEECH

Voice restoration in laryngectomees was revolutionised in 1979 when Dr. Mark Singer, an otolaryngologist and Dr. Eric Blom, a speech pathologist, reported a new surgical procedures described as "tracheoesophageal puncture" (Singer and Blom 1979). The purpose was to provide air from lungs for oesophageal speech. In this technique a small fistula is created in the wall between the trachea and the oesophagus. The opening is maintained by a silicon prosthesis that acts as a one-way valve. When the stoma is occluded, the prosthesis allows air from lungs to pass into the oesophagus while preventing food and liquid from entering the trachea. The puncture can be reversed by removing the prosthesis. Thus improved air supply has advantages over the traditional oesophageal speech for example:

(1) a spontaneous expansion of the loudness range

(2) an increase in pitch variation.

(3) an extension of the duration of sound have been noticed (Robbins, Fisher, Blom and Singer 1984; Singer, 1983).

Further it has been reported that there was also an improvement in sound quality which was not attained earlier with regular oesophageal speech. In addition, the tracheooesophageal fistulisation (TEF) speech is compatible with other types of alaryngeal speech; that is, it does not prevent the alternate use of regular oesophageal speech or an artificial larynx.

Immediate voice restoration is possible by occluding the stoma and patient is instructed about the care of stoma and the prosthesis. The demonstration of significance of controlled respiration, precise articulation, muscle relaxation and daily care involved in using the prosthesis are done by a qualified speech clinician (Singer and Blom, 1980). The surgical procedure for TEP is being carried out in two ways (1) Primary TEP and (2) Secondary TEP.

PRIMARY AND SECONDARY TRACHEOESOPHAGEAL PUNCTURE

Primary T.E.P is defined as "voice restoration at the time of laryngectomy" and secondary T.E.P. as, "voice restoration at a time subsequent to total laryngectomy". Primary voice restoration done at the time of laryngectomy (primary T.E.P.) has developed from concepts derived from secondary T.E.P. technique described by Singer, Blom and Hamaker (1983). Singer et.al., (1983) reported a success rate of 63% and Hamaker, Singer, Blora and Daniels (1985), 69% in their series of primary T.E.P. cases. Singer et.al., (1983) believed that the continued use of a primary puncture procedure was limited by the inability of the newly laryngectomized patient to manage a tracheostoma, puncture and prosthesis simultaneously. Stiernberg, Bailey, Calhoun and Perez (1987) reported 65% success rate in the cases where primary tracheoesophageal fistula procedure was used.

Perry, Cheesman, Mclvor and Chalton (1987) reported that 94% of their patients who underwent secondary voice restoration were successful by two weeks after surgery but this success rate dropped to 73% by three months. The results in the primary series (Perry, 1988) were 94% at three months after surgery.

Wenig, Mulloly, Levy and Abramson (1989) commented that primary and secondary punctures were equally effective in permitting the development of T.E. speech. Hazarika, Murthy, Rajashekhar and Kumar (1990) advocated the use of secondary T.E.P. owing to its high success rate (90%).

PHARYNGO ESOPHAGEAL (P.E.) SEGMENT FUNCTION ASSESSMENT

The structures involved in alaryngeal speech production are different from the normal laryngeal speech. A comparison of laryngeal, oesophageal and TEP speech production in terms of structures involved is presented in Table-I.

Physical requirements	Laryngeal voice	Oesophageal voice	Tracheo-esophageal voice
1. Initiator	Moving column of air from lungs	Moving column of air from oesophagus	Moving column of air from lungs
2. Vibrator	Vocal cords	P.E. segment	P.E. segment
3. Resonator	Vocal tract (i.e., pharynx nose, mouth)	Vocal tract (i.e., pharynx nose, mouth)	Vocal tract (i.e., pharynx nose, mouth)
4. Articulators	Tongue, teeth lips, soft palate	Tongue, teeth, lips, soft palate	Tongue, teeth, lips, soft palate

Adapted from Edels, 1983

Table-I: Different elements involved in alaryngeal speech (both oesophageal and tracheoesophageal) compared with laryngeal speech)

Successful oesophageal voice depends on the ability to inject air into an oesophageal reservoir and then controlling its release through a vibrating segment within the reconstructed pharyngo-oesophageal area (Singer and Blom, 1981). The P.E. segment or sphincter is vibrator in both types of alaryngeal speech and hence problems in this region will affect the successful voice production. Good PE segment in tracheoesophageal speaker enhances the loudness and more sustained speech because of the increased air supply from lungs.

Presence or absence of hypertonicity of the P.E. segment is the key factor in production of alaryngeal voice. The presence of functional spasm in the pharyngeal musculature leads to the failure of spincter to relax even at pressures exceeding lOOcras of H_2O (Seeman (1967). This spasm directs the built-in air towards the stomach instead of pharynx, causing gastric filling and no voice production. This has been demonstrated by cine-flourographic studies (Singer and Blom, 1981). It has been demonstrated that laryngectomees with pharyngoesophageal spasm are at risk for tracheoesophageal speech acquisition (Singer and Blom, 1981; Blom, Singer and Hamaker, 1985). Hence it's mandatory to establish the presence or absence of the spasm. This is being done using oesophageal insufflation test.

The oesophageal insufflation test as described by Blom et.al., (1985) is performed with a disposable system consisting of a special 50-cm long No.14 French latex catheter imprinted with a 25cm marker, a flexible circular tracheostoma housing, adhesives and an insertable stoma adaptor. The patient's nostril is sprayed with a topical anaesthetic and the rubber catheter is transnasally inserted into the oesophagus, until the 25cm marker resides at the nostril. This is to ensure that the tip of the catheter is within the upper thoracic oesophagus. The proximal end of the catheter is then attached to the adaptor which is inserted into the tracheostoma housing. The patient is required to do an inhalation, light stoma occlusion and attempt /a/ phonation on exhalation. The patient is trained till he is used to the procedure. If the patient can sustain phonation without interruption for 8 seconds or longer and can count from 1-15, then he is said to have passed the test. The interpretation is that, he apparently has no pharyngeal constrictor spasm and is considered an ideal candidate for T.E. puncture and B.S. prosthesis fitting. If the patient cannot sustain phonation of /a/ for atleast 8 seconds or phonate at all, then he is said to have failed the test and needs a pharyngeal myotomy along with puncture for good voice (Rajashekar, 1991).

Though controversial, pharyngeal myotomy is reported to facilitate the voice production (Singer and Blom, 1981; Chodosh, Gian Carlo and Goldstein, 1984; Henley, Souliere, 1986; Mahieu, Annyas, Schutte and van der Jaget, 1987). An assessment protocol to successfully assess the PE segment function, using video fluoroscopy and radiological techniques in patients undergoing secondary tracheoesophageal puncture has been reported (Cheesman, Knight, Mclvor and Perry, 1985; Perry, Cheesman, Mclvor and Chalton, 1987; Mclvor, Evans, Perry and Cheesman, 1990).

AERODYNAMIC AND MYOELASTIC CONTRIBUTIONS TO ALARYNGEAL SPEECH

Normal voice production is an aerodynamic-myoelastic event (Van den Berg, 1958). Alterations in respiratory drive and the by-products thereof (e.g. glottal volume flow, subglottal pressure) mediate sound production at the level of the larynx (Atkinson, 1978; Collier, 1975; Fromkin and Ohala, 1968; Monsen, Engebretson, and Vemula, 1978; Ohala, Hirano, 1970; Shipp, Doherty and Morrissey, 1979). According to Moon and Weinberg (1987) voice source controlled or mediated solely on the basis of aerodynamic influences could operationally be described as a "passive" resonant device. They felt that such a device would not be capable of intrinsic and systematic myoelastic adjustment. Alterations in myoelastic properties of the vocal folds also mediate sound production at the level of the larynx (Atkinson, 1978; Baer, Gay and Niirai, 1976; Collier, 1975; Gay, Hirose, Stome and Sawashima, 1972; Hirano, Ohala and Vennard, 1969; Monsen et.al., 1978; Shipp et.al., 1979; Yanigahara and Von Leden, 1966). A voice source controlled in whole, or in part, on the basis of intrinsic and systematic myoelastic adjustments could be described operationally as an "active" voice source.

Both forms of alaryngeal speakers use the upper oesophageal sphincter as a substitute voice source which is different from that used by normal speakers.

Angermeier and Weinberg (1981) have stated that "there is no evidence to support the view that laryngectomized individuals are capable of altering the level of muscular activity within the P.E.segment on a systematic basis to pretune, control or influence the vibratory rate of this sphincter" (P.90). Van den Berg and Moolenaar Bijl, (1959); Snidecor and Isshiki, (1965) have suggested that oesophageal voice production is an aerodynamically mediated event.

Accurate, non invasive measurement of source driving pressure and trans-source airflow rate permitting systematic appraisal of physiological mechanisms underlying production and control of oesophageal voice are now feasible.

Moon and Weinberg (1987) carried out a series of phonatory tasks in tracheoesophageal speakers to assess (a) aerodynamic and acoustic properties of tracheoesophageal voice and (b) aerodynamic and myoelastic contributions to the mediation of fundamental frequency change.

It is possible that some fundamental differences among normal, tracheoesophageal and oesophageal voice production be highlighted. Sustained vowels produced by normal speakers at comfortable levels typically are associated with source driving pressures ranging between 5 and 10cm water, trans-source airflow rates ranging between 100 and 200cc/s, and airway resistances ranging from 30 to 45cm water/L.P.S (liters/second). Vowels produced at comfortable levels by tracheoesophageal speakers were typically associated with source driving pressures ranging between 20 and 50cm water, trans-source airflow rates ranging between 110 and 335cc/s, and airway resistance ranging from about 142 to 383cm water/LPS. Moon and Weinberg (1987) reported that though directly comparable data during sustained production of vowels by oesophageal speakers were not available to them, Snidecor and Isshiki (1965) had shown that trans-source air flow rates during oesophageal voicing ranged between 25 and 72cc/s, while Damste (1958) had shown that oesophageal source driving pressures typically ranged between 15 and 60cm water.

Moon and Weinberg (1987) on the basis of these observations reported that tracheoesophageal voice production was generally characterized by (a) increased trans-source air flow rates, comparable to oesophageal source driving pressures, and decreased airway resistances when compared with conventional oesophageal voice production and (b) comparable to normal trans-source airflow rates, increased source driving pressures and increased airway resistance when compared with normal voice production. These observations, according to them, marked fundamental differences that existed between these three forms of voice production. Both normal and tracheoesophageal speakers use pulmonary airflow, accomplished with a closed tracheal airway, differ from oesophageal speakers who use non-pulmonary air for voicing and is accomplished with an open tracheal airway.

Both normal and TE speakers use pulmonary airflow, accomplished with a closed tracheal airway, differ from oesophageal speakers who use non pulmonary air for voicing and is accomplished with an open tracheal airway.

The tracheoesophageal speakers were capable of varying Fo in association with negatively related variations in trans-source airflow rate. This finding is not in agreement with the views expressed by Van den Berg, Moolenaar-Bijl and Daraste (1958) and Angermeier and Weinberg (1981). Their results, coupled with findings that aerodynamics contributes to TE phonation, are interpreted to suggest that tracheoesophageal voice production should be regarded as an aerodynamic myoelastic event.

AIRWAY RESISTANCE IN OESOPHAGEAL AND B.S. PROSTHESIS AIDED T.E. PHONATION

Normal larynx acts as a valve in the production of voice. The efficient functioning of this valve can be assessed by calculating the laryngeal air way resistance from the ratio between the tracheal pressure and trans-laryngeal flow.

Weinberg, Horii, Blom and Singer (1982) measured the prosthesis airway resistance in five Blom-Singer duck-bill prostheses and oesophageal source airway resistance for five laryngectomees. In their study, airway resistance of the Blom-Singer prostheses ranged from 46 to 121cm water/LPS, while oesophageal source airway resistance ranged from about 155 to 270cm water/LPS. In a follow-up study extended on a larger sample of eighty eight prostheses, the airway resistance was found to vary from 53 to 127cm water/LPS (Weinberg and Moon, 1982). With the average laryngeal airway resistance being 35cm water/LPS (Smitheran and Hixon, 1980), the resistance offered by Blom-Singer prostheses ranges about

1.5 to 3.5 times higher than that offered by the laryngeal source. Thus the results revealed that the opposition of the voice source, used in oesophageal speech production to air flow through them is substantially higher than that established for the normal, laryngeal source.

The results of the study by Weinberg et.al., (1982) reveal specific reasons for the failure of many laryngectomees to develop consistent voice and functional oesophageal speech. Highly proficient speakers using the Singer-Blom method required oesophageal pressures of about 20-35cm water to sustain voicing, although higher pressures were noted during the initial portion of sustained vowel production. Though comparable pressure requirements have been reported for conventional oesophageal speakers, the ability to generate and sustain oesophageal pressures of this magnitude is clearly enhanced in Blom-Singer speakers using pulmonary air, a closed airway, and advantageous background and chest wall forces (Weinberg et.al., 1982).

Weinberg et.al., (1982) stated that active, exhalatory movements of the chest wall would be expected to drive oesophageal pressure upto sufficient levels, however, such movements also increase the likelyhood of producing stoma noise through the patient's open airway.

Depletion of lung volume would be expected to drive oesophageal pressures upto sufficient levels, since it is well established that there is an inverse relationship between lung volume and oesophageal pressure. The lung volume depletion also increases the likelihood of stoma noise production which is not conducive to the production of speech for a larger duration (Weinberg et.al., 1982).

Moon and Weinberg (1987) discussed the optimization and advantage in terms of airway resistance. According to them, airway resistance during both oesophageal and tracheoesophageal voice production was substantially higher than that during normal voice production. Airway resistance during tracheoesophageal voice production was estimated to be lower, on the average, than during conventional oesophageal production, although both relied upon the same voice source. They attributed the difference in airway resistance characteristics between these two speaker groups to a decrease in trans-source airflow rate during oesophageal voice production.

Moon and Weinberg (1987) on the basis of their results suggested that all tracheoesophageal speakers studied, exhibited variations in Fo (Fo standard deviation) comparable to that noted among normal speakers. This led them to comment that tracheoesophageal speakers may be capable of exhibiting more appropriate steady-state control over Fo in comparison with their oesophageal speaking counterparts.

ANALYSIS OF VOICE

The study of various acoustic parameters of speech presents an important body of knowledge and significant area of theoretical and applied study. The knowledge about the acoustic properties of alaryngeal speech can be interpreted in such a manner as to enlarge understanding of speech production following removal of larynx. Increased understanding is accomplished by uncovering relationships among acoustic properties, and physiological, psychological and linguistic aspects of speech production.

Comprehensive data about articulatory changes occasioned by removal of larynx is lacking. Removal of larynx must alter articulatory behaviour (Weinberg, 1980). This is true because total laryngectomy disrupts muscular support for the tongue, occasions major changes in articulatory aerodynamics and produced alteration in vocal-tract morphology. In addition, the intrusion of gestures essential to oesophageal air fillings" must exert disruptions in dynamics of articulatory behaviour of oesophageal speech.

Information about acoustic properties of articulatory by-products in alaryngeal speech are scarce. However, some attempts have been made. Sisty and Weinberg (1972) have shown that formant frequency characteristics of vowels produced by oesophageal speakers are elevated, a finding interpreted to show that laryngectomised speakers have shorter than normal vocal tracts.

Christensen and Weinberg (1976) have shown that spoken vowels of oesophageal speakers are consistently longer than normal speakers a findings supportive of the view that articulatory behaviour is altered.

The study of VOT may reflect the glottal abductor - adductor activity in conjunction with articulatory and aerodynamic responses. The acoustic analysis of speech provides quantitative data from the clinical assessment of laryngeal and articulatory function.

Another advantage of acoustic analysis over other methods is its non-intrusive nature and its potential for providing quantitative data with little expenditure of time for analysis.

One of the most powerful acoustic analytic techniques being sound spectrography, it provides the dissection of acoustic wave into its most basic components. One can read the formant frequencies, study vowel duration and measure the voice onset time and observe the transition of various formants. Of these features that can be studied from a spectrogram, the following features were taken for the purpose of the present study. They are

- formant frequencies of vowels and consonants.
- Vowel durations.
- voice onset time of stop consonants.

These parameters have been reported to be contributing to the intelligibility of speech along with other acoustic and durational parameters. Therefore it was considered to be useful to study these parameters in Indian population speaking Kannada.

FORMANT FREQUENCIES

The acoustic result of vocal fold vibration is termed the source function and the acoustic result of the vocal tract shape and length, the transfer function. The output at the lips is a product of these two functions (plus an effect of sound radiation at the lips).

It is generally accepted that the frequencies of the first two formants are the most important features in the recognition of vowel sounds (Dellattre, Liberman, and Cooper 1952; Peterson and Barney, 1952; Pols, van der Kamp and Plomp, 1969). The resonances of the vocal tract, depicted as broad bands of energy in a spectrogram are known as formants. Fant (1957) defines a formant as a single energy maximum. The transfer function for vowels refers to the control of the formant pattern by the shape of the vocal tract. According to Angelocci, Kopp and Holbrook (1964), the formant frequency pattern of vowels, specially the position of the second formant frequency is an important acoustic correlate of the vowel quality and its phonemic identity. The position of the third formant provides less information with respect to vowel differentiation than the first and second formants. The first formant (F1) decreases in frequency as pharyngeal enlargement accompanies tongue elevation, and it increases in frequency when the constriction moved back in the vocal tract. F2 is high in frequency when the oral cavity is constricted and low in frequency when it is more open or elongated. Relative formant positions for a particular vowel are similar for men, women and children, but the natural resonant frequencies are higher for smaller vocal tracts. The difference in the frequencies of formants is not simply related to change in length, however, because the larger vocal tracts of men have a relatively larger ratio of pharyngeal area to oral cavity area compared to women and children. Levitte (1978) suggested that the vowels are differentiated by the ratio of the first and second formant frequencies i.e., the F2/F1 ratio.

The literature on oesophageal speech presents different pictures in terms of the effects of laryngectomy on vocal tract transmission characteristics. Damste (1958) considers that "the rest of the vocal tract (the pharyngeal and oral cavities) behaves substantially the same in both normal and oesophageal speech. For that reason phonetic events in this region undergo no change". His conclusions were based on studies of German and Dutch speaking oesophageal speakers (Shilling and Binder, 1926; Beck, 1931; Luchsinger, 1952 as cited by Damste, 1958) which demonstrated little difference between the vowel formant frequencies of normal and oesophageal speakers. In contrast, the studies of Rollin (1962) on English speaking laryngectomees and Kytta (1964) on Finnish speaking laryngectomees showed that vowel formant frequencies for oesophageal speakers were generally higher than those for normal speakers.

Sisty and Weinberg (1972) have shown that removal of the larynx does alter vocal-cavity transmission characteristics. They observed that the average vowel formant frequency values associated with oesophageal speech were elevated and interpreted this to support the view that laryngectomees exhibited a reduced vocal tract length. Further, they observed that the changes in formant frequency from vowel to vowel were systematic and were essentially the same for normal and oesophageal speakers.

No reports on the formant frequency characteristics of T.E. speakers are available to the investigator. Since the T.E. speakers also have an altered vocal tract due to surgical extirpation of the larynx similar to the oesophageal speakers, elevated vowel formant frequencies are expected.

The information about the formant frequencies for vowels in oesophageal and T.E. speakers is valuable in understanding the physiology of oesophageal and tracheoesophageal speech production and documenting changes in vocal-tract function in alaryngeal speakers. In this study, these were considered with the view of finding out the contribution of formant frequencies to the intelligibility.

VOWEL DURATION

Measurements of vowel duration have been made using oscillograms, spectrograms, electrokymographic tracings and computers. Vowel duration has been measured in various languages -English (Raphael, 1975; Walsh and Parker, 1981); Kannada (Rashmi 1985; Shukla, 1987).

Although vowel duration differences are very reliably produced, their role in perception is not predictable. The duration of the preceding vowel is often cited as an important cue to the voicing feature of final stop consonants J in English; preceding vowel duration has been called under certain conditions a primary (Klatt, 1976) and even necessary (Raphael, 1972) cue to the voicing distinction.

Information about vowel duration in alaryngeal speech is scarce. Christensen and Weinberg (1976) measured vowel duration in ten oesophageal speakers. They reported that the durations of vowels spoken by oesophageal speakers in voiced consonant contexts were comparable to normals but were longer in voiceless consonant context. In addition, they reported longer vowel durations in voiced as against the voiceless consonant contexts, in oesophageal speakers.

Based on the results of Christensen and Weinberg (1976), Weinberg (1982) commented that total laryngectomy also produced changes in articulatory behaviour as evidenced by altered durational characteristics of vowels. They attributed the changes to be influenced by phonetic context in that the observed differences in vowel duration between normal and oesophageal speakers varied systematically as a function of the voicing feature of their consonant environment. This, according to Weinberg (1982) indicated the preservation of phonological rules governing the durational properties of English, in laryngectomees. The results of their work, as stated by Weinberg (1982) revealed longer vowel durations before voiced consonants than before voiceless consonants, for both oesophageal and normal speakers. Hence, he commented that the influence of postvocalic consonants on vowel duration as observed by House and Fairbanks (1953), Peterson and Lehiste (1960), Dmeda (1975) and Klatt (1976) in normal speakers of American English were present in highly rated oesophageal speakers, the magnitude of the effect being larger.

Weinberg (1982) opines that in laryngectomees, the removal of the larynx eliminates the normal source of phonation altering the speech production with the linguistic form of the speaker's message remaining unimpaired. He also states that vowels before voiced consonants are longer than those before voiceless consonants in oesophageal speech is expected only if assumed that these vowel-length variations are language-specific properties of the English phonological system. The finding that relative increase in vowel duration in the environment of postvocalic consonants being not significantly different from normals was quoted by Weinberg (1982). He also emphasized that only the speech apparatus and not the linguistic code, has been altered in laryngectomees and presumed that the oesophageal speakers make compensatory adjustments in the timing control system in order to realize these variations in vowel length before voiced and voiceless consonants.

Robbins, Christensen & Kempster (1986) compared the vowel duration of fifteen T.E. speakers with fifteen each of traditional oesophageal and normal laryngeal speakers. They reported that the T.E. speakers exhibited the longest vowel durations on the three vowels /i/, /a/ and /u/. The normal speakers had the shortest durations while the oesophageal speakers had intermediate values. The normal speakers did not differ significantly from oesophageal speakers and T.E. speakers did not differ significantly from oesophageal speakers. When compared across groups, the vowels /i/ and /u/ were found to be not significantly different in vowel duration. However, /a/ was significantly longer in duration for all the groups than either /i/ or /u/.

Robbins et.al., (1986) suggested that factors in addition to a pulmonary air driven voicing source influenced the vowel durations in T.E. speakers. Further, they attributed the increased vowel duration in T.E. speakers to the availability of larger air supply and the effect of the interposed prosthesis, creating an average airway resistance, 3.5 times greater than offered by the normal larynx. They felt that the differences in vowel duration between T.E. and oesophageal speakers represented the distinctive aerodynamic components of T.E. speech. They further speculated that the greater vowel duration in T.E. speakers may be attributed to greater air pressures and sustained flow rates driving the neoglottis producing a slower decay in P.E. segment vibrations.

Vowels are considered as carriers of speech sounds and therefore, the information about the vowel duration in alaryngeal speakers was considered to contribute to the understanding of the influence of pulmonary air on the articulatory behaviour and acceptability and intelligibility of speech in laryngectomees.

VOICE ONSET TIME (VOT)

Lisker and Abramson (1967) defined voice onset time (VOT) as the difference between the release of a complete articulatory constriction and the onset of phonation. They stated that the VOT was an useful acoustic cue of the various phonemic categories such as "voiced stop", "voiceless stop" and "voiceless aspirated stop". Lisker and Abramson (1967) further stated that normal speakers of English systematically varied VOT to distinguish pre vocalic stops /p/, /t/, /k/ from /b/, /d/, /g/. Voiced plosives in English normally have a short VOT (less than 20-30msec) and voiceless plosives, relatively long VOT (greater than 50msec). Lisker and Abramson (1971) state that VOT is the "single most effective measure for classifying stops into different phonetic categories with respect to voicing".

Gilbert and Campbell (1978) attributed the increased VOT for voiceless stop consonants to greater intraoral air pressure resulting in the increase in the air flow rate and frication at glottis. This glottal frication inhibits the vocal folds from initiating periodic vibration during the production of voiceless stop consonants, thereby delaying VOT. It has been reported (Borden and Harris, 1980; Lisker and Abramson, 1964) that VOT increases as the place of articulation moved backwards in the oral cavity. (i.e.,) VOT is greater in velars than alveolars and in alveolars than in labials.

According to Weinberg (1982), "it is also now well established that laryngectomized patients using esophageal speech have difficulty achieving voicing contrast between homorgamic stop consonants". Christensen, Weinberg and Alfonso (1978) studied the VOT associated with production of stops in oesophageal speakers. They reported that oesophageal speakers did effect systematic variation in VOT and that the VOT values associated with prevoclaic voiceless stops exhibited lag intervals which were significantly shorter than in normal speakers. They further stated that the VOT characteristics of oesophageal speakers were differentially sensitive to place of articulation.

The observation that the oesophageal speakers effected systematic variation in VOT during the production of phonetically representative speech sounds was considered by Weinberg (1982) as intriguing due to the differences in voice producing systems of normal and oesophageal speakers. Weinberg (1982) commented that in the absence of abductor-adductor properties of the pseudoglottis in oesophageal speakers as compared to the vocal cords in normals, the differences in VOT are expected. He considers that the earlier onset of voicing associated with voiceless stops in oesophageal speakers highlights the contribution of articulatory-aerodynamic factors. Weinberg (1982) cites the earlier VOT in prevocalic stops to account, in part, for the increased vowel duration observed in oesophageal speakers by Christensen and Weinberg (1976). Weinberg (1982) concludes that oesophageal speakers were far less consistent than normals in effecting appropriate variation in the timing of voicing onset.

Robbins, Christensen and Kempster (1986) measured the VOT in voiceless consonants in T.E. speakers and compared it with oesophageal and normal speakers. The VOT was measured from the broad band spectrograms. The VOT values of consonants preceding the vowel provide cue to differentiated front, mid, and back vowels in laryngeal and TE speakers. The oesophageal group did not reflect this distinction. The laryngeal speakers had the longest VOT values for /a/ production (/kap/) followed by the TE group. The oesophageal speakers had the shortest VOT. The laryngeal and T.E. speakers systematically varied VOT with the change of stop loci from labial to velar positions. The oesophageal speakers performed only marginally in this aspect.

Reduced VOT for alaryngeal groups has also been reported by Klor and Milanti (1980) who examined VOT for prevocalic stop productions for laryngeal, oesophageal and Staffieri noeglottic speakers. Based on the above mentioned studies, Robbins et.al., (1986) suggestes that the physical characteristics of the neoglottis exert a major influence on VOT production in alaryngeal speakers. Further, they attributed different VOT effect in alaryngeal groups to aerodynamic capability, myoelastic and motor control properties of the voicing source and consonant-vowel articulatory loci. Thus, the study of VOT is considered useful in determining the coordination between the articulatory and phonatory system and in turn its contribution to the intelligibility of speech in alaryngeal speakers.

INTELLIGIBILITY

Literature on the intelligibility of alaryngeal speakers reveals that esophageal speech is characterised by a reduction in speech intelligibility various studies have shown that the mean word intelligibility scores in conventional esophageal speakers range from as low as 54.9% (Shames et al, 1963) to a highest of only 78.5% (Kalb and Carpenter 1981).

Tardy-Mitzell, Andrews and Bowman (1985) studied the acceptebility and intelligibility of T.E. speakers. They observed a mean intelligibility score of 93% in T.E.P. speakers.

Brown and Blalock (1986) reported that T.E. speakers were rated as raoreintelligible than the oesophageal speakers. Rajashekhar et.al., (1990) reported intelligibility scores of 70% in the oesophageal mode and 97% in the T.E. mode in a dual mode speaker. From another study Rajashekhar (1991), it has been reported mean intelligibility scores of 79.6% in oesophageal speakers, 88.3% in T.E. speakers and 99.1% in normal speakers.

Hence in the present study attempt has been made find out the correlation between intelligibility and various acoustic parameters studied.

The review of literature thus shows the need for studying the acoustic parameters of speech in TEP and oesophageal speakers. There is also a need to study the relationship of the above parameters and explain their influence on the intelligibility of their speech. As has been rightly pointed by Robbins (1984) that such findings are of interest because they are expected to contribute to the understanding of (a) the acoustic output of specific physiologic processes (b) the features that contribute to variation in perceptual response and (c) the physical properties of speech that may signal vocal deviancy. These become important as no such studies are available in Indian context.

Therefore the present study was undertaken to study the various acoustic parameters of speech in TEP and oesophageal speakers and determines their contribution to intelligibility.

METHODOLOGY

The purpose of this study was to compare the speech of the oesophageal, B.S. prosthesis aided T.E. and normal speakers in terms of certain acoustic parameters as these have been considered to be contributing to the intelligibility of speech.

The parameters studied were:

1) Formant frequencies F1, F2 and F3 of vowels /a/, /e/, /u/, /o/ and /i/
2) Duration of vowels /a/, /e/, /u/, /o/ and /i/
3) Formant frequencies F1, F2 and F3 in the burst of the stop consonants /p/, /t/, /k/, /b/, /d/ and /g/

Subjects :

Three groups of male speakers namely T.E.P. with B.S. prosthesis, oesophageal and normals matched in terras of age, sex and number participated in the study. All of them were screened for hearing motor and sensory abilities.

The first group consisted of five subjects who had a tracheoesophageal puncture (T.E.P.) as a secondary procedure having undergone laryngectomy earlier and were using Blom-Singer's voice prostheses (American V. Mueller). All" of them had T.E.P., and Blom-Singer prosthesis fitting and speech services at KMC, Manipal. The mean age of this group was 57.4 years with a range of 50-69 years.

The second group of alaryngeal speakers comprised of five subjects who used oesophageal mode of communication. The mean age of this group was 53 years with a range of 37-67 years.

The third group consisted of five normal laryngeal speakers matched for age and language with the alaryngeal speakers. This group had no speech, voice or hearing impairments. The mean age of the group was 50 years ranging from 38-67 years.

Data collection:

The speech samples of all the subjects were recorded individually, in a sound treated room. Recordings were made on hi-bias metal cassettes, using a professional stereo cassette deck (Akai CS-M4) and a AKG-D222 dynamic cardioid microphone with a flat frequency response from 50-15, 000Hz. The microphone-to-mouth distance was approximately 15cm for all the subjects. The T.E.P. subjects wore a B.S. low pressure prostheses during the recording. All the T.E.P. subjects were recorded within a fortnight after undergoing the T.E.P. and B.S.prosthesis insertion.

Speech material used:

All the subjects were asked to read a standardized passage in Kannada. The subjects were instructed to "read the passage at their comfortable loudness and rate". Each subject was allowed time to familiarise himself with the passage before the recording.

PHOTOGRAPH - A

The passage was "obb^ b^kk^ t^l^J^ m^nuSj^.... (presented in the appendix-1) A set of sixe words were segmented from the passage. These words consisted of vowels /a/, /i/, /u/, /o/ and /e/ and consonants /p/, /t/, /k/, /b/, /d/ and /g/ (the vowels selected for analysis were short ones). Care has been taken to see that the sounds selected for analysis were free from and were not preceeded or followed by semivowels, glides and nasal sound environment since it was considered that these sounds may effect the measurements. The subjects were also asked to read a set of 20 words randomly seleceted from the list given in Appendix-2 for intelligibility rating.

Analysis of Data:

The analysis principally involved the following equipment as shown in photograph-A).

1) Tape deck to play the recorded speech samples.
2) Antialiasing filter (low pass filter having cut off frequency at 3.5/7.5K).
3) A-D/D-A converter (sampling frequency of 8/16KHz, 12 bit).
4) Personal Computer-AT Intel 80386 Microprocessor with 80837 Numerical data processor.
5) Software developed by Voice & Speech Systems, Bangalore.
6) Amplifier and Speaker.

Procedure used to extract different parameters:

The parameters were measured from the sounds in the following words.

/a/ - in hoded<u>a</u>.

/e/ - in hod<u>e</u>da

/u/ - in e<u>tu</u>.

/o/ - in <u>o</u>bba

/i/ - in sakag<u>i</u>.

/p/ - in <u>p</u>unah

/<u>t</u>/ - in e<u>t</u>u

/k/ - in sa<u>k</u>agi

/b/ - in <u>b</u>akka tel^ja

/d/ - in ho<u>d</u>eda

/g/ - in saka<u>g</u>i

From the recorded passage, speech samples of each subject were digitised at the rate of 8KHz using 12 bit VSS data input and output card by feeding the signal from tape deck to the speech interface units through line feeding. The digitised samples were used for the analysis.

Formant frequencies (F1, F2, F3):

The first three formants (F1, F2, F3) for each vowel /a:/, /u/, /o:/, /i/ and /e/ were measured directly from the spectrogram display with sectioning on the screen of the computer. Formant frequency estimates were made by measuring the raid point of the visible dark bands of energy appropriate to the first three vowel resonances.

Vowel Duration (VD):

The vowel duration (msec) for each vowel /a:/, /u/, /o:/, /i/ and /e/ were measured from the spectrogram display. The measurement criteria for vowel duration were based on suggestions by Peterson and Lehiste (1960) i.e., the vowels were identified on the spectrogram and the duration from the onset of phonation indicated by the initial periodic striations of the first formant to the last vertical striation associated with the second formant were considered as duration for each vowel.

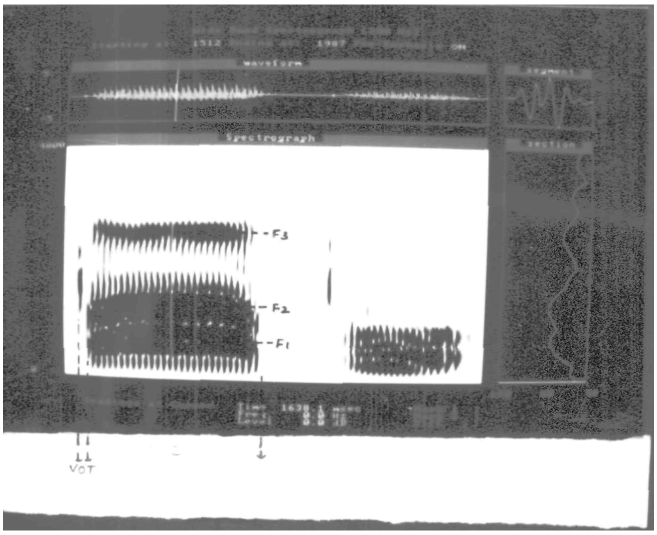
Voice Onset Time (VOT)

VOT (msec) of /p/, /t/, /k/, /b/, /d/ and /g/ were measured using the definition given by Lisker and Abramson (1967) i.e., the time interval between the burst (or brief interval of high intensity noise) that marks release of the stop closure and the onset of quasi-periodic pulsing that reflected laryngeal vibration was the voice onset time.

The formant frequencies of the consonants /p/, /t/, /k/, /b/, /d/, /g/ were measured by sectioning the burst (Photo-8). Thus all the acoustic and temporal parameters of all the three groups were measured and subjected to statistical analysis using Computer package Epistats.

Intelligibility:

Five native speakers of Kannada served as judges. The test material read by the subjects was played to them from a



PHOTOGRAPH - B

tape recorder, the judges were instructed to write down the words on a sheet of paper and to leave a blank for the words that were not intelligible to them.

Intelligibility score was computed as percentage. (No. of words correctly identified/total no. of words x 100).

The scores of all the judges were averaged and that was considered was the intelligibility score for each subject. Inter judge reliability was found to be high.

RESULTS AND DISCUSSION

The present study was undertaken to compare the speech produced by laryngectomees, of the B.S. prosthesis aided TE, and esophageus as source of sound production and normal speakers in terras of following acoustic parameters which were considered to be contributing to the intelligibility of speech.

1) Formant frequencies (F1, F2 and F3 of vowels /a/, /e/, /o/, /u/ and /i/).
2) Duration of vowels (/a/, /e/, /o/, /u/ and /i/).
3) Formant frequency (F1, F2 and F3) in the burst of the stop consonants (/p/, /t/, /k/, /b/, /d/ and /g/).
4) Voice onset time of the stop consonants (/p/, /t/, /k/, /b/, /d/ and /g/).

VOWEL FORMANT FREQUENCY CHARACTERISTICS

The mean, standard deviation and range of the formant frequencies (F1, F2 and F3) are shown in Table-2, 3 and 4 and Graph-1, 2, and 3 respectively.

Vowel	Oesophageal		TEP		Normal	
	Mean	Range	Mean	Range	Mean	Range
/a/	880 (98)	784-1016	639 (190)	370-832	648 (9)	636-658
/u/	443 (75)	382-533	357 (61)	249-392	405 (29)	381-455
/o/	657 (110)	533-800	610 (106)	492-764	468 (63)	392-517
/i/	419 (127)	251-531	363 (60)	257-398	322 (63)	263-398
/e/	628 (107)	520-784	497 (170)	266-658	494 (111)	376-652

Table-2: The Mean, S.D. (in parenthesis) and Range of F1 (Hz) of /a/, /u/, /o/, /i/, /e/ in Oeso, TEP and Normal Speakers

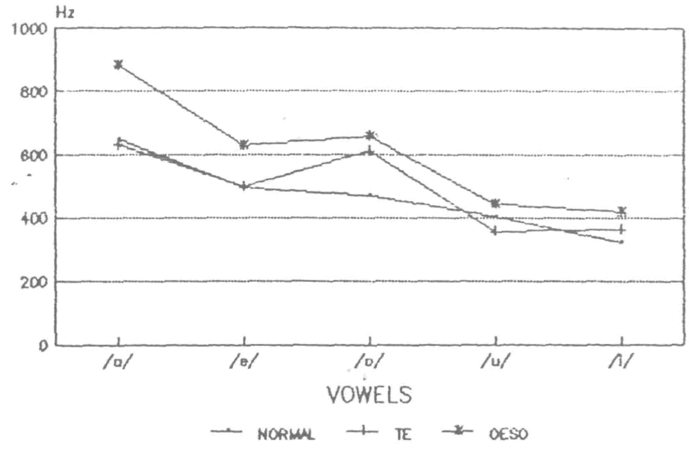
Vowel	Oesophageal Mean	Oesophageal Range	TEP Mean	TEP Range	Normal Mean	Normal Range
/a/	1780 (212)	1552-2074	1580 (163)	1302-1689	1520 (170)	1288-1678
/u/	1350 (331)	916-1694	1210 (230)	909-1537	1318 (303)	909-1670
/o/	1288 (103)	1160-1411	1192 (188)	916-1422	952 (69)	891-1035
/i/	2110 (648)	1284-2337	1897 (408)	1559-2588	2124 (305)	1803-2459
/e/	2075 (258)	1819-2467	2000 (253)	1682-2384	1843 (167)	1687-2070

Table-3: The Mean, S.D. (in parenthesis) and Range of F2 (Hz) of /a/, /u/, /o/, /i/, /e/ in Oeso, TEP and Normal Speakers

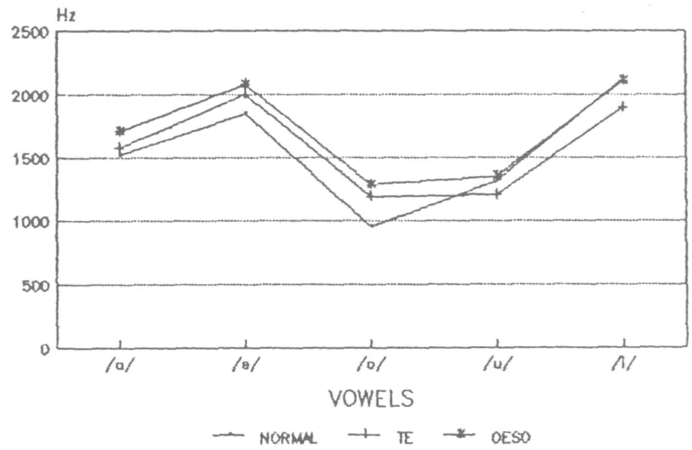
Vowel	Oesophageal Mean	Oesophageal Range	TEP Mean	TEP Range	Normal Mean	Normal Range
/a/	3146 (223)	2856-3470	3074 (345)	2713-3617	2612 (235)	2321-2980
/u/	2777 (648)	1823-3472	2603 (365)	2305-3214	2466 (100)	2313-2586
/o/	2696 (598)	2048-3294	3021 (214)	2833-3347	2671 (207)	2556-2980
/i/	3168 (540)	2586-3752	3019 (394)	2586-3485	2660 (288)	2339-2911
/e/	3094 (484)	2698-3466	3026 (343)	2467-3356	2706 (180)	2472-2933

Table-4: The Mean, S.D. (in parenthesis) and Range of F3 (Hz) of /a/, /u/, /o/, /i/, /e/ in Oeso, TEP and Normal Speakers

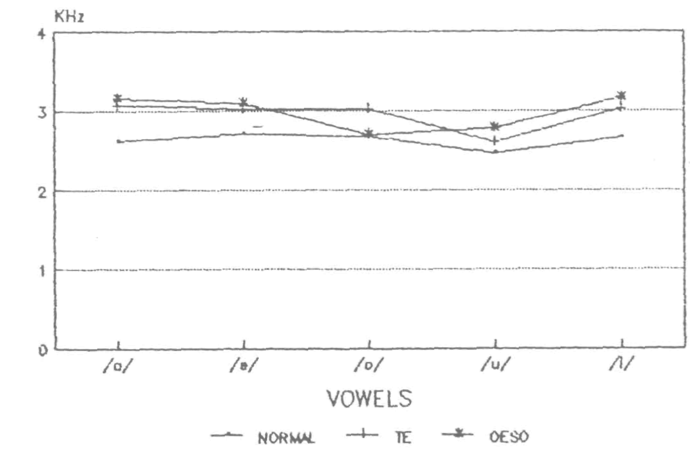
GRAPH-1 COMPARISON OF MEAN VOWEL FORMANT FREQUENCY (F1) IN NORMAL, TE AND OESO SPEAKERS



GRAPH-2 COMPARISON OF MEAN VOWEL FORMANT FREQUENCY (F2) IN NORMAL, TE AND OESO SPEAKERS



GRAPH-3 COMPARISON OF MEAN VOWEL FORMANT FREQUENCY (F3) IN NORMAL, TE AND OESO SPEAKERS



Graph-1, 2 and 3 permits a quick comparison of the average formant frequencies of the esophageal, TEP and normal speakers.

It is evident from the Graph-1 and Table-2 that the first formant frequency of the esophageal speakers for all the five vowels are higher than the normal speakers. The average increase in F1 in esophageal speakers from normal values are 232 Hz for vowel /a/, 97 Hz for /i/, 38 Hz for /u/ 188 Hz for /o/ and 134 Hz for /e/. However statistically significant difference is observed for vowels /a/ and /o/ only at 0.05 levels.

From Graph-2, and Table-3 it can be noted that the F2 values of vowels /a/, /e/ and /o/ in oesophageal speakers are higher than in normals. The F2 values of vowels /u/ and /i/ are almost same in both groups. The average increase from normal values for vowels /a/, /e/ and /o/ are 188 Hz, 336 Hz and 232 Hz respectively. Of these three vowels statistically significant difference in mean formant frequency is seen for vowel /o/ only at 0.05 levels.

In Graph-3 and Table-4 esophageal speakers show higher than normal values of F3 for vowels /a/, /e/, /u/ and /i/. The mean increase in the formant frequency from normal values for these vowels are 534 Hz for /a/, 388 Hz for /e/, 311 Hz for /u/ and 508 Hz for /i/. No Statistically significant difference is found in vowels /e/, /u/ and /i/ except for /a/. There is no statistically significant difference in the value of F3 of vowel /o/ at 0.05 levels..

The formant frequency (F1, F2 and F3) of vowels /a/, /e/, /o/, /u/ and /i/ being higher in oesophageal speakers than the normal speakers is in agreement with the results reported by Sisty and Weinberg (1972); Rajashekhar (1991). Rollins (1962) in a study of English speaking male laryngectomees, Kytta (1964) in a study of Finnish speaking male laryngectomees found higher than normal formants. The consistency of this finding across languages and vowels shows that the removal of the larynx does alter vocal tract transmission characteristics.

A Comparison of formant frequencies as presented by the TE speakers with normal in Graph-1, Table-2 shows that there is no difference in the first formant frequency of vowels /a/ and /e/. Mean formant frequency values of /a/ in TE speakers being 630 Hz and that of normals is 648 Hz. The mean formant frequency of /e/ in TE speakers is 497 Hz and that of normals is 494 Hz.

For vowels /o/ and /i/, increase in F1 is seen, average increase from normal values being 142 Hz and 41 Hz respectively. Statistically significant difference is seen for vowel /o/ only. For vowel /u/, there is a statistically significant decrease in the forraant frequency average decrease from normal value is 48Hz.

From Graph-2 and Table-3 higher than normal F2 values are seen in TE speakers for vowels /a/, /e/ and /o/. The mean increase from normal value being 60 Hz, 157 Hz and 240 Hz respectively. Significant difference is seen for vowel /o/ only. There is a reduction in. the F2 from normal, values of vowels /u/ and /i/ in TE speakers by 100 Hz and 221 Hz respectively.

Graph-3 and Table-4 shows that the F3 values of all the vowels in TE speakers are higher than that of normal speakers. The average difference between TE speakers and normal speakers in terms of F3 in the vowels are 462 Hz for /a/, 359 Hz for /i/, 137 Hz for /u/, 350 Hz for /o/ and 320 Hz for /e/. However significant difference is seen for /o/ alone.

Both alaryngeal speakers showed higher values of formant frequencies (F1, F2 and F3) than that of normal speakers for all the vowels. Its however consistent that the esophageal speakers showed higher values of formant frequencies than the TE speakers. Thus it can be concluded that:

The hypothesis stating that there is no statistically significant difference between:

a) Esophageal and normal speakers.

b) TEP and Normals speakers and

c) TEP and esophageal speakers in terms of formant frequencies (f1, f2 and f3) is accepted with reference to the vowels /a/, /i/, /u/, /e/ and /o/.

FORMANT FREQUENCY RELATIONSHIP

	Oesophageal	TEP	Normals
F3-F1	2266	2444	1964
F3-F2	1488	1494	1092
F2-F1	828	950	872

Table-5 Shows the difference between the formant frequencies in vowel /a/ for oesophageal, TE and normals speakers.

From the Table-5 it is evident that the difference between F3-F1 in oesophageal group and TE speaker is more than in the case of normal speakers by 302 Hz and 480 Hz respectively. The difference between F3-F2 in oesophageal speakers and TE speakers is more than the normal speakers by 346 and 402 Hz respectively. The difference between F2-F1 values in oesophageal and TE speakers are wider by 44 Hz and 78 Hz respectively than normal values.

	Oesophageal	TEP	Normals
F3-F1	2749	2656	2338
F3-F2	1058	2656	536
F2-F1	1691	1534	1802

Table-6 Shows the difference between the formant frequencies in vowel /i/ for oesophageal, TE and normals speakers.

From table-6 it is evident that in both oesophageal and TEP speakers the difference between the F3-F1 is more than normal values by 411 Hs and 318 Hz respectively. Similarly the difference between F3-F2 is also more in oesophageal and TE speakers by 586 Hz and 1122 Hz respectively than normal values. However a decrease in the difference between the F1-F2 is noticed in the oesophageal and TE speakers by 111 Hz and 268 Hz respectively.

	Oesophageal	TEP	Normals
F3-F1	2334	2246	2061
F3-F2	1427	1393	1148
F2-F1	907	853	913

Table-7 Shows the difference between the forraant frequencies in vowel /u/ for oesophageal, TE and normals speakers.

In case of vowel /u/ also the difference between F2 and Fl has increased in oesophageal and TE speakers than in normals by 273 Hz and 185 Hz respectively. The difference between F3 and F2 has also increased than in normals by 279 Hz in oesophageal speakers and 245 Hz in TE speakers. The difference between F2 and Fl is not seen in the oesophageal speakers but the difference has decreased in TE speakers by 60 Hz than in normal values.

	Oesophageal	TEP	Normals
F3-F1	2040	2411	2203
F3-F2	1408	1829	1719
F2-F1	632	582	484

Table-8 Shows the difference between the formant frequencies in vowel /o/ for oesophageal, TE and normals speakers.

The difference between the F3-F1 is reduced in oesophageal group than in normals by 157 Hz and is increased in TE speakers by 207 Hz than in normals. Similar pattern is seen for the difference between F3-F2. The oesophageal group showing a reduction in the spacing of formants by 311 Hz while it has increased in TE speakers by 110 Hz. The spacing of F1-F2 is more in both alaryngeal speakers. The oesophageal group have the formants positioned 148 Hz wider than in normal speech while in TE speakers they are wider by only 98 Hz.

	Oesophageal	TEP	Normals
F3-F1	2466	2529	2212
F3-F2	1019	1026	863
F2-F1	1447	1503	1347

Table-9 Shows the difference between the formant frequencies in vowel /e/ for oesophageal, TE and normals speakers.

The spacing between all the formants is more in both alaryngeal speakers compared to normals. In TE speakers the space between F3-F1 is wider than in normals by 317 Hz, 163 Hz between F3-F2 and 156 Hz between F2-F1. In oesophageal speakers the space between the formants is wider than in normal by 254 Hz between F3-F1, 156 Hz between F3-F2 and 100 Hz between F2-F1.

This change in formant frequency relationship may be one of the factors leading to distortion of vowels and hence reduction in the intelligibility of speech in the alaryngeal speakers. Studies by Shames et.al., (1963); Kolb and Carpenter (1981); Mitzell et.al., (1985); Gates et.al., (1982); Blom et.al., (1986); Rajashekhar et.al., (1990) and Rajashekhar (1991) have reported reduced intelligibility of speech in oesophageal speakers. Hence the spacing between the formant frequencies seems to play an important role in the intelligibility of speech. Thus total laryngectomy results in major changes in articulatory aerodynamics and produce alternation in vocal tract morphology (Weinberg 1986). The changes in the formant frequencies seen to support the above statement and are in agreement with Sisty and Weinberg (1972) that removal of larynx does alter the vocal tract transmission characteristics. The changes in the formant frequency relation also reflect the altered vocal tract transmission characteristics as well as the altered articulatory pattern adopted by the alaryngeal speakers in the production of speech.

VOWEL DURATION CHARACTERISTICS

Conson-ants	Oesophageal Mean	Oesophageal Range	TEP Mean	TEP Range	Normal Mean	Normal Range
/a/	147 (96)	62-304	83 (33)	50-125	76 (24)	39-97
/u/	108 (92)	45-267	79 (68)	31-183	82 (53)	30-153
/o/	85 (18)	58-96	97 (10)	80-106	102 (27)	65-132
/i/	116 (24)	86-146	77 (15)	62-100	66 (9)	57-80
/e/	77 (16)	58-100	64 (19)	46-97	86 (21)	63-122

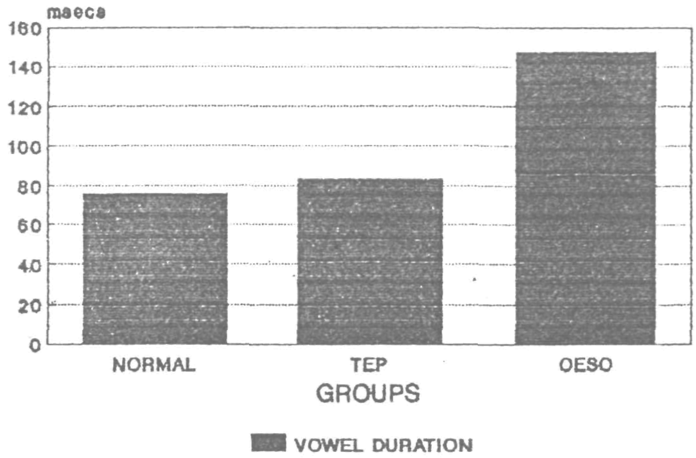
Table-10: The Mean, S.D. (in parenthesis) and Range of Vowel duration (msec) of /a/, /u/, /o/, /i/, and /e/ in Oesophageal, TEP and Normal Speakers

Graph-4, 5, 6, 7, 8 shows the comparison of mean vowel duration of /a/, /i/, /u/, /o/ and /e/ respectively.

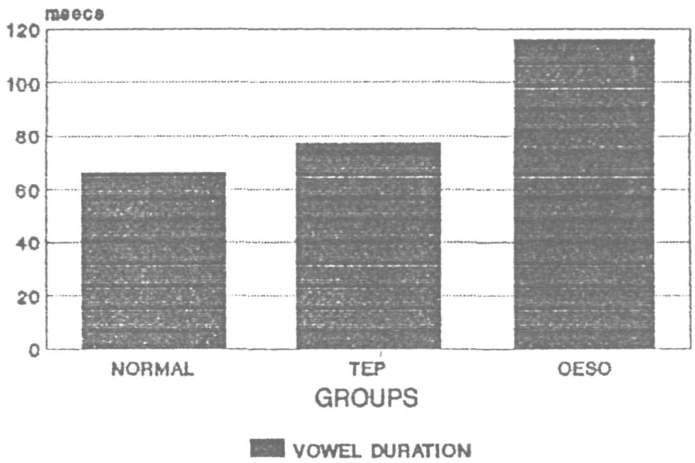
It is clear from graphs-4, 5 and 6, that the vowels /a/, /i/ and /u/ of oesophageal speakers are longer than that of normals. The duration of vowels in oesophageal speakers is 71 msecs more for /a/, 50 msecs for /i/ and 26 msecs for /u/. However no statistically significant difference is seen when the duration of these vowels are compared with normals. The increase in vowel duration for /a/ and /i/ in TE speakers is 7 msecs and 11 msecs respectively and no difference is seen for vowel /u/.

From Graph-7 and 8 it can be seen that the vowels /o/ and /e/ in oesophageal speakers are shorter than that of normals by 17 msecs and 9 msecs respectively. Statistically

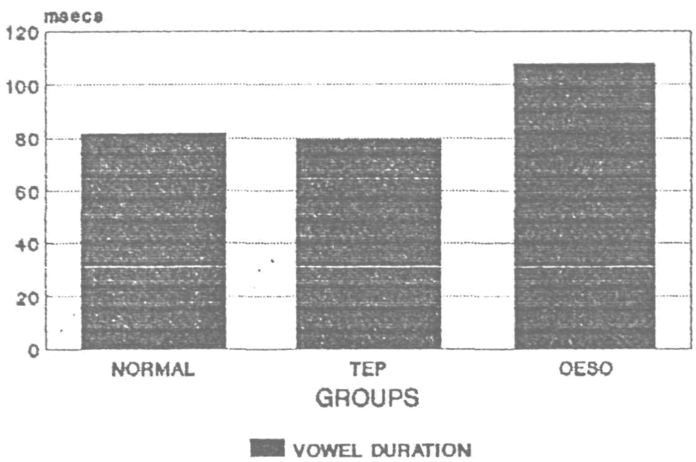
GRAPH-4: MEAN DURATION OF /a/
IN NORMAL, TEP AND OESO SPEAKERS



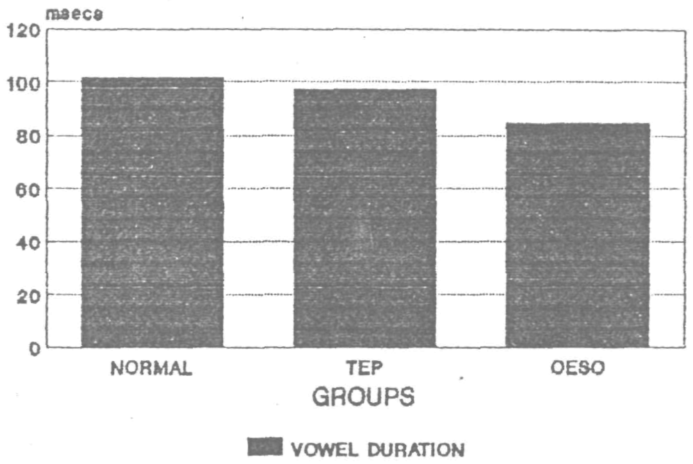
GRAPH-5: MEAN DURATION OF /i/
IN NORMAL, TEP AND OESO SPEAKERS



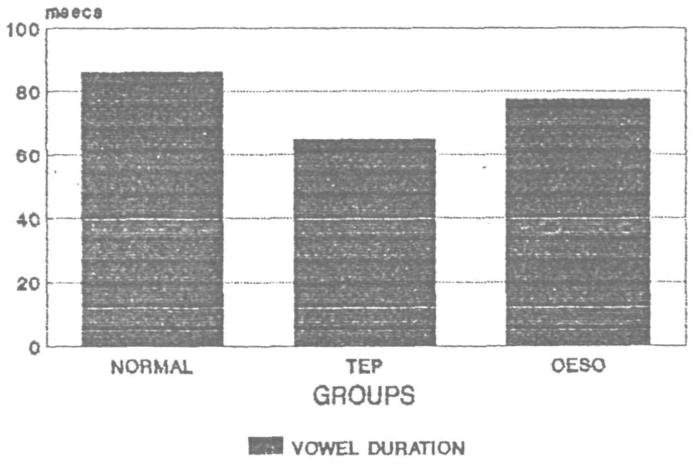
GRAPH-6: MEAN DURATION OF /u/
IN NORMAL, TEP AND OESO SPEAKERS



GRAPH-7: MEAN DURATION FOR /o/
IN NORMAL, TEP AND OESO SPEAKERS



GRAPH-8: MEAN DURATION OF /e/
IN NORMAL, TEP AND OESO SPEAKERS



no significant difference is seen. TE speakers do not differ in the duration of /o/ with that of the normals but the duration of /e/ is shorter by 22 msecs.

Both groups of alaryngeal speakers show longer duration for vowels /a/ and /i/. The oesophageal speakers show the longest and normal speakers have shortest vowel duration and TE speakers fall in between these two groups.

The results that TE speakers having longer vowel duration than normal speakers for vowel /a/ and /i/ are substantiated by the results of Robbins et.al., (1986) who also report longest duration of /a/, /i/ and /u/ vowels.

Increase in the duration of vowels /a/, /i/ and /u/ in oesophageal speakers than in normals is supported by the findings of Christensen and Weinberg (1976). The vowel durations being more in the alaryngeal speakers than in normal may be related to fundamental frequency of voice nature of the P.E. segment as suggested by Doyle, Danhauer and Reed (1988). Further they speculate that the difference in average vowel duration between the two groups of alaryngeal speakers may be due to the aerodynamic differences and the airway resistance provided by the neoglottis.

Weinberg (1982) also comments that total laryngectomy produced changes in articulatory behaviour as evidenced by changes in vowel duration which supports the results of present study. It may also be speculated that since lengthening the duration of vowels increases the intelligibility, the alaryngeal speakers may be making such a compensation. However this feature was not consistent for all the vowels.

Hence the hypothesis stating that there is no significant difference in vowel duration:

1) between oesophageal and normal
2) between TEP and normal
3) between oesophageal and TEP is accepted

From the above findings it can be concluded that the vowel duration in alaryngeal speakers is not significantly different from normal values although higher than normal values.

FORMANT FREQUENCY CHARACTERISTICS OF STOP CONSONANTS

Conson--ants	Oesophageal Mean	Oesophageal Range	TEP Mean	TEP Range	Normal Mean	Normal Range
/P/	389 (154)	266-643	389 (91)	266-523	361 (94)	260-483
/t/	428 (107)	266-533	408 (53)	373-501	339 (73)	251-404
/k/	517 (218)	242-790	496 (172)	360-768	437 (108)	274-517
/b/	285 (112)	125-392	343 (69)	266-398	347 (54)	266-392
/d/	419 (114)	266-562	408 (112)	251-523	334 (116)	244-517
/g/	358 (98)	251-498	255 (10)	248-266	321 (69)	244-398

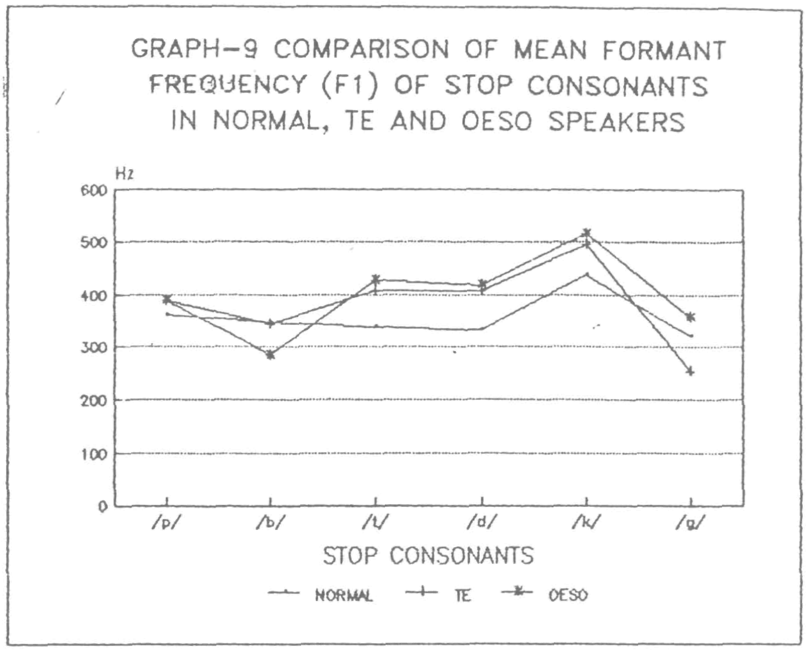
Table-11: The Mean, S.D. (in parenthesis) and Range of Fl (Hz) of /p/, /t/,./k/, /b/, /d/ and /g/ in Oeso, TEP and Normal Speakers

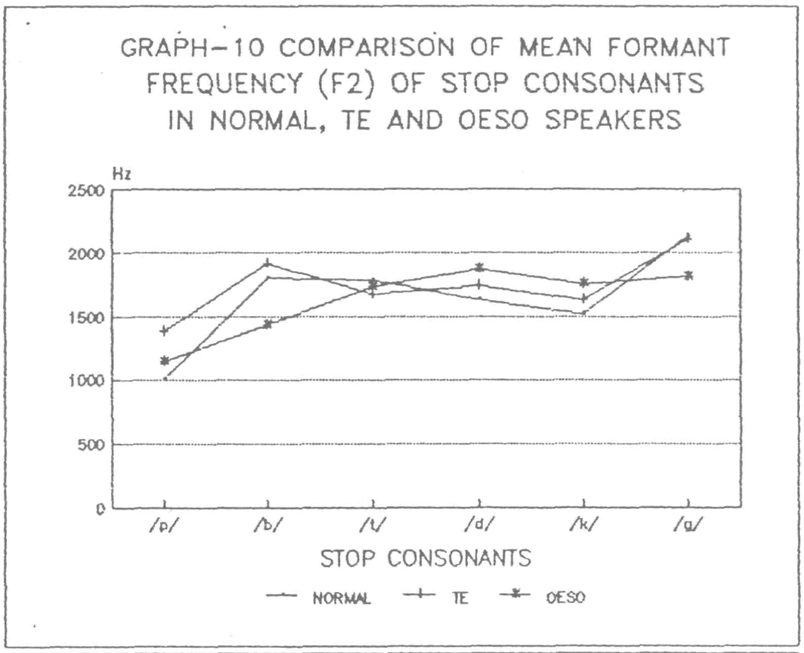
Conson-ants	Oesophageal Mean	Oesophageal Range	TEP Mean	TEP Range	Normal Mean	Normal Range
/P/	1139 (370)	643-1552	1380 (376)	916-1694	1001 (233)	759-1302
/t/	1727 (463)	1402-2447	1669 (348)	1157-2046	1778 (163)	1678-2064
/k/	1755 (187)	1559-2055	1628 (148)	1427-1808	1516 (141)	1333-1678
/b/	1430 (160)	1302-1694	1911 (190)	1662-2180	1796 (242)	1397-2054
/d/	1866 (226)	1552-2180	1735 (311)	1306-2039	1628 (198)	1286-1803
/g/	1810 (181)	1560-1947	2111 (595)	1424-2462	2132 (409)	1662-2704

Table-12: The Mean, S.D. (in parenthesis) and Range of F2 (Hz) of /p/, /t/, /k/, /b/, /d/ and /g/ in Oeso, TEP and Normal Speakers

Conson-ants	Oesophageal Mean	Oesophageal Range	TEP Mean	TEP Range	Normal Mean	Normal Range
/P/	2112 (512)	1422-2654	2428 (166)	2196-2585	1986 (402)	1684-2707
/t/	2762 (305)	2325-3090	2409 (422)	1926-3081	2300 (225)	2036-2645
/k/	2744 (443)	2208-3368	2507 (237)	2196-2718	2517 (285)	2070-2839
/b/	2227 (192)	1945-2462	2716 (456)	2210-3350	2367 (185)	2103-2572
/d/	2628 (485)	2054-3341	2659 (440)	2169-3231	2340 (404)	1678-2776
/g/	2585 (321)	2209-3090	3186 (397)	2846-3623	2687 (356)	2196-3080

Table-13: The Mean, S.D. (in parenthesis) and Range of F3 (Hz) of /p/, /t/, /k/, /b/, /d/ and /g/ in Oeso, TEP and Normal Speakers


GRAPH-9 COMPARISON OF MEAN FORMANT
FREQUENCY (F1) OF STOP CONSONANTS
IN NORMAL, TE AND OESO SPEAKERS
Hz
600
500
400
300
200
100
0
/p/
/b/
/t/
/d/
/k/
/g/
STOP CONSONANTS
NORMAL
TE
OESO


GRAPH-10 COMPARISON OF MEAN FORMANT
FREQUENCY (F2) OF STOP CONSONANTS
IN NORMAL, TE AND OESO SPEAKERS
Hz
2500
2000
1500
1000
500
0
/p/
/b/
/t/
/d/
/k/
/g/
STOP CONSONANTS
NORMAL
TE
OESO

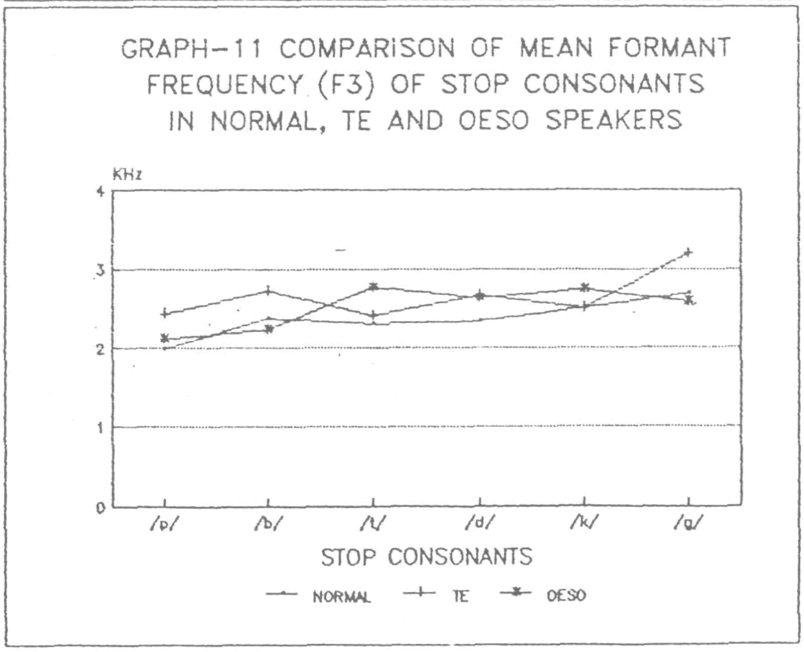

GRAPH-11 COMPARISON OF MEAN FORMANT
FREQUENCY (F3) OF STOP CONSONANTS
IN NORMAL, TE AND OESO SPEAKERS
KHz
4
3
2
1
0
/p/
/b/
/t/
/d/
/k/
/g/
STOP CONSONANTS
NORMAL
TE
OESO

Table-11, 12 and 13 show the mean, S.D. and range of the Fl, F2 and F3 of stop consonants in TE, oesophageal and normal speakers.

Graphs-9, 10 and 11 show the comparison of the mean formant frequencies (F1, F2 and F3) of stop consonants in oesophageal, TE and normal speakers. From Graph-9, it is evident that oesophageal speakers show higher mean Fl than normals in all the stop consonants except for /b/. The mean increase from normal values is 28 Hz for /p/, 89 Hz for /t/, 80 Hz for /k/, 85 Hz for /d/ and 37 Hz for /g/.

The mean decrease in F1, of /b/ in oesophageal speakers is 62 Hz from normal value. However no significant difference is found statistically for any of the consonants.

The mean Fl of TE speakers is also higher than the mean Fl of normals in the stops (/p/, /t/, /k/ and /d/). The mean increase is 28 Hz for /p/, 69 Hz for /b/, 59 Hz for /k/ and 72 Hz for /d/. The mean F1 of /g/ in TE speakers is reduced than normal values by 66 Hz. The mean F1 values for /b/ are almost same for TE and normal speakers.

A comparison between TE and oesophageal speakers reveal that the difference in /p/, /t/, /k/ and /d/ is less than 20 Hz, which is not significant. The F1 of /b/ is reduced in oesophageal speakers than TE speakers by 58 Hz. While the Fl of /g/ is reduced in TE speakers than oesophageal by 103 Hz.

As can be seen from graph-10 the mean F2 of the oesophageal speakers is more than in normals in /p/, /k/ and /d/ by 138 Hz, 239 Hz and 238 Hz respectively, while the mean F2 of /t/, /b/ and /g/ is less than in mean normal values by 51 Hz, 366 Hz and 322 Hz respectively. The mean F2 of the TE speakers is also more than the normal values in /p/, /k/, /b/ and /d/ by 379 Hz, 112 Hz, 115 Hz and 107 Hz respectively.

The F2 values of /g/ and /t/ are less in TE speakers than in normals by 21 Hz and 109 Hz. However differences are not significant. Greater F2 values for /p/, /b/ and /g/ are seen in TE speakers than in oesophageal speakers, the increase being 241 Hz for /p/, 481 Hz for /b/, and 301 Hz for /g/. While F2 is increased in oesophageal for the consonant /t/, /k/ and /d/ by 58 Hz, 127 Hz and 131 Hz respectively.

From Graph-11, it can be seen that the mean F3 values of oesophageal speakers are higher than the mean values of normals in /P/, /t/, /k/, and /d/ by 126 Hz, 462 Hz, 227 Hz and 288 Hz respectively. The mean F3 values of oesophageal speakers is less in /b/ and /g/ by 140 Hz and 102 Hz respectively.

The TE speakers show an greater in the mean F3 for /p/, /t/, /b/, /d/ and /g/ than in normals by 442 Hz, 109 Hz, 349 Hz, 319 Hz and 499 Hz respectively. No difference in the F3 values of normals and TE speakers for /k/ is seen.

A comparison of mean F3 values of TE and oesophageal speakers shows greater F3 values in TE speakers for /p/, /b/ and /g/. The mean difference are 316 Hz, 489 Hz, 601 Hz. However greater F3 values are seen for /t/, /k/. The mean diffe rences are 353 Hz and 237 Hz and no difference in /d/ between two groups.

From the above data it can be concluded that both the alaryngeal speakers show higher formant frequency for most of the consonants. The alaryngeal speakers do not show much difference among themselves in terms of formant frequencies for most of the consonants. However oesophageal speakers show a higher formant frequencies than TE speakers.

The higher formant frequency values in alaryngeal speakers may be attributed to the reduction in the length of vocal tract. However literature on forraant frequencies of stop consonants in alaryngeal speakers is not available to the investigator.

VOICE ONSET TIME CHARACTERISTIC OF ALARYNGEAL SPEAKERS

Graph-12,13 and 14 show the mean VOT values of the labial, palatal and velar stop consonants for the oesophageal, TEP and normal speakers. The VOT values for /p/, /t/, /d/ and /g/ in oesophageal speech are longer than that of normals. The average differece with referece to normal values are 22 msecs for /p/, 3.2 msecs for /t/, 21.6 msec for /d/ and 9 msecs for /g/. The VOT values for /k/ and

/b/ are less than the normal values by 2 msecs and 22 msecs respectively. However no statistically significant difference is seen for any of the consonants.

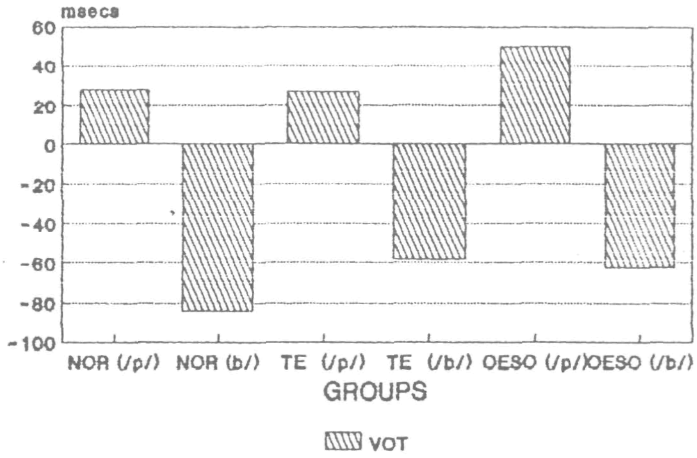
Conson--ants	Oesophageal Mean	Range	TEP Mean	Range	Normal Mean	Range
/p/	50 (23)	13-70	27 (13)	11-44	28 (12)	15-44
/t/	17 (4.6)	12-23	17 (4)	11-24	14 (4)	8-20
/k/	24 (5)	17-28	28 (4)	21-31	26 (5)	20-33
/b/	-62 (29)	45-96	-58 (29)	18-93	-84 (37)	49-140
/d/	-52 (14)	35-74	-31 (5)	25-37	-30 (5)	25-38
/g/	-62 (29)	30-86	45 (17)	30-64	53 (15)	43-80

Table-14: The Mean, S.D. (in parenthesis) and Range of Voice onset time (msec) of /p/, /t/, /k/, /b/, /d/ and /g/ in Oeso, TEP and Normal Speakers

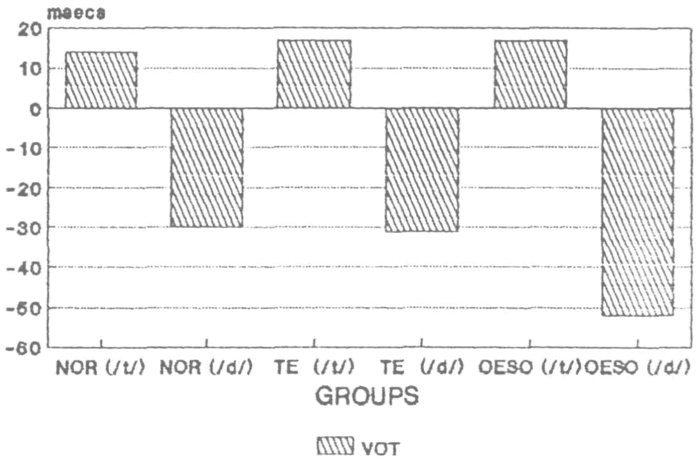
A comparison of TEP speakers with normals reveal similar VOT values for /p/, /t/, /k/ and /d/ in both groups. The VOT values for /b/ and /g/ are lower than normal values in TE speakers by 25 msecs and 8 msecs respectively. Significant difference is seen for /b/ only.

A comparison between TEP and oesophageal speaker reveals no difference in VOT values for /t/ and /k/ while higher VOT values for /p/, /b/, /d/ and /g/ are seen in oesophageal group than for TEP speakers.

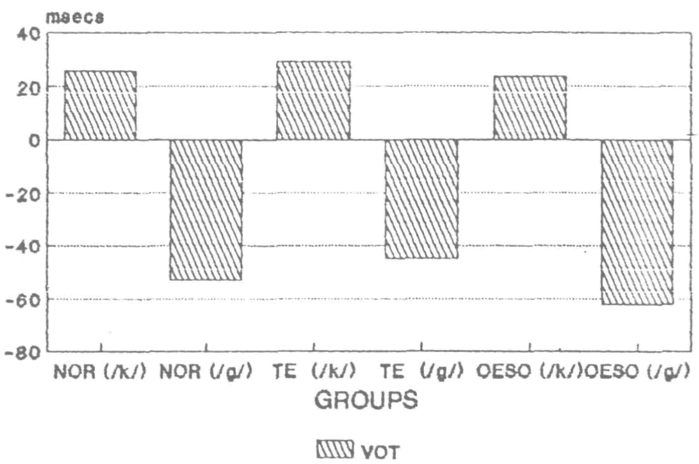
GRAPH-12: MEAN VOT VALUES FOR /p/ & /b/
IN NORMAL, TEP AND OESO SPEAKERS



GRAPH-13: MEAN VOT VALUES FOR /t/ & /d/
IN NORMAL, TEP AND OESO SPEAKERS



GRAPH-14: MEAN VOT VALUES FOR /k/ & /g/
IN NORMAL, TEP AND OESO SPEAKERS



These results are not in agreement with that of previous reports by Christensen et.al., 1978; Klor and Micant, 1980; and Robbins et.al., 1986. However higher values of VOT in oesophageal speakers are reported by Rajashekhar (1991). Variation in the values of VOT may be because of factors such as age of the speakers, language consonants environment material used. It is reported that in a longer context, beyond one or two syllables directly associated with the stop, also influences its VOT. There is a demonstrable sensitivity to such suprasegmental semantic importance and utterance length (Uraeda, 1977; Wisker and Abramson 1967).

The physical characteristics of the neoglottis the different air sources involved, the myoelastic and motor control properties of the voicing source may also be responsible for differences in the VOT.

Higher mean VOT values in oesophageal speakers may be attributed to the aspiration and murmur (aspiration with voicing), as reported by Rajashekhar (1991). This feature may be because of the poor control of the PE segment, the reason for not finding such a feature in the TE speakers may be attributed to the use of conventional air source.

Thus it can be concluded that the hypothesis stating "there is no significant difference in voice onset time between:

1) Oesophageal and normal speakers
2) TEP and normal speakers
3) Oesophageal and TEP is accepted with reference to the above consonants.

INTELLIGIBILITY

	Mean	S.D.	Range
Oesophageal	43.4%	19.37	15-63
TEP	75.8%	15.62	52 - 94
Normal	99.0%	2.23	95 - 100

Table-15: Shows the mean, S.D. and Range of the average intelligibility scores in oesophageal, TEP and normals speakers.

From the above table it is evident that the intelligibility scores of the alaryngeal speakers are lower than that of the normal speakers. The TEP speakers seems to be more intelligible than the esophageal speakers with a mean intelligibility score of 75.8% where as the the mean intelligibility score of esophageal group is 43.4%.

It is also seen that the mean intelligibility scores of both the alaryngeal groups are lower than those reported in the literature. However the reduced intelligibility of the esophageal speakers than the TEP speakers are in agreement wtih the results reported in the literature (Shames et al. , 1963; Kalb and Carpenter 1981; Rajashekhar et.al., 1990 and Rajashekhar 1991).

A correlation coefficient was found for the intelligibility scores and the various parameters for vowels and consonants (formant frequencies F1, F2 and F3, vowel duration and VOT). A low negative correlation ranging from -0.113 to -0.58 for all parameters was found. This indicates that as the values of the parameters measured increased the intelligibility scores tend to decreased. This relationship can be further examined using more number- of subjects.

Thus from the results of the present study can be stated as:

1) Higher than normals values of formant frequencies f1, f2 and f3 were seen in both alaryngeal speakers for vowel and consonants (Sisty and Weinberg 1972; Rajashekhar 1991).

2) Among alaryngeal speakers the duration of vowel /a/ and /i/ were increased while the duration of the vowels /u/, /o/ and /e/ were reduced. However no significant difference was seen for vowel duration (Christensen and Weinberg, 1978).

3) Longer VOT values in alaryngeal speakers seen in most of the consonants (Christensen and Weinberg 1976).

SUMMARY AND CONCLUSION

Speech which is a specialized way of using the vocal mechanism, demands the combination and interaction of mechanisms of respiration, phonation, resonance and articulation. Any abnormality in any of these system leads to a defect in speech. Further speech production is affected to a greater extent, when the phonatory system is affected particularly the vocal folds.

The cancer of the larynx most often warrants immediate surgical procedure called laryngectomy. Although this procedure is a life saving procedure, it results in a high morbidity. A laryngectomee faces a psychological crisis, and immense depression owing to the lack of voice for speech production.

The rehabilitation of a laryngectomee aims at restoring the pre-operative condition of the patient as for as possible in terms of psychological, physiological, social and economic status i.e., basically by restoring voice. This is achieved by the efficiency of the patient in making use of his remaining structures for speaking.

The oesophageal speech has been traditionally considered as the method of choice. Immediate restoration of voice is achieved by electrical devices but has to meet the disadvantage of artificiality, monotonous speech and expense.

With the introduction of new technique (Tracheo-esophageal puncture by Singer and Blom 1980, TE speech has become more accepted method of alaryngeal speech. Only few studies have been conducted to understand various factors that contribute to the intelligibility and acceptability of alaryngeal speech. Studies done by Sisty and Weinberg (1972), Christensen and Weinberg (1976, 1978) show that the formant frequencies, vowel duration, voice-onset time are affected in the laryngeal speech indicating the altered articulatory behaviours in alaryngeal speech.

A few acoustic parameters which were considered to be influencing the intelligibility were considered for the present study. The speech samples from five oesophageal, five TEP and five normal speakers with the mean age of 53 years, 57.4 years and 50 years respectively were obtained.

The following parameters were extracted from the speech sample from the words extracted from the reading of a passage in Kannada:

1) Formant frequencies (F1, F2 and F3) of vowels /a/, /e/, /d/, /u/ and /i/.
2) Vowel duration of /a/, /e/, /d/, /u/ and /i/.
3) Formant frequencies (F1, F2 and F3) of stop consonant /p/, /t/, /k/, /b/, /d/ and /g/.
4) VOT of the stop consonants /p/, /t/, /k/, /b/, /d/ and /g/ in the words:

These words were digitised using 12 bit ADC/DAC broad at the sampling frequency of 8KHz and subjected to spectro-graphic (300 wide band filter) analysis.

The results of the study were subjected to Mann-Whitney 'U' test to find the significance of difference in the mean values of each group for the above parameters.

The following conclusions were drawn:

1) Higher formant frequencies than in normals were seen in both alaryngeal speakers for the vowels and consonants. However significant difference between the groups was found only for vowel /o/ and consonant (Sisty and Weinberg 1972 and Rajashekhar, 1991).

2) Among alaryngeal speakers the duration of vowels /a/ and /i/ were increased while the duration of vowels /u/, /o/ and /e/ were reduced. However no significant difference was seen for vowel duration (Cheistensen and Weinberg, 1978).

3) Longer VOT values in alaryngeal speakers were seen for most of the consonants (Christensen and Weinberg 1978).

4) The intelligibility scores of the alaryngeal speakers were found to be lower than that of the normal speakers. The intelligibility scores of oesophageal group were poorer than that of the TE speakers. It was also found that a negative correlation existed between the intelligibility scores and variables parameters studied. Their relationship is to be further examined in detail.

It is evident from the above findings after laryngectomee the articulatory behaviours are altered. These may be because of the aerodynamic, myoelastic properties of the P.E. segment and the extent of surgical removal of the tissue.

FURTHER RECOMMENDATION

1) The parameters may be studied in a larger group.
2) More parameters can be taken up for the study the transitions, transition duration and speed of transition.
3) Studying the suprasegmental aspects in alaryngeal speakers would provide information about the other factors contributing to intelligibility.
4) Studies using synthesis may be carried out to confirm the role of spacing between the formant frequencies in improving the speech in alaryngeal speakers.

BIBLIOGRAPHY

Angelocci, A.A., Kopp,G.A., & Holbrook, A. (1964). The vowel formants of deaf and normal hearing 11 to 14 year old boys. J.S.H.D., 29, 156-170.

Angermeier, C.B., & Weinberg, B. (1981). Some aspects of fundamental frequency control by esophageal speakers. J.S.H.D., 24, 85-91.

Aronson, A.E. (1980). Clinical Voice Disorders - An interdisciplinary approach. Brian C. Decker, a div. of Thieme-Stratton, Inc: New York.

Atkinson, J.E. (1978). Correlation analysis of the physiological factors controlling fundamental voice frequency. J. Acoust. Soc. Am., 63, 211-222.

Baer,T., Gay.T., & Niimi, J. (1976). Control of fundamental frequency, intensity and register of phonation. Haskins Laboratories: Status report on Speech Research, SR-45/46.

Blom, E.D., Singer, M., & Hamaker, R. (1982). Tracheostoma valve for postlaryngectomy voice rehabilitation. Annals of Otology, Rhinology and Laryngology, 91, 576-578.

Blom, E.D., Singer, M.I., & Hamaker, R.C. (1985). An improved oesophageal insufflation test. Arch Otolaryngol Head Neck Surg, 111, 211-212.

Blom, E.D., Singer, M.I., Hamaker, R.C. (1986). A prospective study of tracheoesophageal speech, Arch. Otolaryngol. Head Neck Surg. 112, 440-447.

Borden, G.J., & Harris, K.S. (1980). Speech Science Primer. Baltimore, USA.

Cheesraan, A.D., Knight, J., Mclvor, J., & Perry, A. (1985). Assessment procedures for post-laryngectoray patients who desire surgical voice restoration J. Laryngology and Otology, 100, 191-199.

Chodosh, P.L., Gian Carlo, H.R., Goldstein, J. (1984). Pharyngeal myotomy for vocal rehabilitation post laryngectomy. Laryngoscope, 94, 52-57.

Christensen, J., and Weinberg, B. (1976). "Vowel duration characteristics of esophageal speakers". J.S.H.R., 19, 678-689.

Christensen, J., Weinberg, B. & Alfonso,P.J. (1978). Productive voice onset time characteristics of esophageal speech. JSHR, 21, 56-62.

Collier, R. (1975). Physiological correlates of intonation patterns. J.Acoust. Soc. Am., 58, 249-255.

Damste, P.H. (1958). Oesophageal speech after laryngectomy. Groningen, Netherlands; Gebr. Hoitsema.

Delattre, P.C., Liberman, A.M., Cooper, F.S. & Gerstman, L.J. (1952). An experimental study of the acoustic determinants of vowel color. Word, 8, 195-210.

Diedrich, W.M., & Youngstorm (1977). Alaryngeal speech. Charles C. Thomas, Springfield, Illinois.

Edels, Y. (1983). Pseudo-voice its theory and practice. In Edels, Y. (Ed), Laryngectomy: Diagnosis to rehabilitation. London, Croom Helm.

Fant, G. (1957). Modern instruments and methods for acoustic studies of speech. RIT Stockholm Technical Report No.8, (19-).

Fromkin, V.A. & Ohala, J. (1968). Laryngeal control and a model of speech production. UCLA Working Papers in Phonetics, 10, 98-110.

Gates, G.A., Ryan, W., Cooper, J.C., et al., (1982). Current status of laryngectomee rehabilitation: I. Results of therapy. Am. J. Otolaryngol, 3, 1-7.

Gay, T., Hirose, J.H., Stome, M. & Sawashima, M. (1972). Electromyography of the intrinsic laryngeal muscles during phonation. Annals of Otol. Rhinol. & Laryngology. 81, 401-409.

Gilbert,H.R., & Campbell, M.I. (1978). Voice onset time in the speech of hearing impaired individuals. Folia phoniat, 30, 67-81.

Goldstein, L.P. (1982). History and development of laryngeal prosthetic devices. In A. Sekey and R.Hanson (Eds), Electroacoustic analysis and enhancement of alaryngeal speech. Springfiled: Charles C. Thomas.

Greene, M.C.L. (1964). The voice and Its Disorders, Pitman Medical, London.

Hamaker, R.C., Singer, M.I., Blom, E.D., & Daniels, H.A. (1985). Primary voice restoration at laryngectomy. Archives of Otolaryngol, 111, 182-186.

Hazarika, P., Murthy, P.S., Rajashekhar, B., & Kumar, A. (1990). Surgical voice restoration in alaryngeal patients. Ind. J. Otolaryngol. 42, 107-111.

Henley, J., Souliere, C Jr. (1986). Tracheoesophageal speech failure in the laryngectomee: The role of constrictor myotomy. Laryngoscope, 96, 1016-1020.

Hirano, M., Ohala, J. & Vennard, W. (1969). The function of laryngeal muscles in regulating Fo and intensity of phonation. JSHR, 12, 618-628.

House, A., & Fairbanks, G. (1953). The influence of consonant environment upon the secondary acoustical characteristics of vowels. J. Acoust. Soc. Am., 25, 105-113.

King, P.S., Fowlks, E.W., & Pierson, G.A. (1968). Rehabilitation and adaptation of laryngectomy patients. Am. J. Physical Medicine, 47, 192-203.

Klatt, D.H. (1976). Linguistic uses of segmental duration in English: Acoustic and perceptual evidence. J. Acous. Soc. Am., 54, 1203-1221.

Klor,B.N., & Milanti, F.S. (1980). Voice onset time in neoglottic, esophageal and normal speakers. ASHA, 22, 688.

Kytta, J. (1964). Finnish oesophageal speech after laryngectomy: Sound spectrographic and cineradiographic studies. Acta Otolaryng. (Stockholm), Suppl. 195, 7-91.

Kytta, J. (1964). Spectrographic studies of the sound quality of esophageal speech. Acta Otolaryngol, Suppl. 188.

Levitt, H. (1978). "The acoustics of speech production". Auditory management of hearing impaired children (eds), T.Giolas and M.Ross, Baltimore, Univ. Park Press, 45-115.

Lisker,L. & Abramson,A.S. (1971). Distinctive features and laryngeal control. Language, 47, 770.

Mahieu, H.F., Annyas, A.A., Schutte, H.K., Van Der Jagat, E.J. (1987). Pharyngoesophageal myotomy for vocal rehabilitation of laryngectomees. Laryngoscope, 97, 451-457.

Mitzell, S., Andrews, M.L., & Bowman, S.A. (1985). Acceptability and intelligibility of tracheoesophageal speech. Arch Otolaryngol, Head Neck Surg, 111, 213-215.

Monsen, R., Engebretson, A. & Vemula, N. (1978). Indirect assessment of the contribution of subglottal air pressure and vocal-fold tension to changes of fundamental frequency in English. J.Acoust. Soc. Am., 64, 65-80.

Moon, J.B., Weinberg, B. (1987). Aerodynamic and Myoelastic contributions to tracheoesophageal voice production. J.S.H.R., 30, 387-395.

Nataraja, N.P., & Jagadeesha, A. (1984). Vowel duration and fundamental frequency. J.All India Inst.Sp.Hear., 15.

Ohala, J. & Hirano, M. (1970). Studies of pitch change in speech. UCLA Working Papers in Phonetics. 15, 1-192.

Perry, A. (1988). Surgical voice restoration following laryngectomy: The tracheo - Oesophageal Fistula technique (Singer - Blom), B.J.D.C., 23, 23-30.

Perry, A., Cheesman, A.D., McIvor, J., & Chalton, R. (1987). A British experience of surgical voice restoration as a secondary procedure following total laryngectomy. J. Laryngology & Otology, 101, 155-163.

Peterson, G., & Barney, H.L. (1952). Control methods used in a study of the vowels. J. Acoust. Soc. Am. 24, 175-184.

Peterson, G.E. and Lehiste, J (1960). Duration of syllable nuclei in English. J.Acoust. Soc. Am. 32, 693-703.

Pols, L.W.C., van der Kamp, L.J. & Plomp, R. (1969). Perceptual and physical space of vowel sounds. J.Acous. Soc. Am., 46, 458-467.

Rajashekhar, B., Nataraja, N.P., Rajan, R., Hazarika, P., Murthy, P.S., & Venkatesh, C.S. (1990). Comparison of esophageal arid T.E.P. mode of alaryngeal speech in a single laryngectomee. The J. of Indian Speech and Hearing Association. 7, 43-46.

Raphael,L.J. (1975). Physiological control of durational differences between vowels preceding voiced and voiceless consonants in English. J. Phonetics, 3, 25-36.

Rashmi, M. (1985). Acoustic aspects of the speech of children. Unpublished Master's Dissertation, Univ. of Mysore.

Robbins, J., Christensen, J. & Kempster,G. (1986). Characteristics of speech production after tracheoesophageal puncture: Voice onset time and vowel duration. J.S.H.R., 29, 499-504.

Robbins, J., Fisher, H., Blom, E., & Singer, M.I. (1984). A comparative acoustic study of normal, esophageal and tracheoesophageal speech production. J.S.H.D., 49, 202-210.

Robert M. Deupree. The muscles of voice and speech in Travis, 1971, Ed. Hand book of Speech Pathology and Audiology, Prentice Hall-Inc, Englewood Cliff, Newjersy.

Rollin, W.J. (1962). A comparative study of vowel formants of esophageal and normal speaking adults. Doctoral dissertation, Wayne state univ.

Seeman, M. (1967). Rehabilitation of laryngectomized subjects. Acta Otolaryngol, 64, 235-241.

Shipp,T., Doherty, E. & Morrisey, P. (1979). Predicting vocal frquency from selected physiologic measures. J.Acoust. Soc. Am., 66, 678-684.

Shukla, R.S. (1987). Objective measurements of the speech of the hearing impaired. Unpublished Doctoral Thesis. Univ., of Mysore.

Singer, M.I. (1983). Tracheoesophageal speech: Vocal rehabilitation after laryngectomy. Laryngoscope, 93, 1454-1465.

Singer, M.I., & Blom, E.D. (1980). An endoscopic technique for restoration of voice after laryngectomy, Annals of Otology, Rhinology, and Laryngology, 89, 529-533.

Singer, M.I., Blom, E.D. (1979). Tracheoesophageal puneture: Surgical prosthetic method for postlaryngectoray speech restroation. Third International Symposium Plas Reconstr Surg Head Neck.

Singer, M.I., Blom, E.D. (1981). Selective myotomy for voice restoration after total laryngectomy. Arch Otolaryngol, 107, 670-673.

Singer, M.I., Blom, E.D., & Hamaker, R.C. (1983). Voice rehabilitation after total laryngectomy. J. Otolaryngol., 12, 329-334.

Sisty, N., & Weinberg, B. (1972). Formant frequency characteristics of oesophageal speech. J.S.H.R., 15, 439-448.

Snidecor, J.C., & Isshiki, N. (1965a). Air volume and airflow relationships of six male esophageal speakers. J.S.H.D., 30, 205-216.

Stiernberg, C.M., Bailey, B.J., Calhoun, K.H., & Perez, D.G. (1987). Primary tracheoesophageal fistula procedure for voice restoration: The University of Texas Medical branch experience. Laryngoscope, 97, 820-824.

Umeda, N.(1975). Vowel duration in American English. J. Acous. Soc. Am., 58, 434-445.

Van Den Berg, J.W. (1958). Myoelastic. aerodynamic theory of voice production. J.S.H.R., 1, 227-244.

Van Den Berg, J. and Moolenaar - Bijl, A.J. (1959). Cricopharyngeal sphincter, pitch, intensity and fluency in oesophageal speech, Pract. Otorhinolaryng (Basel), 21, 298-315.

Van Den Berg, JW., Moolenaar, Bijl, A.J., & Damste, P.H. (1958). Esophageal speech. Folia. Phoniatrica, 10, 65-84.

Walsh, T., & Parker, F. (1981). Vowel length and voicing in a following consonant. J. Phonetics, 9, 305-308.

Wardrip-Fruin, C. (1982). On the status of temporal cues to phonetic categories preceding vowel duration as a cue to voicing in final stop consonants. J. Acous. Soc. Am., 71(1), 187-19521.

Weinberg, B. (1981). Speech alternatives following laryngectomy. In John K. Darby.Jr; Grune and Stratton, Inc. (Eds), Speech evaluation in Medicine.

Weinberg, B. (1982). Speech after laryngectomy: An overview and review of acoustic and temporal characteristics of esophageal speech. In A Sekey and R. Hanson (Eds), Electroacoustic analysis and enhancement of alaryngeal speech. Spring field. Charles C Thomas.

Weinberg, B. (1986). Acoustical properties of esophageal and tracheoesophageal speech. In R. Keith and T. Darley (Eds), Laryngectomee Rehabilitation (22nd Ed)., San Diego: College Hill Press.

Weinberg, B., Horii, Y., Blom, E. & Singer, M. (1982) Airway resistance during esophageal phonation. J.S.H.D., 47, 194-199.

Wenig, B.L., Mulloly, V., Levy, J., & Abramson, A.L. (1989). Voice restoration following laryngectomy: The role of primary Vs Secondary tracheoesophageal puncture. Ann Otol. Rhinol. laryngol, 98, 70-73.

Wetmore, S.J., Krueger, K., Wesson, K., & Blessing, M.L. (1985). Long-term results of Blom-Singer speech rehabilitation procedure. Archives of Otolaryngology, 111, 106-109.

Yanagihara, N., Koike, Y., & Von Leden, H. (1966). Phonation and respiration. Function study in normal subjects. Folia Phoniat., 18, 323-340.

Yanagihara, N. & Von Leden, H. (1966). The cricothyroid muscle during phonation. Ann. Otol. Rhinol. & Laryngology, 75, 987-1005.

☆ RajaShekhar., (1991). Acoustic Analysis of Alaryngeal Speech (T.E.P. with B.S. Prosthesis and Oesophageal Modes, Unpublished Thesis submitted to the University of MYSORE.

APPENDIX - 1

bʌkkʌt̪ʌlʌjʌ mʌnuʃjʌ mʌt̪t̪u noṇʌ

obbʌ bʌkkʌt̪ʌlʌjʌ mʌnuʃjʌ nid̪d̪ʌ. bEsigEjʌlli ond̪u d̪inʌ ʌvʌnu kElʌsʌ ma:ḍi sa:ka:gi kuḷit̪ukonḍa. a: sʌmʌjʌkkE sʌṛija:gi ond̪u noṇʌ bʌnd̪u ʌvʌnʌ nuṇṇanEjʌ t̪ʌlEjʌ sut̪t̪ʌ ha:ṛa:ḍut̪t̪ʌ bʌkkʌt̪ʌlEjʌnnu kʌtʃtʃʌla:rʌmbisit̪u.

noṇʌvʌnnu hoḍEjʌbe:kEnd̪u ʌvʌnu kaiEt̪t̪i hoḍEd̪ʌ noṇʌ t̪ʌppisikonḍit̪u. e:ṭu ʌvʌnʌ t̪ʌlEgE bit̪t̪u. noṇʌ t̪iṛugi bant̪u. ʌvʌnu t̪iṛugi hoḍeḍa. punʌh ʌvʌnʌ t̪alEgE e:ṭu bit̪t̪u. a:gʌ ʌvʌnigE bud̪d̪hibant̪u. kʃudra pra:nigʌlʌnnu gʌmʌni suvud̪arind̪a, namagE ha:ni jEnd̪u konḍa.

Appendix – 2

LIST OF WORDS (KANNADA) USED AS TEST. MATERIAL

INTELLIGIBILITY ASSESSEMENT

1) ತಿರುಗಿ	t̪iɽugi
2) ರುಚಿ	rutʃi
3) ಹೊಡೆದ	hoɖed̪a
4) ಹಗ್ಗ	hagga
5) ಏಟು	eːʈu
6) ಚಿಪ್ಪು	tʃippu
7) ಗುಂಜು	gundʒu
8) ಪ್ರದೇಶ	prad̪eːʃa
9) ವಿದ್ಯುತ್	vid̪jut̪
10) ಉತ್ಪಾದನೆ	ut̪paːd̪ane
11) ಜನರು	dʒanaru
12) ಬೇಲೂರು	beːluːru
13) ಅಣೆಕಟ್ಟು	aɳekaʈʈu
14) ತಿರುಗು	t̪irugu
15) ನೊಣ	noɳa
16) ತಪ್ಪಿಸಿ	t̪appisi
17) ಸಮಯ	samaja
18) ಕರ್ನಾಟಕ	karnaːʈaka
19) ನಾರು	naːru
20) ಬುದ್ಧಿ	bud̪d̪hi
21) ಹಾಸಿಗೆ	haːsige
22) ಊರು	uːru
23) ಅಡಿಗೆ	aɖige
24) ಮನುಷ್ಯ	manuʃja
25) ಭೀಮಾ	bʰiːma

26) ನಮ್ಮ	n̪amma
27) ನೋಡಲು	no:ḍalu
28) ನಂದಿ	nand̪i
29) ಕೊಬ್ಬರಿ	kobbari
30) ಬೆಂಗಳೂರು	beŋgaḷu:ru
31) ರಾಗಿ	ra:gi
32) ಹಳದಿ	haḷad̪i
33) ಕೆಲವು	kelavu
34) ಕೆಲಸ	kelasa
35) ರಾಜ್ಯ	ra:dʒja
36) ಎಳನೀರು	eḷani:ru
37) ಬೊಂಬಾಯಿ	bomba:ji
38) ಕೃಷ್ಣಾ ನದಿ	kriʃṇa:n̪ad̪i
39) ಜಮಖಾನ	dʒamakʰa:n̪a
40) ಹಾನಿ	ha:n̪i
41) ಪರ್ವತ	parvat̪a
42) ಜೋಗ	dʒoga
43) ಸರಿಯಾಗಿ	saṛijagi
44) ಬರುವರು	baṛuvaru
45) ಹಸಿರು	hasiru
46) ದೊಡ್ಡ	d̪oḍḍa
47) ಬೇಸಿಗೆ	be:sige
48) ಕಚ್ಚು	katʃtʃu
49) ಗುಂಡು	guṇḍu
50) ಪ್ರಾಣಿಗಳು	pra:ṇigaḷu