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ANALYSIS OF COMMUNICATION AND SWALLOWING
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ANALYSIS OF COMMUNICATION AND SWALLOWING IN THE SLEEP APNEA POPULATION

By

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ABSTRACT

ANALYSIS OF COMMUNICATION AND SWALLOWING IN THE SLEEP APNEA POPULATION

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This is a descriptive study of the communication and swallowing characteristic of 35 subjects diagnosed with sleep apnea. An additional component of this study is comparison of a reference group on non-treated sleep apnea subjects with a group of sleep apnea subjects receiving continuous positive air-pressure (CPAP) treatment for 1 to 3 months. The five areas of study were respiration during speech, speech production, resonance, phonation/voice and swallowing. Information was gathered by the use of a patient questionnaire, clinician perceptual judgment and objective clinical measures. The subjects had high Body Mass Index (BMI) scores that may have had a negative effect on communication. Communication and swallowing ratings based on the perceptual judgment of a clinician revealed mild difficulties in (32) 94% of the subjects. Non-normative ratings occurred for 65% of the subjects on speech production, 50% of the subjects on voice, 47% of the subjects on resonance, and 9% had abnormally judged swallowing. The objective data revealed that sleep apnea subjects had frequent abnormal scores in the respiration during speech area that were sufficient inhalation, duration of exhalation and maximum phonation time. There were also a high number of sleep apnea subjects with low fundamental frequencies. Individuals with high BMI ratings and low Apnea Hypopnea Index (AHI) ratings were all rated lower in the area of speech

production and had below normal maximum phonation times. In addition, self-reported smokers all had below normal abilities in the respiratory tasks.

The reference and CPAP treatment groups showed the same trend between the initial and follow-up data. There were no statistical significant results that differentiated between the two groups. However, there was a tendency for improvement with the CPAP group in the areas of resonance, voice and swallowing abilities perhaps related to less edema in the upper airway after CPAP use.

In summary, the 35 sleep apnea subjects used in this study were obese and had severe sleep apnea scores. Almost all of them were evaluated as outside of normal limits in one or more components of communication. There was no significant change for those subjects who went on a CPAP treatment protocol for 1 to 3 months compared to those subjects who choose no regime of treatment.

To Mom and in memory of Dad, for always having the greatest faith in me.

May I show that same faith in Sally.

And for David who has assisted me in realizing one of my dreams.

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INTRODUCTION

Obstructive sleep apnea (OSA) is a respiratory disorder related to the collapse of the upper airway during sleep. Snoring may be one of the early signs of sleep apnea. Sleep apnea is defined as the cessation of breathing lasting 10 seconds or longer during sleep. Hypopnea, a related disorder, is defined as a reduction of airflow causing arterial oxygen desaturation greater than 4% (Reeves-Hoche, Meck, and Zwillich 1994; Sforza, Addati, Cirignotta, and Lugaresi 1994). Sleep apnea is diagnosed by a study called polysomnogram that provides information on brain wave activity, eye movements, muscle tone, heart rate, oxygen saturation and respiration during a minimal six-hour period. A confirmed diagnosis of sleep apnea is often given after the apnea-hypopnea index (AHI) is computed, which is defined as the average number of apneas plus hypopneas per hour of sleep. Hypopneas are a reduction of $\geq$ 30% reduction in airflow or thoracoabdominal excursion accompanied by a $\geq$ 4% drop in oxyhemoglobin saturation. The AHI provides information on the severity of the apnea. AHI scores of 0 – 4 are normal, 5 – 9 asymptomatic, 10 – 19 represents a mild apnea, 20 – 39 a moderate apnea and any score above 40 is considered to be a severe apnea (L. Marmion, personal communication, April 2001). However, Croft and Golding-Wood (1990, p. 871) point out "There is no universally accepted grading system for snoring or apnoea."

Snoring and sleep apneas are both caused by a combination of anatomical and functional problems. Snorers have anatomical and physiologic abnormalities of the pharynx that distinguish them from non-snorers and snorers with obstructive sleep apnea (Bradley et al., 1986). Drugs, alcohol, fatigue, and smoking all contribute to snoring and sleep apnea by increasing muscle hypotonia and decreasing respiratory drive (Krespi, Pearlman, and Keidar, 1994; Lugaresi, Cirignotta, and Montagna, 1988; Robinson, White, and Zwillich, 1985).

A large number of individuals with obstructive sleep apnea present with structural deviations that differentiate them from the normal population. Obstruction in the airway may be caused by a multitude of anatomical or physiological reasons including hypertrophic tonsils and adenoids, rhinitis, deviated nasal septum, upper airway edema, vocal fold paralysis, airway stenosis, neoplastic disease, vocal cord dysfunction, goiter, relapsing polychondrites and tracheomalacia. Anatomical characteristics that are frequently noted in the OSA population include micrognathia – small jaw, retrognathia - under developed jaw, and macroglossia – large tongue (Shelton, Woodson, Gay, and Suratt 1993). Ono, Lowe, Ferguson and Fleetham (1996) noted that craniofacial structures have a major influence on jaw and tongue muscle function. Men may have a greater prevalence of nasal obstruction secondary to contact sports and physical fighting. On CAT Scan cross-sectional analysis from the hard palate to the tip of the epiglottis, a group of 15 obstructive sleep apnea subjects demonstrated a reduction in the size of the pharynx when compared to 10 normal controls (Stauffer, White, and Zwillich, 1990).

Functional differences in size and shape caused by relaxation of the muscles of the soft palate, uvula, and pharynx may result in more complex obstructive sleep apneas. Contributing to the airway obstruction may be the difference between the closure shape of the pharynx between normal subjects and subjects with sleep apnea. Rodenstein et al. (1990) reported that the healthy subjects in their study had a coronal closure shape while the apnea subjects had a sagittal or circular closure shape. Skolnick and Cohen (1989) have described four velopharyngeal closure patterns: coronal, circular with Passavant's ridge, sagittal, and circular. The coronal pattern is when there is opposition between the soft palate and the posterior pharyngeal wall. Circular closure with Passavant's ridge is a sphincter type closure with soft palate opposition to a localized bulge of the posterior pharyngeal wall. The sagittal closure results in greater medial movement of the lateral pharyngeal walls. Equal movement between the velum, lateral and posterior pharyngeal wall is observed with a circular closure pattern. The type of closure pattern an individual exhibits can result in a need to modify the type of surgical reconstruction planned with children who exhibit velopharyngeal insufficiency and may have implications for other medical procedures that involve this mechanism.

Contributing to the upper airway collapse are over-generous amounts of tissue and weakened muscle tone. A study by Yoshida, Thumm, and Siebert (1995) (cited in Wiltfang et al., 1999) reported that the muscle tone of the geniohyoid muscles are decreased in OSA patients. It is the genioglossus and geniohyoid muscles that are involved in providing upper airway patency. In an effort to increase muscle tone, Wiltfang et al. (1991) used electrical stimulation on the suprahyoid muscle and found that this stimulation resulted in less tongue collapse and apnea.

Individuals with airway obstruction have increased pharyngeal airflow resistance when compared with control subjects (Stauffer et al., 1990; White, Lombard, Cadieux, and Zwillich, 1985). Pharyngeal resistance is measured by assessing pressure between the area of the choanae to the epiglottis. Some hypothesize that there is a delayed and insufficient contraction of the pharyngeal dilator muscles during inspiration (Lugaresi et al., 1988). Moreover, repeated heavy inspirations over time may change the individual's anatomy by lengthening and narrowing the laryngo-tracheo-bronchial tree downwards and shifting rib cage movement as well as contributing to changes in the tongue and jaw anatomy (Lugaresi et al., 1988).

Prevalence

Phillips, Cook, Schmitt, and Berry (1989) estimated that the incidence of sleep apnea for the general population in the United States is 1%. However, other studies report the incidence for middle aged males in the United States to be as high as 4%, whereas women have an OSA incidence of 2% (Young, Palta, Dempsey, Skatrud, Weber, and Badr 1993). The likelihood of sleep apnea increases above age 50 years for both men and women. Zamarron, Gude, Otero, Alvarez, Golpe, and Rodriguez (1999) recently published some information on an older population that is thought to have a greater incidence of sleep apnea. Zamarron and his colleagues found the prevalence of sleep apnea syndrome in 50 – 70 year olds in Spain to be almost 7%. He and his colleagues also cited a difference in the prevalence between men and women.

Sleep Apnea and Weight

Obese individuals have many chronic health problems. Sturm and Wells (2001) conducted a telephone survey of 9585 adults and found that obese people have an average of twice as many chronic health problems as those with normal weights. Sloan and Shapiro (1995) define obesity as body weight of 20% greater than ideal on the Body Mass Index (BMI). Body Mass Index (BMI) is a method of adjusting body weight of individuals related to their height. The formula for BMI is: BMI kg/m2 = [(weight (lb.)/height (in)^2] x 705 (Mahan and Escott-Stump, (Eds.), 2000). In addition, the BMI ranges are established ranging from malnutrition to obese. The ranges are severe malnutrition (<16 kg/m2), moderate malnutrition (16.0 – 16.9 kg/m2), mild malnutrition (17.0 – 18.4 kg/m2), normal (18.5 – 24.9 kg/m2), overweight (25 – 29.9 kg/m2), obese (30 – 34.9 kg/m2) and very obese (35+ kg/m2) (Nieto et al., 2000; Shils, Olson, and Shike, 1994). Bray, Jordan, and Sims (1976) report there is increased risk of health problems if the BMI is greater than 27.

The frequency of OSA has been documented to be 25 times higher in patients who are obese compared to non-obese patients (Peiser, Lavie, Ovnat, and Charuzi 1984). About 80% of individuals with obstructive sleep apnea are more than 20% or more overweight; the fatty infiltration of the oropharyngeal musculature most likely reduces efficiency (Lugaresi et al., 1988). Sloan and Shapiro (1995) reported on a group of 40 women who were consecutive referrals from an eating disorders clinic and were not receiving assessments for sleep disturbances until participation in the study. They found 10% of these women had OSA. The 10% of the women subjects that had OSA also tended to have a higher percentage of body fat and higher Body Mass Index scores than did the non-apnea group.

Body fat distribution typically differs in men and women. Men typically carry their body fat in the upper body while women typically carry their body fat in the lower body (Sloan and Shapiro, 1995; Stradling and Crosby, 1991). Sloan and Shapiro (1995) feel that this distribution of body fat may be more important than the amount of obesity in OSA patients. Rollheim, Osnos, and Miljeterg (1997) found that there was a correlation between increasing BMI scores and anatomically lower pharyngeal obstructions. Stradling and Crosby (1991) reported that the most significant predictors of OSA are nocturnal hypoxemia and neck size. Nieto et al. (2000) in a descriptive study of 6132 subjects reported that neck circumference and waist-to-hip ratio were higher in participants with high AHI values.

Horner et al. (1989) studied the sites and sizes of fat deposits using MRI around the pharynx in weight-matched references and OSA patients. Their study reported large fat deposits located posterior-lateral to the oropharyngeal space at the level of the soft palate. The study revealed that there was a greater amount of fat present with the OSA subjects than with the references. Shelton et al. (1993) measured volume of fatty tissue in the upper airway and compared this to AHI severities. There was a positive correlation between the volume of fatty tissue and number of apneas and hypopneas per hour. The location of the fatty tissue was located laterally possibly explaining the frequent lateral pharyngeal collapse. Two of the patients from this study who lost weight showed a decrease in fatty tissue in the pharyngeal area and also had fewer apneas and hypopneas.

These studies provide evidence that when there is increased weight there may be an increased amount of fat in the tongue and soft tissue contributing to increased collapse/obstruction of the airway during sleep. Increased weight could also decrease the cross-sectional area or increase the muscle load needed to keep the airway area patent. The changes in the airway due to weight may also affect the airway during waking hours. Therefore, increased weight may affect many body systems including respiration, speech production, voice, resonance, and swallowing. Increased weight is a common risk factor with many chronic diseases such as pulmonary disease, cardiovascular disease, diabetes, and cancer (Centers for Disease Control, 1999)

Anatomical Relationships

Respiration, communication and swallowing all involve interdependent anatomy and complex motor planning that is dependent on the central nervous system. The anatomy that serves these overlapping systems is the oral and nasal cavities and the oropharynx (often referred to as the upper airway). It is important to understand normal anatomy and function of the airway area during respiration, speech production, phonation, and swallowing to get an appreciation for the integration of these systems. An understanding of a normal model will also assist in observations of an abnormal system and the need for corrective measures when appropriate. When there is an abnormality in one system, the performance of another system may be affected. For example, an appropriate valving of the oral air stream is needed to produce pressure consonants; when there is insufficient valving, intelligibility to a listener maybe diminished. Individuals with respiratory disorders may be at higher risk for speech deficits, voicing disorders and/or swallowing difficulties because respiration supports these activities or is coordinated with these tasks (Logemann, 1983; Sataloff, 1991). Changes by disease or surgical revisions directed at improvement of function in one system might affect the performance in another related system such as removal of tonsils to aid breathing or swallowing may at times improve upon or hinder resonance.

Normal Anatomy and Function

The normal route of breathing during wakefulness is predominantly through the nose (Sher, 1990). This route allows the air to be warmed and humidified. Inhalation occurs when alveolar pressure within the lungs is sufficiently decreased from outside atmospheric pressure (Hixon, 1973). Exhalation occurs when the opposite conditions are met. Airflow during both inhalation and exhalation proceeds from an area of high pressure to an area of low pressure. Both passive non-muscular forces and active muscular forces are involved in this function. The muscle activity assists in stiffening or dilating the pharynx. In addition to sustaining life, breathing during wakefulness supports speech and phonation as well as other activities.

During sleep many breathing modifications occur. Ventilation is decreased during sleep (Gleeson, Zwillich, Braier, and White 1986). Men more frequently change the route of their breathing during sleep to increase the amount of mouth breathing versus nasal breathing (Gleeson et al., 1986). During sleep the skeletal muscles are generally more flaccid, especially during rapid eye movement sleep, and may contribute to pharyngeal collapse (Krespi et al., 1994; Wiegand and Zwillich, 1994). This pharyngeal soft tissue collapse in part explains the greater pharyngeal airflow resistance and decreased patency of the nasal-oral-pharyngeal area relative to other more fixed portions of the respiratory system such as the nasal passage or trachea. Unfortunately, information on the patency of the pharynx in normal individuals is limited. Patency is typically determined by size of the pharynx from the hard palate to the tip of the epiglottis and by pharyngeal and supraglottic resistance. Phillipson (1993) feels that patency in the upper airway depends critically on the action of the dilator muscles.

The upper airway is supported by neurological signals that are involved in maintaining patency and coordinating movement for breathing, speech and swallowing. The pharyngeal plexus innervates the soft palate and upper pharyngeal muscles, which are part of the velopharyngeal port. The pharyngeal plexus comprises the branches of the glossopharyngeus and vagus cranial nerves. There are two exceptions to this velopharyngeal mechanism innervation. The tensor is innervated by the mandibular branch of the trigeminal nerve, and the musculus uvula is innervated by the spinal accessory nerve and may receive some innervation from the palatine nerves of the facial nerve (McWilliams, Morris, and Shelton 1990; Nishio, Matsuya, Machida, and Miyazaki 1976a; Nishio, Matsuya, Ibuki, and Miyazaki et al., 1976b).

During respiration the velopharyngeal port is open, forming a continuous passage between the nasal and oral pharynx. The velopharyngeal musculature begins at the posterior edge of the hard palate and extends to the posterior pharyngeal wall. The mechanism consists of the soft palate, uvula, posterior pharyngeal wall and lateral pharyngeal walls. The anterior faucial pillars are on the lateral borders and the tongue is the inferior border. The palatoglossus muscles form the anterior faucial pillars. These pillars assist in lowering the velum and retracting the tongue. The branches of the palatopharyngeus muscle form the posterior faucial pillars extending from the posterior pharyngeal wall to the soft palate. The palatopharyngeus acts to narrow the velopharyngeal orifice and raise the larynx. The superior constrictor muscle forms the lateral and posterior pharyngeal walls, which is responsible for medial movement of the lateral walls and anterior movement of the posterior pharyngeal wall.

During speech the velopharyngeal mechanism works as one of the components of articulation by changing the direction of airflow and providing shaping (Moon and Kuehn, 1996), as it is open for nasal sounds and closed for oral sounds. This modulation affects the shape of the vocal tract and, hence, the resonance of one's voice. The musculus uvula is an intrinsic muscle. Cassell and Elkadi (1995) stated:

It has been suggested that the musculus uvulae assists velopharyngeal closure by thickening during phonation, a result of its contraction, which shortens the muscle, adding bulk to the point at which it overlies the levatores. The actual contribution of the musculi uvulae to speech remains uncertain, however. (p 55)

During swallowing the velum lowers and bulges forward to control the transit of the bolus (Logemann, 1983) while the faucial pillars (palatoglossus muscle) are thought to be involved in the initiation of the swallow response (Logemann, 1983; Moon and Kuehn, 1996). Finkelstein, Talmi, and Zohar (1988) reported that in addition to its role in speech, the uvula's function is related to closing off the nasal cavity from the oropharynx while bending over and drinking, such as from a drinking fountain. Later, Finkelstein, Meshorer, Talmi, Zohar, Brenner, and Gal (1992) reported on an expanded role of the uvula to produce saliva to lubricate the oropharynx and prevent dryness.

The nasal-oral-pharyngeal area is a highly vulnerable and, in part, collapsible system. Maintenance of a patent nasal-oral-pharyngeal area depends on neurologic control, air pressure and peripheral feedback. Intervention directed at the patency problem results in the various management techniques used for OSA patients, including lifestyle changes, medical non-surgical procedures, and surgery.

Management of Obstructive Sleep Apnea

Many treatments and strategies are used to help improve sleep apnea. The first recommendations made are usually lifestyle changes such as weight loss, sleep position modifications, meal scheduling, and smoking cessation (Lombard and Zwillich, 1985; Wiegand and Zwillich, 1994). Compliance with these first-line recommendations has been problematic. For some milder forms of sleep apnea, dental appliances that assist in forward positioning of the tongue and jaw are options (Lombard and Zwillich, 1985). However, such dental appliances are often discontinued because of discomfort.

The two most common treatment regimes for moderate and severe sleep apnea are continuous positive air pressure (CPAP) or surgical intervention. CPAP therapy is the most widely used treatment for OSA (Wiegand and Zwillich, 1994). The CPAP device is a blower that delivers room air of a set pressure via a tube and nasal mask to the nasal airway when worn by a patient. CPAP keeps the upper airway open by generating high airflow and pharyngeal resistance. It is thought that nasal stimulation occurring during CPAP therapy may result in reflex activation of the upper airway muscles and contribute to increased patency (Lombard and Zwillich, 1985). A contrasting view is reported by Strohl and Redline (1986) - they report that upper airway muscle activity is unchanged during CPAP therapy. Anecdotal complaints by patients using this intervention usually have to do with the noise of the CPAP machine and difficulty traveling with this type of intervention. In addition, there are some complaints of dryness in the mouth area. Lombard and Zwillich (1985) stated that dry nasal mucosa, sinusitis, middle ear infections, pneumothorax and pneumomediastinum are potential problems arising from CPAP use; however, there are no documented studies on these possible side-effects. Lombard and Zwillich (1985) stated that "Medical therapy for the OSA (obstructive sleep apnea) patient is unlikely to be beneficial if surgically correctable anatomic abnormalities of the upper airway are present." In other words, CPAP therapy may not be as effective if anatomical problems that obstruct airway access such as a deviated nasal septum or enlarged tonsils are not taken care of first prior to the initiation of CPAP.

Surgical remediation typically is a combination of tonsillectomy and/or resectioning of the nasal turbinates or septoplasty and the uvulopalatopharyngoplasty (UPPP) procedure. The UPPP procedure trims tissue from the uvula and posterior soft palate. The goal of these procedures is to remove the obstruction in the nasal and/or pharyngeal area and improve the free flow of air in the upper respiratory system. The reviews on the effectiveness of surgery for treating OSA have been disappointing (Janson et al., 1997; Troell, Riley, Powell, and Li, 1998). There are a number of studies that report on the communication or swallowing characteristics post-surgery of the UPPP patients. Interestingly, most studies determine whether after UPPP surgery there are changes in communication or swallowing. Yet the post-surgery condition of the pharyngeal area may be similar to the normal airway of the general population. In fact, the pre-surgical or untreated OSA population to begin with was not similar to a normal population because of the large amount of airway obstruction they experience.

There are a number of reported changes in communication and swallowing after UPPP surgery. Most of the studies reporting these changes (Croft and Golding-Wood, 1990; Haavisto and Suopaa, 1994; Prichard, Marshall, Ahmed, Thomas, and Hanning, 1994) are based on questionnaires that reported on occurrences after surgery or that ask questions about communication and swallowing only after surgery. A study by Murry and Bone (1989) did compare the OSA subjects' pre-surgery results from specific speech tasks to post-surgery results. They also compared the results obtained at both the initial and final sessions to published norms in the literature from the normal population. They found that the length of time it took for their sleep apnea subjects to read a passage prior to surgery was below norm for all the subjects, whereas after the UPPP surgery all of their subjects had improved reading rates. The UPPP procedure and its effects on communication appears to have been more strongly researched than the abilities of the OSA population without intervention or with the more widely used intervention of CPAP. Results from the combined studies reveal relationships to communication and swallowing. Complications from the UPPP surgery include velopharyngeal incompetence (Croft and Golding-Wood, 1990; Sher, Thorpy, Shprintzen, Spielman, Burack, and McGregor, 1985), pharyngeal dryness (Croft and Golding-Wood, 1990; Haavisto and Suonpaa, 1994; Salas-Provance and Kuehn, 1990), loss of taste (Haavisto and Suonpaa, 1994; Croft and Golding-Wood, 1990), nasal regurgitation of fluids (Haavisto and Suonpaa, 1994; Prichard et al., 1994; Sher et al., 1985; Zohar, Finkelstein, Talmi, and Bar-Ilan, 1991), swallowing dysfunction (Salas-Provance and Kuehn, 1990), tongue numbness (Fairbanks, 1990), middle ear dysfunction (Zohar et al., 1991), sneezing (Zohar et al., 1991), speech/voice changes (Haavisto and Suonpaa, 1994; Murry and Bone, 1989, Prichard et al., 1994; Zohar et al., 1991), difficulty singing (Haavisto and Suonpaa, 1994), and difficulty playing a wind instrument (Haavisto and Suonpaa, 1994).

One reported type of speech change resulting from UPPP surgery was change in pronunciation. Zohar et al. (1991) commented that 10 individuals in their study of 71 subjects after UPPP had difficulty with pharyngeal productions especially guttural /ch/ and /r/. These authors noted that the /r/ and /ch/ were changed to alveolar or dental productions. Nakai, Sakakura, Takahashi, Sadaoka, and Kakitsuba, (1996) examined monosyllabic speech productions of speakers pre- and post-UPPP surgery and found no significant differences in any of their productions. As noted above, reading rates improved for subjects following UPPP surgery (Murry and Bone, 1989).

Vocal quality was also reported as changed by some UPPP patients. On perception tasks listener-judges were able to tell the difference between the reference subjects versus the UPPP subjects particularly with judgments related to phonation and articulation (Salas-Provance and Kuehn, 1990). Instrumental analysis of resonance has described little change by actual aerodynamic measurement (Salas-Provance and Kuehn, 1990).

Swallowing has also been reported as changed following the UPPP procedure. Levring-Jaghagen, Nilsson, and Isberg, (1999) studied individuals post-UPPP surgery. They found that after the UPPP procedure 29% of the subjects had complaints of persistent dysphagia, and upon follow-up with videofluoroscopy the researchers found pharyngeal difficulties in 71% of these individuals with complaints.

There have been a handful of studies on communication and swallowing abilities after surgical remediation of OSA. However, most of these have explored UPPP surgery; the more frequent remediation technique, CPAP, has fewer studies on the effects of this therapy on communication and swallowing abilities. Brander, Soirinsuo, and Lohela, (1999) reported that OSA patients tend to describe nasopharyngeal problems such as dryness, sneezing, mucus in the throat, blocked nose and rhinorrhea. These complaints are noted prior to treatment and increase after CPAP use.

Communication and Swallowing Characteristics

Many of the communication and swallowing characteristics that could provide some additional information on this patient population have yet to be studied. One of the important characteristics to evaluate with this population is respiration. The link between speech production and respiration is described well by Hixon (1973):

> To be more specific, the respiratory pump participates in speech by displacing structures, creating pressures behind valves, and generating flows through constrictions within the larynx and upper airways. These activities, in association with intricate and rapid maneuvers of other parts of the speech apparatus, create the disturbances of air that constitute speech at the acoustical level. Since respiratory forces provide the basic energy source for all speech and voice production in the English language, the events of speech respiration are of fundamental importance in any account of oral communication. Within the broad spectrum of physiological function in speech, the respiratory pump is involved in the regulation of such important parameters as speech and voice intensity (loudness), vocal fundamental frequency (pitch), linguistic stress (emphasis), and the division of speech into various units (syllables, words, phrases, etc.). (pp. 98 - 99)

Individuals with respiratory disorders are often found to have traumatized and swollen pharyngeal tissue that may also correspond to voice and swallowing changes. Respiratory measures can help determine the severity of a speech and/or voice disorder, monitor change and assist in treatment planning. Measures of maximum phonation time, breath groups per minute during speech production, sufficient inhalation gauged by chest wall movement, and average duration of exhalation, are important measures to provide descriptive objective information regarding respiratory support for speech. Maximum phonation time assists in determining effectiveness of breath support for speech. Colton and Casper (1990) also feel that maximum phonation time has a role in estimating glottal efficiency and laryngeal control. Breath groups per minute during reading and picture description tasks provide information on glottic efficiency and respiratory use. Sufficiency of inhalation provides information on gross adequacy of respiratory support for speech production. In addition, the individual's average length of exhalation while speaking assists in observing trends of efficient use and the reserves that an individual may be able to call upon. The obstructive sleep apnea population may have smaller respiratory capacities to support dynamic functions such as speech, voice and swallowing coordination.

Investigations of oral motor movements and swallowing in the obstructive sleep apnea population can improve our understanding of subtle changes in the anatomy and function of the respiratory and speech mechanism. Ruscello, Tekieli, and Van Sickels, (1985) studied speech production before and after orthognathic surgery and found that when collapsing data from multiple studies, 72% of the individuals had articulation errors before surgery. However, after surgery 88% of the subjects with pre-operative errors had either reduced or eliminated articulation errors.

Speech production is a combination of articulatory positioning, neurological motor programming and coordination with the airstream. Perceptual evaluation of articulation can provide inferences about anatomical structure and function. Dental occlusions, poor tongue position, or weakened muscles can result in distorted speech sounds. Poor respiratory support can result in consonants with weak pressure, diminishing intelligibility.

Speech production is usually assessed by having the individual produce a series of words with a variety of consonants targeted or by taking a sample of speech produced during reading, talking about a picture, or conversation. Speech production is judged by listener perception. Standardized oral motor examinations and swallowing trials provide additional insight into the patient self-reports. Oral agility measures may help provide some additional information related to articulation and swallowing changes.

Phonation quality and characteristics of phonation are products of the laryngeal mechanism. These contribute to our knowledge about health, flexibility and the efficiency of the respiratory, communication, and swallowing systems. The size, shape, mucosal quality of oral, nasal, and pharyngeal cavities, the function of the glottis, and respiratory support for phonation determine the individual's vocal quality. Vocal abuse or misuse, such as using an abnormally low pitch, can result in laryngeal hyperfunction and decreased respiratory efficiency. After a more global perceptual assessment of phonation is made, specific tasks that assist in describing the voice and inferring structure and function are typically performed. For example, to better understand normal or abnormal laryngeal vocal quality, the acoustic measures of fundamental frequency and jitter perturbation can be analyzed. Jitter perturbation is the cycle-to-cycle variability of fundamental frequency (Horii, 1979). Perturbation measures provide information about the stability of the vocal fold vibratory pattern. Gilbert (1975) reported that jitter perturbation is sufficiently sensitive to pathological changes in the phonatory process and perhaps even to severe respiratory insufficiency. In addition, variations of the vocal tract configuration such as the production of different vowels result in changes of jitter perturbation. Excessive jitter perturbation is an acoustical physical correlate for hoarseness. Another task that probes for laryngeal function is the s/z ratio, a gross measure of laryngeal pathology. The cognates voiceless /s/ and voiced /z/ are produced at the longest duration possible and the ratio reflects the influence of laryngeal valving.

Another characteristic that needs to be studied more in the OSA population is resonance. Resonance is the quality that is produced by sound waves caused by air flow vibrating in the nasal, oral, pharyngeal and laryngeal cavities. Here, a unique quality is produced based on the size and shape of the cavity. Movable parts of the pharynx, pyriform sinus, chest, trachea, tongue, jaw, soft palate, and lips are involved in changing resonance. There is a range of this quality that is perceptually pleasing to our ear. Resonance is judged perceptually by listening and can be quantified by physical measures such as nasalance, a ratio of oral versus oral-and-nasal acoustic energy. If resonance occurs outside a normal range, it is considered to be either denasal/hyponasal, or conversely, hypernasal. Deviant resonance is often perceived to be distracting to the listener and may result in decreased intelligibility of the speech signal. For example, an individual with a retracted tongue and little mouth opening may sound hypernasal with a tense, pinched sounding resonant quality. Enlarged tonsils may result in snoring, obstructive sleep apnea, and denasal vocal quality. Denasal children often undergo removal of their tonsils for remediation. After tonsillectomy and/or adenoidectomy some individuals experience transient hypernasality, whereas others experience a more permanent increase in hypernasality as a complication of the surgery which enlarges the oropharyngeal area.

Changes to the structure or function of the respiratory mechanism may lead to changes in speech production, voice, resonance and swallowing. Monoson and Fox (1987) used 39 age-matched subjects divided into three groups: OSA, chronic obstructive pulmonary disease (COPD) and subjects' without OSA or COPD. They assessed speech production in these three groups by having the subjects read sentences and then having trained listeners make binary judgments (disorder present or absent) of the subject's speech productions. They found abnormal speech in 62% of their sleep apnea group, in 23% of their COPD subjects, and in just 8% of their reference group. The clinicians that rated the speech samples commented on the dysarthric-like speech with abnormal resonance of the sleep apnea subjects.

There are studies present in the literature that reflect that changes in the oral cavity through disease or intervention do change communication and swallowing. Ichikawai, Komado, Horiucki, and Matsumoto, (1995) found that both voice onset time (time between the release of the stop consonant and the voicing of the vowel) and consonant duration increased with palatal augmentation, possibly due to changes in oro-sensory feedback, laryngeal compression or indirect aerodynamic feedback. Siefert, Ronte, Riebandt, Lamprecht-Dinnessen, and Bollmann, (1999) found that alterations in the oral cavity from a dental prosthesis caused perceptual changes in voice; however, fundamental frequency was not changed at a statistically significant level. More directly, a study by Zohar, Grusko, Sulkes, and Melloul, (1998) found that during swallows, as documented by scintigraphy, the OSA subjects had longer oral transit times than both healthy subjects or OSA subjects following UPPP intervention.

Systems Approach

It appears that the sleep apnea group may already be at higher risk for various communication and swallowing disorders. The increased risk may relate to the abundant pharyngeal tissue, crowded oral cavities, decreased neurologic function, or a combination of any of these deviancies. Likewise, the interventions used to help sleep apnea by decreasing the amount of pharyngeal tissue or having air pressure forced into the airway may also create changes in communication and swallowing abilities.

Noninvasive measurement may be helpful for early detection of neurologic or muscular changes. Functions of the upper airway are dependent on a sequence of volitional and reflexive neural control. Although coordinated functions exist between the shared structures for respiration, speech, resonance, phonation, and swallowing, it should be appreciated that differences in the motor control and peripheral feedback occur for these functions. In both speech and swallowing, pharyngeal muscle contraction is present for vocal tract posturing to produce various sounds and resonance patterns or to propel the bolus. Tongue strength, range and coordination can affect articulatory precision, nasality of voice (by directing the airflow), vocal quality (by adding tension to the muscles of the pharynx and larynx), and swallowing (by initiating the swallow in response to tongue movement). There is a need to interface clinical and instrumental findings of respiration, resonance, phonation, oral mechanism movements and swallowing.

One example of how a functional change in one system can result in an unintended change in a second area can be found in examining the relationship between dysphagia and dysarthria. Consideration of long-held insights regarding the shared symptomology for dysarthria and dysphagia relates to issues that may gain further enlightenment when examined from the perspective of obstructive sleep apnea research. Robbins (1985) discusses a significant link between individuals who present with dysarthric speech and have symptoms of a swallowing disorder. She identified this link as the coordination of respiration. Respiration stops momentarily to allow for a swallow to occur and at the same time protect the nasopharynx and airway. Respiration coordination is required for speech production, enough pressure to produce sounds and put together a string of words. When breath support is reduced additional stress may be put on these systems which are dependent on fine timing and coordination of muscular movements.

On the other hand, an example of how a structural change can result in a change of function in one system and an unexpected change of function in a second can be found in the relationship between airflow and voice. Children with borderline velopharyngeal inadequacy are more likely to have vocal nodules (McWilliams, Morris, and Shelton, 1969) because they have a routinely increased demand on the respiratory system for pressure. Hyperfunction of the vocal folds occurs to create adequate power (i.e., voice intensity) to overcome the open chamber and decreased resistance in the upper pharynx. There are many vocally abusive behaviors that result in malfunctioning or organic changes in the laryngeal mechanism. Years of heavy snoring could result in repetitive vocal abuse to the laryngeal mechanism as the individual has sudden choking or gasping at the end of the snore cycle. Similarly throat clearing is considered vocally abusive to the system as the individual abruptly closes his or her vocal folds together. Further vocal hyperfunction may be more likely to occur with the tongue collapsed during sleep by increasing mass to the pharynx and possibly adding tension to the laryngeal mechanism.

The relationship among multiple systems seems obvious when noting that changes in loudness, pitch, and syllable emphasis effects subglottic pressure. Voice therapy utilizes breathing exercises and efficient use of respiration to improve laryngeal vocal quality and resonance. Articulation also affects subglottic pressure by changing airflow and resistance as well as having an effect on resonance. Brancewicz and Reich (1989) found perceptions of nasality increased in normal speakers when the rate of speech decreased, possibly related to changes in nasal airflow. Therefore, if respiration is significantly compromised, it seems intuitive that laryngeal quality, resonance and speech production may also be adversely effected.

During an initial clinical evaluation for snoring and obstructive sleep apnea, an oral examination of structure and function is conducted to learn how the characteristics of the mouth may have an effect on snoring. Evaluation may reveal a small jaw or large tongue for the oral cavity, redundant faucial arches and tonsillar tissue, and a reduced distance between the velum and posterior pharyngeal walls. The above traits are risk factors for snoring and obstructive sleep apnea. However, a similar evaluation of the oral mechanism assists in providing information about articulation and intelligibility. The tongue carriage may be too far back so that there are distortions in some phoneme productions or a throaty tone may be present. The oral cavity may be small or disproportionally sized and result in a muffled tone. Enlarged tonsillar tissue can inhibit velar and/or tongue movement, contribute to making the individual sound denasal and/or may be responsible for containing food in the oral cavity during swallowing. The mouth may be so crowded that airflow is directed out of the nose or there is decreased tongue propulsion during the initiation of the swallow. Obstruction in the oropharyngeal area could also cause anterior displacement of the tongue and interfere with chewing and swallowing.

Purpose

A detailed study of the communication and swallowing abilities in the obstructive sleep apnea population is missing from the clinical literature. Moreover, there has been no clinically well-documented outcome data profiling whether the most recommended therapy technique for sleep apnea, CPAP, may effect changes in respiration during speech, speech production, phonation, resonance, and swallowing. The first part of this study provides descriptive information regarding sleep apnea subjects' characteristics in the areas of contextual speech, oral motor abilities, respiration for speech, phonation/voice, resonance and swallowing. It is important to investigate patterns and characteristics across multiple dimensions that may vary within a diagnostic group that specifically deviates from the normal population. A wide net of clinical tasks was developed to gain information on the areas that might be most affected with changes in a normal upper airway system.

The second part of this study compares the communication and swallowing results of two different sleep apnea groups; those that did not receive treatment (reference group) and those who received CPAP treatment. Multiple task analysis can help us learn about how connected or independent the systems may be. The null hypothesis of the experimental protocol was as follows: there will not be a significant difference between the non-treatment (reference group) and CPAP treatment groups after CPAP therapy.

Chapter 2

METHODS

Typically the investigations into sleep or respiratory disorders, dysarthria, voice, or dysphagia are narrowly focused with the investigators looking at variables within a single area of clinical focus or contrasting and comparing one area to a second (e.g. dysarthria/dysphagia, apnea/respiratory function). Broader conclusions to appreciate the larger linkages among these areas (i.e. respiration during speech, speech production, resonance, phonation, swallowing) may be better grasped by examining the interdependence between structure and their changes affecting functional equilibrium. Consequently, permutations of change may be set up to influence systems that are beyond the scope of a narrow study. Models which allow recognition and accounting for this linkage may be valuable in making suitable predictions when intervention is contemplated in any single dimension.

The characteristics to be studied--respiration during speech, speech production, voice, resonance and swallowing--are outlined below. Self-reported questionnaires, clinical and instrumental measures of assessment were used to measure these communication and swallowing characteristics in an attempt to evaluate structural and functional abilities and deficits. The clinical measures chosen were selected because they are used in speech pathology departments in academic and medical facilities.

Subjects

The medical director at a mid-western Sleep Lab referred potential sleep apnea patients to the Speech - Language Pathology department for the purpose of this study. The primary investigator would schedule a week per month at the sleep lab to collect data from subjects prior to their scheduled overnight sleep study. The potential subjects were then called and asked if they would be willing to participate in a research study prior to their overnight polysomnographic test at the Sleep Lab. All subjects gave written consent to participate in this study. The subjects participated in the initial part of the study prior to their sleep apnea test and the follow-up component after the diagnosis was confirmed. The subjects in this study had a confirmed diagnosis of obstructive sleep apnea with an AHI score of 10 or greater from their overnight sleep study. The subjects self-reported no neurological history of CVA, brain injury or progressive degenerative disease, and no histories of cleft lip and/or palate or vocal disease or surgery (e.g. vocal nodules, polyps, cancer, uvulopalatopharyngoplasty). Subjects that were not excluded from the study included those having had tonsillectomy, adenoidectomy, dental procedures and/or nasal surgeries. Additional information collected included whether the subject had any allergies and what medications the subject was taking.

Thirty-five adult volunteer subjects with a confirmed diagnosis of sleep apnea were studied. The subjects were not assigned to a group until after their initial visit and the sleep lab had contacted them with the results of their polysomnographic testing. Subjects were then put into either the reference group or CPAP group depending on their future plans for treatment. The 16 subjects in the reference group returned from 10 to 62 days after their initial assessment. Individuals in the reference group decided on a variety of treatment plans. Some were not going to receive any treatment, others were planning on exploring a dental prosthesis, whereas still others were going on to CPAP in the future. The 19 subjects in the CPAP group had been on CPAP for 30 days or more at the time of the follow up.

There was a wide representation of participants by gender and age in the obstructive sleep apnea population sampled. There were (11) 31% females and (24) 69% males. This is consistent with the general sleep apnea population where the prevalence is two to three times more in men than in women (Young et al., 1993). The subjects ages ranged from 23 years and 1 month to 73 years 6 months, with a mean age of 50.2, S.D. 11.9, and a median age of 48.4. This again is consistent with the general sleep apnea population as this condition peaks during age 40 to 50 years (Wiegand and Zwillich, 1994).

Equipment

Several standard clinical tasks and instruments were used to provide a reference of the normal population. Cafet-^{R} for Voice, a microcomputer based instrument, uses a strain gauge to monitor chest wall movement and provide information on relative airflow while the subject is speaking (Goebel, 1992). It uses a pressure transducer to convert air pressure to an electrical signal. The signal estimates movement of the lungs during volume displacement. There is a microcomputer attachment and audio input to coordinate voicing with respiratory measures. Baseline calibration occurred with each subject during quiet breathing. The Cafet-^{R} for Voice provides visual feedback on respiratory movement and vocal fold vibration.

Kay Elemetrics Nasometer ^{R} model 6200 R with PC attachment was used. The Nasometer ^{R} is a microcomputer-based instrument that provides numerical values of nasal energy from a ratio of nasal energy over total oral and nasal energy. This device records oral and nasal sound pressure using two condenser microphones mounted on each side of a sound separator plate that rests between the upper lip and nose. The Nasometer

R was calibrated according to the manufacturer's instructions before sample collection was taken each day.

The Visi- Pitch R model 6097 is a microcomputer instrument that is used to capture acoustic information providing a waveform that represents fundamental frequency (f_o). The Visi-Pitch R was used to gain information on fundamental frequency and jitter perturbation. The data were obtained by the production of the /a/ phoneme produced across the Visi-Pitch screen. Selection of the steadiest visual tracing was done, and then the cursors were set for a 2-second interval. The Visi-Pitch R microphone was hand held by each subject, positioned one inch to the right of the center and one inch in front of the subject's mouth during the data recording.

Procedures

Each subject filled out an initial and follow-up questionnaire (Appendices A and B). The subjects performed various well-established clinical tasks that allowed for a baseline and follow-up comparison of clinician-perceptual ratings and objective measurements of respiration, speech, voice, resonance, and swallowing characteristics. A hearing screening was given in a quiet room at the sleep lab during the initial session only. The test was given in both ears at 25db SPL at 500, 1000, 2000, and 4000 Hz. The initial data collection session took approximately 45 minutes and the follow-up session approximately 30 minutes.

Information about respiration for speech consisted of four measures. Maximum phonation time was obtained by having the individual prolong the /a/ vowel for as long as possible after a maximum inhalation. Maximum phonation time was recorded on two consecutive trials. The longer of the two trials was used in the database. The maximum phonation time normative data used as a benchmark was from Hirano, Koike, and von Leden, (1968). Chest wall movement and coordinated acoustic measures were gained through use of instrumental analysis on a Computer Assisted Fluency Evaluation Trainer (Cafet-^{R} for Voice). The data were gathered while the subject read the California Passage (Hoit and Hixon, 1975) and talked spontaneously about the Cookie Thief (Goodglass and Kaplan, 1983) picture for sixty seconds with each stimulus. The two samples were than averaged together. The Cafet-R instrumentation calculated measures of number of breaths per minute, inhalation sufficiency (60% of the maximum voltage level of expansion reached during calibration when the individual is demonstrating quiet breathing) and average length of exhalation while speaking. The information calculated by the Cafet – R was collected while the subjects were standing. If the strain gauge did not fit around the subject at the recommended level (approximately 1-inch below the bottom rib), it was typically moved to a superior position for improved fit and calibration. Information gathered for this study from the CAFET- ^{R} instrumentation was compared to normative data provided in the CAFET-^{R} training manual (Goebel, 1992).

Oral mechanism evaluations were done by the investigating speech - language pathologist to gain information on structure, function and diaodochokinetic rates through administration of the Oral Speech Mechanism Screening Examination - Revised (OSMSE – R) (St. Louis and Ruscello, 1987). Two judges computed the diaodochokinetic rates (rapid repetitive movements) by agreeing on the frequency of productions from audio and visual cues. One of the listeners was the primary investigator and the other a non-clinical volunteer.

Speech production was assessed by having the individual read the California Passage and spontaneously describe the Cookie Thief picture for 60 seconds each. One subject that had difficulty reading repeated a stimulus sentence. If the individual had difficulty describing the picture, they were told to talk about an interest of theirs or about their day. There may be a difference between speech production when reading and during spontaneous speech; therefore, using only a spontaneous speech sample does not insure a variety of phonemes will be used. The speech samples were recorded onto audiocassettes.

The passages were judged using a 7-point scale for speech production developed by the American Speech- Language- Hearing Association - ASHA (1995) for clinical outcome (Appendix C). The ASHA-functional communication scales are based on a severity hierarchy with the low number representing profound impairment ascending to severe, moderately severe, moderate, mild-moderate, mild and within normal limits. One of the key concepts used in the speech production scale is the concept of intelligibility, which is the degree of understandability of the utterances spoken. Specific criteria for each severity level have been outlined. A speech-language pathologist who had no contact with the subjects listened to all of the audiotapes and applied the perceptual scales.

The individual who listened to the audiotapes and made all the perceptual judgments on the subjects knew the subjects had a diagnosis of sleep apnea. However, she had no knowledge of whether the individual was in the reference group or the CPAP group. The perceptual rater/listener is a certified speech-language pathologist. Her primary areas of expertise include articulation, cleft palate and voice. She is active on two cleft palate teams and therefore an experienced listener to articulation, voice and resonance.

There were four measures used to contribute to the assessment of resonance. Information related to resonance was evaluatedby audiorecording and by use of a Nasometer R. An audio recording of each individual's reading was subjected to perceptual ratings of nasality using a 7-point scale ranging from denasal to hypernasal. The scale used was modified from a resonance scale reported by Wilson in 1971 (Appendix E). The subjects read or repeated the Zoo Passage (Kay Elemetrics) for the perceptual rating. The Nasometer R provides a quantitative assessment of nasalance. Two condenser microphones placed near the nose and mouth detect acoustic energy. Data collected while using the Nasometer R were derived from the following stimuli selections: a high-pressure oral passage, the Zoo Passage, oral Low Pressure (Karnell, 1995) sentences and Nasal Sentences (Kay Elemetrics). One subject who had difficulty with reading repeated the passages after the investigator. The Zoo Passage is a standard passage that has no nasal consonants and is frequently used during evaluations of velopharyngeal insufficiency. The Low-Pressure Sentences were designed to minimize or eliminate the effects of turbulent nasal airflow (Karnell, 1995). The Nasal Sentences passage has many nasal consonants; decreased scores during production of this stimulus indicate nasal or upper pharyngeal obstruction. A facial mask was fitted on the subject's head and remained in position for all recordings. With the facial mask in place, the subjects were asked to read each passage silently before the recording to assist with gaining an accurate recording. Nasalance data were compared to norms of Seaver, Dalston, Leeper, and Adams, (1991).

There were four measures used to evaluate voice. Phonation/voice was judged perceptually by a speech - language pathologist using a 7-point scale of functional communication measures - voice disorders from the American Speech-Language-Hearing Association, 1995 (Appendix D). The perceptual rating was made based on the California Passage and Cookie Thief picture audiocassette recordings. Voice was assessed by production of a s/z ratio over two trials and taking the longest trial during each session. The investigator used a stopwatch to measure the /s/ and /z/ productions. The subjects were instructed to take a diaphragmic breath and produce the target phoneme. Voicing was further evaluated by having the individual prolong the vowel /a/ at a comfortable pitch. This was viewed on the Visi-Pitch ^{R} screen set at 15 seconds. The measures of fundamental frequency and jitter perturbation were found from positioning the cursor on the most consistent 2-second sample (from visual inspection) of the total sample taken. Jitter perturbation is the cycle-to-cycle change in fundamental frequency. The Visi-Pitch^{R} calculated relative average perturbation using Koike's formula (Kay Elementrics). This was measured concurrently from the same /a/ sample. Information on fundamental frequency was compared with norms from Fitch (1990).

To gain information on swallowing abilities, clinical perceptual observation was used. The individual took a sip of water while the clinician noted by a yes/no judgment if there was a change in vocal quality such as a wet and gurgly voice. The same procedure was followed when the individual took a small bite of a cracker. Linden and Siebens (1983) found that the most suggestive clinical signs of laryngeal penetration were the combination of wet-hoarse voice quality and impaired pharyngeal gag reflex. Daniels, Brailey, Priestly, Herrington, Weisberg, and Foundas, (1998) found the presence of 2 of the following six indicators were predictors of dysphagia in stroke patients: abnormal volitional cough, abnormal gag reflex, dysphonia, dysarthria, cough after swallow or voice change after swallow. The investigating clinician estimated the timeliness of the swallow response from observation of when oral formulation of the bolus has stopped to when the larynx was felt to rise (as felt by the clinician's fingers positioned on the submandibular region and thyroid, and thumb near the temporomandibular joint). The clinician gathering the data used the American Speech-Language-Hearing Association – functional communication measure on swallowing to rate swallowing abilities (Appendix F).

Data Analysis

Data collected from the previously described variables were ratings or numerical scores. Descriptive data were analyzed by computing percentages, mean, standard deviation and ranges. Visual inspection of the raw data reduced the number of variables for further analysis. For example, the clinician's perceptual rating for swallowing was collapsed into one group for both the tasks of liquid and solid intake since visual inspection of the data was so similar. Since the perceptual judgments for reading or spontaneous speech were nearly identical, further analysis was only made on the spontaneous speech passage that more closely represents daily speech activities. Each subject's data was compared to published critera to look for the number of occurrences that fell within and outside the normal range. These data were then reported in a frequency distribution, indicating the number of individuals falling into a specific category (e.g., normal, above norm, below norm). The various norms used were those from previously published studies.

Further analysis was accomplished by comparing the initial and follow-up results and the reference and CPAP groups. The areas chosen for statistical analysis were based on visual inspection of the data, noting change in the frequency data from the initial to follow-up session or differences between the two groups. Parametric testing was done when the distributions of the data were appropriate. In most cases, non-parametric statistics using the number of occurances were employed. The non-parametric analysis was chosen because the subject pool was different from a normal distribution and the data were not continuous. The score data on a number of variables were skewed toward the normal range. This was an expected finding, as clinically the sleep apnea population is not identified on many speech clinician's caseloads.

Chapter 3

RESULTS

There were 66 individuals who participated in the initial gathering of data. There were 36 individuals who participated in the initial and follow-up phase of this research project. The thirty individuals that did not complete the follow-up were those without a confirmed diagnosis of sleep apnea (i.e. low AHI score) or who, for personal reasons, were unable to return for the follow-up study. One individual was disqualified after data collection because of a low AHI score. Thus, there are 35 subjects with initial and follow-up data that form the following results.

Hearing screenings were done at 500, 1000, 2000 and 4000 Hz with passing criteria at 25 decibels in both ears. The screening revealed that (11) 31% of the subjects passed and (24) 69% of the subjects did not pass. The majority (19) 79% of the subjects that did not pass the screen had difficulty in both ears. Difficulties were distributed fairly evenly between low, high and mixed frequencies respectively (9) 38%, (7) 29% and (8) 33%. Recall that the mean age of the subjects in this study was 50.2 with a range from 23 years 1 month to 73 years 6 months. It is not unusual for the age of the subjects in this study to have difficulty on a hearing screening.

The subjects' physical characteristics are displayed in Table 1. This was a clinical population and subjects in the reference and CPAP groups were not matched according to any criteria (e.g. gender, BMI, AHI). Body Mass Index (BMI) is used to objectively compare one subject's size to another subject's size, taking stature into account. BMI calculations were based on self-reported height and weight. The subjects had their weight and height measures taken at their physician's appointment at the Sleep Lab just prior to the initial data collection. Approximately 10% of the sample was checked with medical records and found to be accurate between the self-report and recorded chart information. The BMI of the subjects (N = 35) revealed a heavy group of subjects. Subcategories revealed (1) 3% of our subjects had BMI scores in the normal range, (8) 23% were in the overweight range, (9) 26% in the obese range and the majority of our subjects (17) 49% were in the very obese range. Body mass index mean was 36.71, S.D. 8.9 with a range from 23.74 - 57.66, compared to approximately 38% of Michigan residents that have a healthy body weight (BMI =18.5 to 25) (Behavioral Risk Factor Surveillance System).

The apnea-hypopnea index (AHI) scores revealed that over half of the subjects in this study (21) 60% had scores of 40 or greater. These scores were in the severe range. The next largest group of subjects (11) 31% had moderate AHI scores of 20 – 39 followed by (3) 9% of the subjects having mild scores of 10 – 19. The mean AHI score was 55.10, S.D. 29.83 with a range of 11.2 – 100.8. Recall that to participate in this study, a person had to have an apnea-hypopnea index score of at least 10 (mild AHI range.

Table 1 - Physical Characteristics of Subjects

Subject No.	Gender	Age	Wt/Ht. lbs. – ft., in	Body Mass Index Kg/m^2	Apnea Hypopnea Index
1 – Reference	F	48.5	170 – 5'2	31.18	13.4
2 – Reference	F	38.3	250 – 5'4 ½	42.37	92.5
3 – Reference	F	41.8	180 –5'5	30.04	71.9
4 – Reference	M	49.2	204 – 5'10	29.35	11.2
5 – Reference	M	46.6	250 – 6'2	32.19	29.5
6 – Reference	F	37.3	280 – 5'4	48.19	18.7
7 – Reference	M	55.5	230 – 6'5	27.35	37.8
8 – Reference	M	40.9	340 – 5'10	48.92	48.5
9 – Reference	M	44.8	260 – 5'10½	36.88	48.1
10 – Reference	M	50.6	240 - 5'11	33.56	91.7
11 – Reference	F	59.8	152 – 5'3	27.0	34.3
12 – Reference	M	48.3	165 – 5'10	23.74	96
13 – Reference	M	65.10	340 – 6'3	42.61	32.6
14 – Reference	M	61.6	254 – 6'0	34.54	45.1
15 – Reference	M	45.7	290 – 5'10	44.39	72.4
16 – Reference	M	60.10	185 – 6'0	26.77	18.7
17 – CPAP	M	48.10	385 – 6'1	50.93	31.1
18 – CPAP	M	30.9	189 – 5'9 ¾	27.39	23.0
19 – CPAP	F	73.6	163 – 5'0	31.92	44.3
20 – CPAP	M	54.9	300 – 6'0	40.80	88.7
21 – CPAP	M	44.4	371 – 5'11	51.89	32.8
22 – CPAP	M	31.11	280 – 6'1	37.04	92.4
23 – CPAP	F	64.9	235 – 5'1 ½	43.8	80.6

Continue Table 1

Subject No.	Gender	Age	Wt/Ht. lbs. – ft., in	Body Mass Index Kg/m^2	Apnea Hypopnea Index
24 – CPAP	M	45.3	227 – 6'1	30.03	82.3
25 – CPAP	M	61.4	335 – 5'4	57.66	100.1
26 – CPAP	F	40.5	200 –5'4	34.42	88.9
27 – CPAP	M	60.5	240 –5'11 ½	33.10	100.8
28 – CPAP	M	49.8	349 – 5'11	48.81	94.7
29 –CPAP	F	62.3	245 –5'3	43.52	63.7
30 – CPAP	M	71.4	245 – 6'2	43.52	21.4
31 – CPAP	F	43.10	158 - 5'6	25.57	21.
32 – CPAP	M	23.1	210 – 6'2	27.04	25.1
33 – CPAP	M	48.9	263 – 5'10	37.84	41.5
34 – CPAP	M	41.2	333 – 6'1	44.05	75.9
35 – CPAP	F	69.5	176 – 5'6	28.48	57.9
Mean	F = 11 M = 24	50.2	F_wt = 200.82 M_wt = 270.21 F_ht =5'3 M_ht = 5'9 ¾	36.71 F_35.14 M_37.93	55.10
S.D.		11.90	F_wt = 44.11 M_wt = 62.03 F_ht = 1.88 M_ht = 2.49	8.9	29.83
Range		23.08 – 73.5	F_wt = 152 – 280 M_wt = 165 – 385 F_ht = 5' – 5'5 M_ht = 6' – 6'6	23.74 – 57.66 F_25.57-48.19 M_23.74-57.66	11.2 – 100.8

The initial data were gathered prior to the investigator or the subject's knowing into which group they would be placed. After the subjects received a confirmation of their diagnosis and had a planning session occur with their physician regarding treatment they were placed in the reference or CPAP group. Subjects in the reference group were either going to try medication, weight reduction, a dental appliance or CPAP at a later time. The reference subjects had their follow-up at an average of 36.69 days after their initial data collection. The range for the reference group was from 10 – 62 days; a few of these extremes were secondary to scheduling purposes. The subjects receiving CPAP treatment were the independent experimental variable. They were asked to come to the follow-up appointments after 30 days on CPAP. Their mean number of days from the initial data gathering to the follow-up averaged 56.74 days, with a range of 32 – 105 days. Delays were caused by scheduling difficulties, initiating CPAP use, or with returning for the follow-up study appointment.

Self-Perceptions

There were three main areas of data collection including self-perception, clinical judgment and objective measures. Information on self-perception was gathered using initial and follow-up questionnaires. A baseline questionnaire (Appendix A) was given to all subjects to obtain a self-report on their perception of their respiration support for intelligibility and capacity for sustained speech, speech production, voice quality, resonance (i.e., tone of voice) and swallowing. The total group had a self-perception of adequate (89% or better) breath support for speech, clear speech productions, appropriate resonance and vocal quality. There were fewer self-reports of adequate swallowing (77%) (see Table 2).

Table 2 – Percentage of Subjects Self-Reported Difficulties Across Various Categories

Subjects N = 35	Respiration for speech	Speech Production	Voice	Resonance	Swallowing
Total	6%	9%	11%	9%	23%

Clinician Perceptual Judgments

Perceptual judgments were made by a speech-language pathologist to gain a better understanding regarding the functional ability of each subject's communication process. There were four areas in which perceptual judgments were made, three using the Functional Communication Measures as established by ASHA, the national professional organization. These areas were speech production, voice and swallowing. Scales for speech, voice and swallowing are based on a seven point scale going from 0 – 7. Zero is unable to test and one is the most profound moving toward seven as normal. The judgments for speech production, voice and resonance were made by a speech pathologist listening to the subject's audio-recordings. One subject had a noisy recording; therefore, perceptual judgments of her data were not made by the therapist and the swallowing data were not used in the aggregate data. Resonance was judged using a modified scale from Wilson (1971)(Appendix E). The resonance scale is a seven-point scale from –2 denasal moving to 0 normal and +4 severe hypernasal. Swallowing was judged at the time of the data gathering by the primary investigator. The primary investigator works in a large metropolitan acute care hospital with experience in clinical and instrumental dysphagia evaluations. Ratings on respiration were not made perceptually.

Data describing spontaneous speech production indicated that (12) 35% of the subjects received a normal perceptual rating and (22) 65% of the subjects received a rating of six, revealing speech is intelligible in and out of context, but the production is sometimes distorted (see Table 3). The deviations noted by the clinician included distortions of the /s/ and /r/ phonemes, which are both lingual alveolar sounds.

Perceptual judgment of voice indicated a wider distribution of ratings, from normal to mild-moderately difficulty. There were (17) 50% subjects who received a normal rating; (13) 38% received a rating of six indicating voice production is appropriate in most situations although minimal difficulty may occur. Another (4) 12% of subjects had ratings of 5 described as a mild-moderate disorder where voice is consistent in most contexts and voice quality is distracting to some listeners (see Table 3). The clinician judge commented repeatedly that many samples were "low-pitched at the bottom of their range."

Resonance/vocal tone judgments indicated that the majority of subjects (18) 53% were judged as having normal resonance. This was followed by (15) 44% being perceived as having moderate hypernasal a score of 2 and (1) 3% of the subjects as having a mild denasal pattern a score of –1 (see Table 3).

Swallowing abilities were primarily judged as normal with (32) 91% of the subjects receiving this rating. Mild difficulties, a rating of six, were observed with (3) 9% of the subjects, indicating functional eating activity with periodic difficulties or the need for additional time when eating (see Table 3).

Table 3 – Percentage of Subjects Rated Outside of the Normal Range for Various Perceptual Categories

Type of rating	Speech Production N = 34	Voice N = 34	Resonance N = 34	Swallowing N = 35
Outside of Normal Range	65%	50%	47%	9%

Of the 34 participants used for analysis, (32) 94% had one or more abnormal perceptual ratings (see Table 4). Only (2) 6% had normal scores on all four of the perceptual measures. None of the subjects were abnormal in all four ratings. Specific information on clinician ratings in each of the perceptual areas can be found in Table 3.

Table 4 – Percentage of Subjects Judged as Within or Outside of the Normal Range by Combined Perceptual Categories (Speech Production, Voice, Resonance, and Swallowing)

Subjects N = 34	Normal All Parameters	One Abnormal Parameter	Two Abnormal Parameters	Three Abnormal Parameters
TOTAL	6%	41%	38%	15%

Objective Information

Oral Abilities

On the oral motor screen of structure and function using the OSMSE-R (N = 35), (11) 32% of the subjects scored below norm, (18) 51% in the appropriate norm range for their age and (6) 17% above the norm for their age. Reference norms were taken from the OSMSE-R manual according to the age of the subject (St. Louis and Ruscello, 1987). Mean score for our total group was 51.82, S.D. 2.74, range 44 – 55, (see Table 5). Review of the completed forms indicated the most frequent reason that subjects were rated down in structure was due to significant ridges on their tongue. This is often caused by a forward resting position and may be secondary to trying to enlarge the airway. On the function portion of the OSMSE-R the area most frequently marked down was also tongue range of motion. Diadochokinetic rates of "puh", "tuh", "kuh", "puhtuh" and "puhtuhkuh" showed a wide range of abilities. Four 11% of the subjects producing all 5 repetitions within or better than norm (St. Louis and Ruscello, 1987). The remaining (31) 88% produced the targeted repetitions below norm: one repetition below norm (7) 20%, two of the repetitions below norm (6) 17%, three targets (8) 23%, four targets (3) 9% and below norm on all targets (7) 20%.

Table 5 – Distribution of Subjects on the Oral Speech Mechanism Screening Examination –R

Subjects	Below -2 S.D.	-2 S.D.	-1 S.D.	Normal	+1 S.D.	+ 2 S.D.
Total N = 35	7	1	3	18	6	0
%	20%	3%	9%	51%	17%	0%

Respiratory Measures

The majority of subjects (24) 70% had appropriate number of breath groups per minute (norm, 12 – 26) while talking for one minute. For the three other respiratory measures the majority of scores revealed abnormal findings. Duration of exhalation during speech was mostly too short or too long. A longer than normal duration of exhalation (norm, 2.6 – 3.2 seconds) while speaking was noted for (19) 55% and too short of a duration was noted for (10) 30% of all subjects. The data for sufficient inhalation (norm, 0%) revealed the majority of subjects (32) 97% were not reaching 60% of tidal volume when speaking and had insufficient inhalation. The data were segmented into groups of 1 – 25, 26 - 50, 51 - 75, 76 – 100 and 101 - 125 percent of occurrences of insufficient inhalations and indicated peaks at 26 – 50 and 76-100. The further away from zero, the more frequently the individual demonstrated a shallow type of breathing. Insufficient inhalation scores can occur as a percentage expressed over 100% because the measures are calculated from voiced occurrences of speech and at times the individual will have unvoiced cycles (M. D. Goebel, personal communication, September 2001). The maximum phonation times were below the normal range for subjects (33) 94% of the time and normal performance was noted (2) 6% of the time for our subjects. Norms for maximum phonation time used were 30.2 – 39.4 seconds for males and 22.9 – 28.7 seconds for females (Hirano, Koiki, and von Leden, 1968). See Table 6 for Respiratory data as well as comparative norms from the CAFET-R training manual (Goebel, 1992).

Table 6 – Descriptive Characteristics for Several Respiratory Parameters

Area	Number of Subjects	Below Norm	Norm	Above Norm	Mean	Standard Deviation	Range
Breath Groups per Minute Norm		< 11	12 – 26	> 27			
No. of Subjects	33	18%	70%	12%	16.83	6.88	8 – 37
Sufficient Inhalation Norm			0				
No. of Subjects	33	97%	3%	0%	61.18	33.84	0 – 105
Duration of Exhalation Norm		< 2.4 seconds	2.5 – 3.2 seconds	> 3.3 seconds			
No. of Subjects	33	30%	15%	55%	3.30	1.3	1 – 6.4
Maximum Phonation Time Norm		<	M = 30.2 – 39.4 F = 22.9 – 28.7	>			
No. of Subjects	35	94%	6%	0%	19.57	7.22	6 – 39

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Resonance

The subjects' scores were compared to norms noted in a study by Seaver et al. (1991); the Zoo Passage mean is 15 % with a standard deviation of 6 and the Nasal Sentences mean is 62% with a standard deviation of 6. The Zoo Passage, a high-pressure oral passage, indicated the majority of subjects' nasalance scores were in the normal range with a tendency of some subjects to have slightly lower nasalance (see Table 7). The group's mean was 13.86, S.D. 5.27 and the range was 7.19 - 28.99. The results of the Nasal Sentences, a group of sentences with abundant nasal consonants, indicated the majority of scores were in the normal range followed by low nasalance scores for the next largest group of subjects. The total group's mean was 55.37, S.D. 10.68 and range of 11.17 – 68.17. Each subject's Low Pressure Sentence, nasalance score, was compared with his or her scores on the Zoo Passage; the comparisons revealed that the passage scores were within 10 points of each other on (34) 97% of the subjects' recordings, indicating there were no indications of nasal emission.

All the subjects had a mean of 15.17, S.D. 7.27 and a range of 7.28 – 38.83 on the Low Pressure Sentences. The Low Pressure Sentences data were not present in the tables as there are no norms for this passage. The Low Pressure Sentences passage was used as a screening to help identify nasal turbulence from an overall high nasalance outcome.

Table 7 - Nasalance Data Distribution

Stimulus	- 3 S.D.	- 2 S.D.	- 1 S.D.	Normal	+1 S. D.	+ 2 S. D.
Zoo N = 35	0%	0%	17%	69%	11%	3%
Nasal N = 35	6%	11%	23%	57%	3%	0%

Voice Parameters

Norms for fundamental frequency of vowels (males 115.6 –164.4 Hz and females 229 – 288 Hz.) were made using data from Fitch (1990). The fundamental frequency (f_o) was in the normal range for (10) 29% of the subjects and below norm for (25) 71% of the subjects. A lower than expected f_o was predominant with the female subjects (N = 11): (9) 82% were below norm and (2) 18% were in the normal range. There were (16) 67% of males (N = 24) with lower than expected f_o and (8) 33% had scores in the normal range. No one in the study had a f_o higher than the normal range. The males had a mean f_o of 107.86 Hz, S.D. 17.45 and a range of 79.1 to 146.5. The females had f_o averaging 203.02 Hz, S.D. 23.22 and a range of 170.8 to 239.70 (see Table 8).

Table 8 – Fundamental Frequency Data

Subjects	Within Normal Range	Below Normal Range
Total Group N = 35	29%	71%
Females N = 11	18%	82%
Males N = 24	33%	67%

For these subjects the s/z ratio indicated (8) 25% of the subjects had ratios of less than .79, the physical correlate of breathy voice, the majority (18) 51% had s/z ratios falling in the norm area .8 – 1.29 (Hirano et al., 1968). Finally, (9) 26% had ratios above 1.3, raising suspicion regarding deviant voice with the physical correlate of harshness. The mean for the total group, s/z ratio was 1.11, S.D. .41 and range of .4 – 2.4. Jitter perturbation indicated the majority of subjects, (31) 89% had normal scores of 1.25 % or less (Kay Elemetrics). The group mean for jitter was .79 % relative average perturbation; the S.D.was .71% and the range was .21 – 3.8%.

Swallowing

There was no audible change in vocal quality after eating or drinking for any of the 35 subjects. The majority of swallows were timely. The swallows were prompt for (33) 94% of the subjects with liquid swallows and for (22) 65% of the subjects with solid consistencies. Delays with liquids were 1-second in duration for (2) 6% of the subjects. Delays with solids were 1-second in duration for (10) 29% of the subjects and 2 -seconds in duration for (2) 6% of the subjects.

Summary of Baseline Characteristics

There was a broad distribution by age, and approximately a third of our subjects were female. Increased body weights are common in the OSA population (Wiegand and Zwillich, 1994). It is common for 80% of the OAS population to have overweight ratings (Lugaresi, 1988). This sample had (34) 97% of the subjects with BMI scores above the normal range. The majority of our subjects had moderate or severe sleep apnea, with (10) 29% and (21) 60% respectively based on their AHI scores (see Table 1).

The subjects most typically rated their own communication abilities as adequate, with a small number of subjects self-reporting some swallowing difficulties. The perceptual baseline as judged by a clinician revealed that a majority of subjects had less than completely normal communication. Only (2) 6% of the subjects had completely normal communication ratings across all areas of speech, voice, resonance and swallowing. Most judgments put subjects in the category of mild difficulties. In the area of resonance, subjects were frequently judged as having moderate difficulties.

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The OSA subjects revealed differences from the normal population in the area of respiration (Goebel, 1992). Three respiratory tasks revealed inadequate performance: sufficient inhalation, duration of exhalation and maximum phonation time.

Nasalance was normal for the majority of subjects with both the Zoo Passage stimuli for (24) 69% of the subjects, and with the Nasal Sentence stimuli for (20) 57% of the subjects. This was followed by low nasalance for the next largest group of subjects. Vocal quality did not appear to be a large problem for those subjects showing normal abilities with s/z ratio (Hirano et al., 1968) and jitter (Kay Elemetrics). A majority of subjects, (25) 71% had lower fundamental frequencies than published norms (Fitch, 1990).

Oral motor abilities as a group were found to be in the normal range (18) 51% the majority of the time with the next largest percentage of subjects receiving scores below norm (11) 32%. However, combining normal and above normal abilities resulted in (24) 68% of the subjects falling in positive performance areas. The only notable swallowing finding was a delayed swallow for (12) 35% of the subjects when eating solids.

Follow-up Procedure Results

At the time of follow-up it was known what group, reference or CPAP, the subjects were placed in. There were 16 subjects in the reference group and 19 subjects in the experimental CPAP group. The reference group's mean age was 49.19, S.D. 8.65 with range of 37.03 – 65.10, whereas the CPAP groups mean age was 50.38, S.D. 14.33 with a range of 23.01 – 73.06. The BMI and AHI severity were similar for the reference group and the CPAP group. The BMI mean for the reference group was 34.94, S.D. 8.04, with a range of 23.74 – 57.66, whereas the BMI for the CPAP group was 38.20, S.D.

8.04, with a range of 23.74 – 48.92. A parametric t-test ($\alpha = .05$, df = 33) did not show a significant difference between the two groups. The AHI scores indicating the severity of the sleep apnea appeared to show higher scores for the CPAP group as a whole. AHI scores over 40 are considered to be severe. The AHI mean scores for the reference group were 47.65, S.D. 28.88, with a range of 11.2 – 96.0. The CPAP group had more severe AHI scores with the mean of 61.38, S.D. 29.91 and a range of 21.0 – 100.8. However, a t-test analysis ($\alpha = .05$, df = 33) showed no significant differences between the two groups. Both the reference and CPAP groups had the same basic characteristics.

Self-Perception Follow-up

All subjects participated in a second trial of the various communications and swallowing tasks. Subjects completed a questionnaire (Appendix B) which asked whether their abilities had stayed the same, were better, or were worse since the subject's initial participation. Further examination of the initial data revealed that there were differences between the group of subjects who would be in the reference and CPAP groups. The CPAP group had more frequent complaints than did those who would be in the reference group. Compared to the reference subjects, the CPAP subjects had more descriptions of problematic vocal tone (0% vs. 16%), impaired vocal quality (0% vs. 21%) and difficulty swallowing (19% vs. 26%). At follow-up there were also five questions asked; the questions included one on respiratory support for speech, speech production, voice quality, resonance and swallowing. Subjects rated their abilities compared to the initial session as unchanged 94% of the time or greater. The reference group rated themselves as having the same skill in all five areas 100% of the time. A number of subjects from the CPAP group (4) 21% reported improvements in three areas:

(2) 11% laryngeal vocal quality, (1) 5% resonance/tone of voice, and (1) 5% swallowing. The area of respiration for speech became worse for one person, 5% of the CPAP group.

Table 9 – Percentage of Subjects Self-Reporting Difficulties Across Various Categories, at Follow-up

Change	Respiratory N = 35	Speech N = 35	Voice N = 35	Resonance N = 35	Swallowing N = 35
Same	97%	100%	94%	97%	97%
Better	0%	0%	6%	3%	3%
Worse	3%	0%	0%	0%	0%

Clinician Perceptual Judgment Follow-up

On follow-up the four areas involving clinician perception continued to show that the majority of subjects had at least one or more areas that were judged to fall outside of the normal range (see Table 10). However, the areas judged perceptually had the most consistent and greatest change in the positive direction. The number of subjects that had all 4 perceptual areas (speech, voice, resonance, and swallowing) rated as normal improved nearly 5 times, moving from (2/34) 6% initially to (10/35) 29% at the time of follow-up. Notably the largest positive change occurred for the CPAP group moving from (0) 0% of the subjects receiving normal ratings in all four areas initially to (7) 20% receiving normal ratings at follow-up. Similar to the initial data collection, no subjects had abnormalities in all four perceptually rated areas. A chi square (x^2) analysis ($\alpha = .05$, df = 1) revealed no significant difference between the two groups when comparing the perceptual judgments.

Table 10 – Percentage of Subjects as Within or Outside of the Normal Range by Combined Perceptual Categories (Speech Production, Voice, Resonance, and Swallowing) at Follow-up

Groups	Initial N = 34				Follow-up N=35			
	All Normal Parameter	1 Abnormal Parameter	2 Abnormal Parameters	3 Abnormal Parameters	All Normal Parameters	1 Abnormal Parameter	2 Abnormal Parameters	3 Abnormal Parameters
Total	6%	41%	38%	15%	29%	20%	29%	23%
Reference	13%	31%	44%	13%	19%	19%	38%	25%
CPAP	0%	50%	33%	17%	37%	21%	21%	21%

When looking at the perceptual ratings area by area, the largest movement in judgments corresponded to changes in speech production (see Table 11). During the initial data collection the majority of subjects (22) 65% scored a 6, mild difficulty on the Functional Communication Measure – Speech Production (ASHA, 1995). At the time of the follow-up the majority of subjects (19) 54% scored a 7, normal. Both the reference and CPAP groups improved 19%. A chi square (x^2) analysis ($\alpha = .05$, df = 1) revealed no significant difference between the reference and CPAP group with regard to the perceptual ratings of speech production.

For the perceptual judgments of resonance (18) 53% of the subjects initially received a normal rating compared to (17) 49% receiving a normal rating at the time of follow-up. Shifts occurred with more individuals being rated in the hypernasal area scores of +1 and +2. There were no group changes observed in the areas of voice perception or swallowing as judged perceptually. For voice perception the majority of subjects scored a Functional Communication Measure of 7 - normal, during the initial (17) 50% and follow-up session (19) 54%. Swallowing results were the same for the initial and follow-up rating with (33) 94% of the subjects receiving a normal rating of 7 on the Functional Communication Measure – Swallowing.

Table 11 – Percentage of Subjects Scoring a 6 or 7 Rating on the Functional Communication Measure- Speech Production (FCM-SP), Initial and Follow-up Comparison

Subjects	Initial FCM-SP N = 34		Follow-up FCM-SP N = 35	
	Rating 6	Rating 7	Rating 6	Rating 7
Total	65%	35%	46%	54%
Reference	69%	31%	50%	50%
CPAP	61%	39%	42%	58%

Objective Data – Initial versus Follow-up

When comparing the total group's initial to final scores on the variables within the 5 main areas, a consistent pattern was observed. There was not one area where the trend changed significantly (see Table 12). Observation of the major areas (i.e., oral motor abilities, respiration, voice, resonance and swallowing) revealed respiration was consistently the measure falling most frequently outside of the normal range, followed by a split on the responses to the nasalance tasks. On the nasalance task the stimuli used affected the results with the subjects falling into the normal range or showing low nasalance, with infrequent scores of high nasalance.

Oral Motor Follow-up

Oral motor abilities, which are often associated with speech production, did not change for the total group. During the initial and follow-up session, (24) 68% of the total group of subjects were ranked as within or better than norm, and there were (11) 32% below norm. It was noted that there was an inversion of performance for the two groups, with the CPAP group initially placing more frequently at norm or better (14) 74% and reference group (10) 63%. However, at follow-up it was the reference group (12) 76% more frequently at norm and not the CPAP group (12) 64% (see Table 13). Chi –squared

Table 12 - Objective Data Comparison of Initial and Follow-up Results

Rating	Session	Abnormally Low	Normal	Abnormal High	Comments and Findings
OSMSE- R	Initial N = 35	32%	51%	17%	
	Follow-up N = 35	32%	57%	11%	
BGPM	Initial N = 33	18%	70%	12%	
	Follow-up N = 34	29%	65%	6%	
Sufficient Inhalation	Initial N = 33	97%	3%	NA	Low = % of time not reaching 60% of tidal volume X^2 NS
	Follow-up N = 32	88%	13%	NA	
Duration of Exhalation	Initial N = 33	30%	15%	55%	Low = short High = long
	Follow-up N = 34	26%	12%	62%	
Maximum Phonation Time	Initial N = 35	94%	6%	0%	
	Follow-up N = 35	86%	11%	0%	X^2 NS
Fundamental Frequency	Initial N = 35	71%	29%	0%	
	Follow-up N = 35	69%	31%	0%	X^2 NS
Jitter Perturbation	Initial N = 35	NA	89%	11%	Higher scores indicate difficulties X^2 NS
	Follow-up N = 35	NA	94%	6%	
S/Z Ratio	Initial N = 35	23%	51%	26%	Low scores indicate breathiness High scores indicate harshness
	Follow-up N = 35	34%	54%	11%	
Nasalance – Zoo	Initial N = 35	17%	69%	14%	
	Follow-up N = 35	26%	63%	11%	
Nasalance – Nasal	Initial N = 35	40%	57%	3%	
	Follow-up N = 35	37%	51%	12%	
Vocal Quality – Liquid	Initial N = 35	0%	100%	NA	Low = change in quality
	Follow-up N = 35	3%	97%	NA	

Continue Table 12

Rating	Session	Abnormally Low	Normal	Abnormal High	Comments
Vocal Quality – Solid	Initial N = 35	0%	100%	NA	
	Follow-up N = 35	0%	100%	NA	
Promptness – Liquid	Initial N = 35	NA	94%	6%	High = long
	Follow-up N = 35	NA	97%	3%	
Promptness – Solid	Initial N = 35	NA	65%	35%	High = long X^2 NS
	Follow-up N = 35	NA	80%	20%	

NA = not appropriate X^2 = chi squared NS = not significant

Analysis ($\alpha = .05$, df = 1) revealed no significant difference between the reference and CPAP group. Diadochokinetic rates at follow-up mirrored the initial results with a wide range of abilities and a similar number of subjects producing all repetitions of "puh", "tuh", "kuh", "puhtuh" and "puhtuhkah" at or above expected norms (St. Louis and Ruscello, 1987). Initially, (4) 11% of the subjects produced all 5 targets at or above norm on follow-up (5) 14% obtained this status.

Table 13 – Percentage of Subjects Scoring Below or at Norm or Better on the Oral Speech Mechanism Screening Examination (OSMSE-R) - Initial and Follow-up Comparison, Summary of the Reference and CPAP Groups

Subjects	Initial OSMSE –R N = 35		Follow-up OSMSE-R N = 35	
	Below Norm	Norm or Better	Below Norm	Norm or Better
Total	32%	68%	32%	68%
Reference	37%	63%	25%	76%
CPAP	27%	74%	38%	64%

Respiratory Follow-up

The same trend was noted on the initial and follow-up data for the total group for all the respiratory tasks (breath groups per minute, sufficient inhalation, duration of exhalation and maximum phonation time). Comparison of the data by reference and CPAP group was unremarkable for sufficient inhalation and duration of exhalation. Similar to the initial trials, on three of the four respiratory tasks the subjects showed abnormal performance, indicating reduced respiratory support for speech. For breath groups per minute, the both groups, reference and CPAP repeatedly showed a majority of subjects had abilities in the normal range. The CPAP group had more subjects in the normal category than the reference group at the time of both the initial and follow-up trials. In addition, there were changes made during the maximum phonation time task. There were a small number of subjects from the reference group (2) 13% that initially scored in the normal range at follow-up however, this doubled to (4) 25% in the normal range. By contrast, at follow-up; (19) 100% of the CPAP group remained below normal range for maximum phonation time (MPT)(see Table 14). At both sessions no individuals had MPT above norm.

Table 14 – Percentage of Subjects Scoring Within or Outside of Norm for Maximum Phonation Time (MPT), Initial and Follow-up Comparison

Subjects	Initial N = 35			Follow-up N = 35		
	<Norm	Norm	> Norm	<Norm	Norm	>Norm
Total	94%	6%	0%	89%	11%	0%
Reference	88%	13%	0%	75%	25%	0%
CPAP	100%	0%	0%	100%	0%	0%

Resonance Follow-up

The objective nasalance data showed the same trend for the large group during the initial and follow-up sessions as well as for the reference and CPAP groups (see Table 15). The majority of subjects had normal nasalance for both stimulus passages, followed by low nasalance scores. With the Zoo Passage, (24) 69% initially had scores in the normal range, and at follow-up there were (22) 63% of the subjects in the normal range. With the Nasal Sentences measure the majority of subjects performed within the normal range of nasalance, (20) 57% initially and (18) 51% at follow-up. The next largest group of subjects had low nasalance scores for both sets of stimuli. There did not appear to be a considerable difference between the reference and CPAP group for nasalance on the high pressure Zoo Passage. There was a trend of low nasalance for the reference group on the Zoo Passage at follow-up. Chi-squared analysis ($\alpha = .05$, df = 1) on nasalance data on the Zoo Passage and the Nasal Sentences both revealed no difference between the reference and CPAP groups. Thirty-two of the 35 subjects (91%) had similar data between the Low Pressure and Zoo Passage. This did not differ from the comparison initially of (34) 97%, indicating agreement between the scores received for two oral passages.

Table 15 - Nasalance Data Distribution, Initial and Follow-up Comparison

Subject	Initial N = 35						Follow-up N = 35					
	-3 S.D	-2 S.D	-1 S.D	Norm	+1 S.D.	+2 S.D	-3 S.D	-2 S.D.	-1 S.D.	Norm	+1 S.D.	+2 S.D.
Total Zoo	0%	0%	17%	69%	11%	3%	0%	0%	26%	63%	11%	0%
Reference	0%	0%	13%	75%	13%	0%	0%	0%	38%	65%	6%	0%
CPAP	0%	0%	21%	63%	11%	5%	0%	0%	16%	68%	16%	0%
Total Nasal	6%	11%	23%	57%	3%	0%	0%	11%	23%	51%	9%	3%
Reference	6%	6%	19%	69%	0%	0%	0%	3%	9%	62%	6%	0%
CPAP	5%	16%	26%	47%	5%	0%	0%	16%	26%	42%	19%	5%

Voice Parameters Follow-up

In two areas where quantitative voice measures were taken (i.e., jitter perturbation and s/z ratio), scores fell in the normal range at both the initial and follow-up sessions for the total group. The fundamental frequency data remained below normal for the majority of subjects. There was a slight movement to the normal range for subjects in the CPAP group at follow-up. This positive movement occurred for one female in the CPAP group (see Table 16). The jitter perturbation data did not differentiate between the reference and CPAP groups initially. However, upon follow-up the reference group demonstrated slight improvement toward norm while the CPAP group was unchanged (see Table 17). The s/z follow-up data had the same distribution as the initial data with the majority of the total group of subjects in the normal range. There were some differences between the reference and CPAP groups; however, the movement trend was the same. Initially and at follow-up the reference group was more pronouncedly placed in the normal range. At follow-up some movement to below the .8 level occurred, a finding that indicated the correlate of a more breathy voice for the reference subjects. The largest portion of the CPAP group (7) 37% initially were in the above normal range 1.3+; and upon follow-up after they had participated in the CPAP treatment, a greater number of CPAP subjects (11) 58% then placed in the normal range. Thus, both the reference and CPAP groups at the time of follow-up moved to lower ratio levels, possibly indicating more breathiness with their phonation (see Table 18).

Table 16. Percentage of Subjects Within or Outside of Norm for Fundamental Frequency, Initial and Follow-up

	Initial f_0		Follow-up f_0	
Subjects N= 35	Norm	Below norm	Norm	Below norm
Total	29%	71%	31%	69%
Reference	31%	69%	31%	69%
CPAP	26%	74%	32%	68%
Females	18%	82%	27%	73%
Males	33%	67%	33%	67%

Table 17. Percentage of Subjects Within or Outside of Norm for Jitter Perturbation, Initial and Follow-up

	Initial Jitter Perturbation		Follow-up Jitter Perturbation	
Subjects N = 35	Normal	Outside Norm	Normal	Outside Norm
Total	89%	11%	94%	6%
Reference	88%	13%	100%	0%
CPAP	89%	11%	89%	11%

Table 18. Percentage of Subjects Within or Outside of Norm for s/z Ratio, Initial and Follow-up

	Initial s/z			Follow-up s/z		
Subjects N = 35	Below Norm	Norm	Above norm	Below norm	Norm	Above norm
Total	23%	51%	26%	34%	54%	11%
Reference	13%	75%	13%	44%	50%	6%
CPAP	32%	32%	37%	26%	58%	10%

Swallowing Follow-up

There was no substantial change in the data for the total group from the initial to follow-up data gathering with regard to vocal quality or promptness of swallowing liquids. The same trend also emerged for the promptness of swallowing a solid, with the majority of subjects in both the reference and CPAP group showing timely swallows (22)

65% initially and (28) 80% at the time of follow-up. There were greater improvements within the CPAP group versus the reference group while both moved in a positive direction (see Table 19), chi-squared analysis ($\alpha = .05$, df = 1) revealed no significant difference between the reference and CPAP groups with the promptness of their swallowing solids.

Table 19 – Percentage of Subjects With Timely Swallowing of Solids, Initial and Follow-up Comparison

Subjects	Initial Timeliness of Swallow N = 34			Follow-up Timeliness of Swallow N = 35		
	Timely	1 sec	2 sec	Timely	1 sec	2 sec
Total	65%	29%	6%	80%	14%	6%
Reference	56%	38%	5%	69%	25%	6%
CPAP	72%	22%	6%	89%	5%	5%

Summary of Follow-up Data

Both groups started with similar baseline characteristics including body mass index and apnea-hypopnea index scores. The follow-up data revealed that self-perception of abilities and the objective data taken showed little change from the initial trends established for the total group. There was, however, a movement toward normal ratings for the stimuli judged perceptually by the speech clinicians. A closer look was taken of the differences between subjects in the reference group and those participating in the CPAP group when reviewing the follow-up data. A positive trend was noted during speech production judged perceptually, maximum phonation time, and the timeliness of the subject's swallow. The improvements were more frequently observed with the CPAP subjects. There were no significant differences between the reference and CPAP groups on

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on areas where additional statistical analysis was done. A review of the data by each individual subject revealed that most subjects stayed the same on tasks. However, there was individual variation in positive and negative directions with some individuals, but these were not sufficient to change the group means.

Chapter 4

DISCUSSION

This sample of obstructive sleep apnea patients is different from the nationally normal population in a number of communication areas. The difference is primarily noticeable in two areas of this study. The first is with the perceptual judgments made by the speech-language pathologist. The second is with the subjects' abilities, as recorded during the objective collection of data, in the major area of respiratory support for speech production.

A large percentage of the study population was judged as having mild communication deficits in speech, voice or resonance. Only (2) 6% of the 34 subjects had perceptual ratings that were normal in all four perceptual areas. However, there was a noticeable difference between patients' self-report of communication and swallowing abilities and the clinician's judgment. The majority of patients judged their abilities as normal 89% of the time or better in the communication areas and normal 77% of the time with swallowing. This may be due to the subtle communication deviations of the subjects at a time when the patient is focused on improvement in the soundness of their sleep and daytime alertness. The clinician providing the perceptual ratings for speech, voice and resonance did not have visual contact with the subjects. It is possible that the subjects' physical characteristics would have made the speech sample more acceptable to the clinician, thus creating the difference between the self-rating and clinician perception.

There are other reports citing that perceptual judgment of resonance only moderately correlate with nasalance measures (Dalston, R.M., Warren, D.W. and Dalston, E.T., 1991). This was true in our study as well. However, the deviant perceptual scores did parallel the deviant nasalance scores, but not always in the corresponding direction. For example, there were a higher percentage of low nasalance scores and a high number of hypernasal perceptual ratings, both ratings showing deviance. The mid-western sample used in this study should not present dialectical differences that would affect comparing this sample to published norms. Previously, an unpublished study on local nasalance norms showed that the published norms fit our normal subject population of adults (Parker, 1995).

Speech production was the area most often rated by the clinician judge as mildly impaired, this may relate to the more frequent oral narrowing and less flexible airways found in the sleep apnea population (Lowe, 1990; Sher, 1990). Oliver and Evans (1986) found speakers with a noticeable articulation deficit have a tendency toward having smaller oral dimensions than those individuals who have normal articulation. The subjects in this current study also may be similar to the subjects from the Ruscello, Tekieli, and Van Sickels, (1985) study, which showed 72% articulation errors before jaw surgery with improvement after surgery highlighting that abnormal oral structure can have an effect on articulation abilities. The current study supports the previous study by Monoson and Fox (1987) which found that 62%, the majority of sleep apnea subjects in their study, were judged as having abnormal speech. The perceptual findings in this study were also similar to the findings of Salas-Provance and Kuehn (1990) who found listener-judges were able to tell the difference between the reference (non-sleep apnea) subjects versus the UPPP subjects primarily in the areas of phonation and articulation.

The body mass of this population showed 98% of their BMI scores were above the normal range. There is an abundance of information in the literature demonstrating a connection between being overweight and many types of chronic disease including hypertension, pulmonary disease, cardiovascular disease and digestive deficits. There are also reports of a relationship between sleep apnea and high blood pressure, heart failure, heart attack, pulmonary difficulties, and stroke (Koskenvuo, Kapno, Partinen, Langinuainio, Sarna, and Heikkila, 1985, Waller and Bhopal, 1989). The question then emerges: are there typical communication and swallowing features that relate to increased weight? The decreased respiratory support for speech may indeed be related to the increased body mass of our subjects. The increased body mass may result in an overall decrease in their respiratory systems' capacity secondary to obstruction and bulk. The additional body mass may result in an overly stressed system with correspondingly less flexibility to control rapidly changing airway dynamics, especially with the overlaid function of voice production. Also, the instrumental equipment may have reduced capacity to work effectively with individuals of larger size secondary to the fit of the strain gauge, or decreased detection of movement for abdominal/thoracic excursion, often a sign of hypopneas.

Respiration is the foundation for speech, voice and resonance. Decreased respiratory support for speech may impact the intelligibility of the overall message by producing weaker endings for utterances or diminishing the crispness of certain sounds. None of our subjects' had above normal maximum phonation times this reveals an opportunity for further investigation. Maximum phonation time provides information on expiratory airflow during phonation requiring the upper airway to remain relatively open and unobstructed. Were the reduced maximum phonation times related to the large size of the subjects, and would a sample of OSA subjects with reduced size obtain similar results?

The sample studied mostly showed characteristics of normal voice. The perceptual difficulties noted with voice and the objective data indicating lower fundamental frequency and reduced length of non-vibratory/vibratory productions for this population may also be related to the reduced respiratory support and subject's increased size. The high number of subjects with low fundamental frequencies, especially in women, may be related to each subject's size and concurrent increased mass in the area of the vocal folds, causing slower vibrations and lower pitch. Because none of the subjects in this current study had above normal fundamental frequencies, additional investigation in this area would be beneficial. For example, the use of reading as a stimuli has demonstrated the most consistent measure of fundamental frequency and may provide additional information (Fitch, 1990). A study looking at fundamental frequency from a read sample, which is a more consistent measure (Fitch, 1990), may be helpful. Also, investigation of appropriate subgroups within OSA may provide additional insight. For example, subjects were not excluded from the study if they were smokers; this also may have had an impact on respiratory and voice measures. Smoking is an irritant to mucosal tissue and may cause redness, swelling and inflammation (Sataloff, 1991). The edema is thought to increase vocal fold mass and change the vibratory movement of the vocal folds. Information on smoking was gathered informally during the medical history interview; however, it was not specifically questioned. There were 5 self-reported smokers in our total group, 3 from the reference group and 2 from the CPAP group. There were 4 male smokers and 1 female smoker. Sorensen and Horii (1984) found a trend of lower fundamental frequencies, without statistical significance, with smokers versus non-smokers. This pocket of subjects showed some interesting trends. When reviewing data of these five subjects, it was found that they all had abnormal sufficient inhalation, duration of exhalation and maximum phonation times. Four out of five of these subjects had abnormal breath groups per minute. There was a strong tendency for abnormal respiratory findings from this subset. Another subset of OSA subjects would be those with gastroesophageal reflux disease (GERD). GERD is known to cause edema in the pharynx/larynx and to contribute to voice and swallowing disorders (Koufman, 1991).

Nasalance could be affected by increased body weight causing additional airway obstruction, especially in the oropharynx and nose area. This obstruction would typically result in decreased nasalance scores. The subjects in the study showed a mix of normal and low nasalance scores, an indication of obstruction. However, there was not a significant difference between the reference and CPAP groups. This current study supports the study by Salas-Provance and Kuehn (1990) who found aerodynamic measurements pre- and post-UPPP surgery used to estimate resonance did not change.

With regard to swallowing, there were two areas that revealed difficulties. The subjects (8) 23% self-rated themselves as having difficulty with swallowing. The second area was that (12) 35% of the subjects initially had delayed swallows with solids and (7) 20% at the time of follow-up. This was similar to findings by Zohar et al. (1998) which found longer oral transit times for OSA subjects compared to healthy subjects or those who have had UPPP intervention. The functional communication measure regarding swallowing and vocal quality judgment following eating and drinking were in the normal range. However, the swallowing assessments were not done during a contextual meal when a greater number of distractions occur and when there is less regulation of bite size and speed. Based on the overall clinical swallowing data, there may be a subset of the OSA population that may have mild swallowing difficulties. Further instrumental investigation would be warranted.

Of interest was a subgroup of 5 subjects with very high BMI scores all above 42 (falling in the very obese range 35+) and relatively low AHI scores falling below 32 (mild 10 – 19 and moderate 20 – 39). In addition to decreased maximum phonation times these subjects all showed abnormal speech production ratings as judged by a speech pathologist. Four out of the five also had decreased fundamental frequency and insufficient inhalation. These parameters may be fertile areas for further investigation of relationships between communication and increased weight.

An additional part of this study was whether the treatment of CPAP appeared to effect the communication and swallowing characteristics of the subjects. In most instances there did not appear to be a change after the CPAP treatment. This confirms the concept of a dynamic upper airway that is able to compensate for minor adjustments. There was a tendency for improvement in the area of voice and swallowing with CPAP use for a number of individuals. On follow-up there were (11) 58% of the individuals from the CPAP group were placed in the normal range with the s/z task, previously 32%. Improvement was noted in the promptness of their swallowing with solid foods for (4) 22% of the CPAP group. One possibility could be that with the shunting effect of CPAP, there was less repetitive vocal abuse occurring in the upper airway from snoring and obstructive sleep apnea. With CPAP forcing air through the nasal passage, there may be more warming and humidification of air than when the air passes through the oral cavity for obstructed non-CPAP breathing. A previous study has reported a decrease in gastroesophageal reflux with CPAP use, possibly due to a reduction in symptoms that may predispose individuals to nocturnal gastroesophageal reflux, e.g., lowered intrathoracic pressure, increased arousal and movement (Kerr, Shoenut, Millar, Buckle, and Kryger, 1992). Another study using MRI has shown that after CPAP use there is an increase in airway volume (Ryan, Lowe, Li, and Fleetham, 1991). Both of these studies may reflect a reduction in inflammation of the airway tissue. A reduction in inflammation may relate positively to better voice production and swallowing comfort and speed. A frequent anecdote from the CPAP subjects seen at the follow-up session was that they reported drinking a great deal of water to combat the dryness caused by the CPAP. This increase in hydration is a well-known and positive strategy for optimizing voice and keeping the upper airway healthy. More and more CPAP machines also feature humidification options. On the other hand, CPAP might increase evaporation so increased hydration might mean no net gain of hydration; there may even be a loss in hydration.

The speech-language pathologist's current caseload may have some individuals who have not been diagnosed as having sleep apnea, although signs and symptoms of sleep apnea may be present (e.g., self-report of snoring, daytime sleepiness, choking and awakening episodes at night). Knowledge of the signs and symptoms of sleep apnea can alert the speech-language pathologist to initiate counseling with their patient and make an appropriate referral to a specialist. Other health practioners would benefit from increased awareness of subtle communication and swallowing deficits with the sleep apnea population. However, with multiple medical co-morbitites their communication skills and swallowing may be a lower priority issue to individuals with obstructive sleep apnea.

Limitations of the Study

The subjects in this study were volunteers, thereby having a self-selection bias. Either those with more concerns about their communication and swallowing may have volunteered, or conversely those with high confidence in their communication and swallowing abilities may have participated.

The respiratory instrumental measures may be suspect because of the inconsistent placement of the strain gauge resulting from the girth of several of the subjects. The gauge was stretched to its maximum capacities at times and for one subject data were not collected because the strain gauge did not fit around the subject. Conversely, with increased body girth there could have been internal absorption of muscle movement by the surrounding body fat; therefore, the strain gauge did not sense the movement that may have occurred. However, non-instrumental respiratory measures such as maximum phonation time and sustained productions for [s] and [z] also demonstrated a reduction from normal for a majority of subjects. The clinical tasks supported the instrumental outcomes obtained with the strain gauge.

There were no controls made for the time of day during the experiment, as every attempt was made to accommodate the subject's schedules in order to gain their participation. However, there may be an effect related to the time of day the data were obtained. For example, many subjects had their initial testing done in the mid-evening and follow-up typically late afternoon or early evening. The amount of typical voice use may have been different for these subjects and possibly greater amounts of vocal fatigue at the initial testing.

Perceptual ratings of live voice instead of tape-recorded voice may also have resulted in different ratings. The visual observation of the subjects may have influenced the rating, as the size of the subject would have been taken into consideration. Additional raters would have strengthened the reliability of the ratings. Also, there may be a difference in the ratings if lay raters were used opposed to speech-language pathologists.

Data were not analyzed by age, and there may have been some contribution of aging to some of the measures taken such as fundamental frequency, maximum phonation time and other respiratory measures. Lynne-Davies (1977) reported respiratory changes with aging, including less stability, less elasticity of the system, less capacity and decreased muscle mass. Fundamental frequency lowers in females and increases in males with advanced age (Boone, Bayles, and Koopmann, (1982).

There may not have been a significant difference between the reference and CPAP groups on the communication or swallowing tasks because the length of time that the individuals were on the CPAP approximately 36 days was not a long enough time period to create the changes in these parameters. There may also have been uncontrolled variables (e.g., compliance with CPAP, trial of nasal strips, change in medications) that were unaccounted for with the subjects.

Areas to be Explored in the Future

A set of 5 individuals with high BMI scores and low AHI scores highlight the need for additional studies of speech and respiratory measures as they relate to size of an individual. Recall that this subset of 5 individuals was all rated as having reduced perceptual ratings in speech and decreased maximum phonation times.

The large number of subjects (24) 69% that did not pass the hearing screening provokes the question of whether individuals that are prone to snoring have an increased frequency of acquired loss of hearing. This population is known to have a high incidence of mouth breathers possibly resulting in Eustachian tube dysfunction. Complete audiological testing would be an area of follow-up that is warranted.

It would be interesting to explore the results of respiratory support exercises such as working on diaphragmatic breathing or adjusting volume to see whether there would be improved outcomes with this population. A protocol for muscle strengthening with OSA patients who are untreated or prior to the CPAP treatment option maybe beneficial for this population to further investigate the effects on resonance, voice and swallowing. Oral motor exercises that are tailored to strengthen the posterior tongue and palate are supported by the literature as interventions with positive outcomes. Kuehn (1991) uses nasal CPAP with contrasting oral and nasal sounds to strengthen the velopharyngeal muscles and assist with palatal closure when speaking. Wiltfang et al. (1999) found benefit to stimulation of the suprahyoid muscle on decreasing tongue collapse.

The relationship between CPAP use and hydration would also be important to test. This would enable health care practitioners to be in a better position to educate CPAP users on their need for fluids. Another interesting study would be the effect of introducing a hydration protocol with this population to determine whether there would be a positive impact on structure, physiological parameters, and voice.

More information on the relationship between communication (an activity that occurs when the individuals are awake), and changes in physiology with sleep is warranted. For example, does the sleep deprivation that occurs with OSA affect complex neural timing that may affect physiological function used during communication? Harrison and Horne (1997) found a reduction in word fluency and articulation/intonation changes following a night without sleep.

The group of sleep apnea individuals in this study revealed that there are differences with the communication abilities of those individuals with sleep apnea compared to normal references cited in the literature. In conclusion, this study accepted the null hypothesis that there would not be significant differences between the non-treatment (reference group) and CPAP treatment groups. Use of the CPAP does not significantly affect the communication and swallowing abilities of the subjects. There is a trend in the areas of resonance, voice and swallowing for improvement with CPAP use possibly because of the effects of decreased edema.

APPENDICES

APPENDIX A

Baseline Questionnaire

Subject No.:

Date:

Is your breath strong enough to support speech production (voice does not sound weak, there is enough air to produce a string of syllables)?

Yes No If no, explain:

Are all of your speech sounds pronounced clearly (without lisp, slurring, slowness, misarticulations)?

Yes No In no, explain:

Is the quality of your voice clear (without breathiness, hoarseness, strained quality)?

Yes No If no, explain:

Does the tone of you voice seem appropriate (without too much air coming out of your nose or sounding like you have a cold)?

Yes No If no, explain:

Do you swallow without difficulty (without coughing, choking, or frequent throat clearing, wet voice after swallowing, the feeling of something getting stuck in your throat)?

Yes No If no, explain:

Please add any descriptions you have about your speech, voice or swallowing?

APPENDIX B

Follow-up Questionnaire

Subject No.:

Date:

Have there been any changes in your respiration for speech?

Worse Same Better Please explain changes:

Have there been any changes in your pronunciation of sounds?

Worse Same Better Please explain changes:

Have there been any changes in the quality of your voice?

Worse Same Better Please explain changes:

Has there been any change in the tone of your voice?

Worse Same Better Please explain changes:

Have you had any changes in your swallowing abilities?

Worse Same Better Please explain changes:

If you have noticed any other changes in your speech, vice or swallowing please describe:

APPENDIX C

Functional Communication Measure:
Speech Production Disorder

Level 0	Unable to test
Level 1	Production of speech is unintelligible
Level 2	Spontaneous production of speech is limited in intelligibility. Some automatic speech and imitative words or consonant/vowel combinations may be intelligible.
Level 3	Spontaneous production of speech consists primarily of automatic words or phrases with inconsistent intelligibility.
Level 4	Spontaneous production of speech is intelligible at the phrase level in familiar contexts; out of context, speech generally is unintelligible unless self-cueing and self-monitoring strategies are applied.
Level 5	Spontaneous production of speech is intelligible for meeting daily living needs; out of context, periodic repetition, rephrasing, or provision of a cue is required.
Level 6	Spontaneous production of speech is intelligible in and out of context, but the production is sometimes distorted.
Level 7	Production of speech is normal in all situations.

APPENDIX D

Functional Communication Measure
Voice Disorder

Level 0	Unable to test
Level 1	Voice production (pitch, quality, loudness) is non-functional for communicating.
Level 2	Voice production is functional for brief episodes; most communication must be accomplished by non-vocal means.
Level 3	Voice production is unreliable, although some vocal communication may occur in limited contexts.
Level 4	Appropriate voice production is limited. Self-monitoring and self-correcting skills are inconsistent. Voice quality is distracting to most listeners.
Level 5	Appropriate voice production (pitch, quality, loudness) is consistent in most contexts. Self-correcting skills are used appropriately. Voice quality is distracting to some listeners.
Level 6	Voice production is appropriate in most situations, although minimal difficulty may occur.
Level 7	Voice production is normal for all speaking situations.

APPENDIX E

Resonance Scale

-2	Denasal
-1	Mild denasal
0	Normal Resonance
1	Mild hypernasal (sound specific)
2	Moderate hypernasal (intermittent)
3	Marked hypernasal
4	Severe hypernasal

APPENDIX F

Functional Communication Measure

Ability to Swallow Function

Level 0	Unable to test
Level 1	Swallowing is not functional.
Level 2	Swallowing disorder prevents eating for all nutritional needs, but some swallowing is possible.
Level 3	Swallowing disorder prevents eating for a portion of nutritional needs and one-to-one supervision is required for eating.
Level 4	Swallowing disorder does not prevent eating to meet nutritional needs, although general supervision is required to ensure use of compensatory techniques.
Level 5	Swallowing is functional to meet nutritional needs, although self-monitoring and compensatory techniques are used.
Level 6	Swallowing is functional for most eating activity, although mild difficulty may occur periodically; additional time may be necessary for eating.
Level 7	Swallowing is normal in all situations.

APPENDIX G Initial Raw Data

Subjects	Speech Reading - FCM	Speech Spontaneous – FCM	OSMSE R Structure	OSMSE R Function	OSMSE R Total	Breath Groups Per Minute	Percent Sufficient Inhalation	Duration Of Exhalation (Secs)	Voice Perception FCM	Voice Max Phonation Time (Secs)	Sustained S (Secs)	Sustained Z (Secs)	S/Z Ratio	Fo (Visipitch)	Jitter	Resonance Perceptual Scale	Zoo Passage Percentage	Nasal Sentences Percentage	Low Pressure Percentage	Liquid & Solid FCM	Change of Vocal Quality – Liquid	Change of Vocal Quality – Solid	Promptness of swallow- Liquid	Promptness of Swallow – Solid
1	7	7	31	24	55	12.0	79.2	4.4	7	12	11	11	1.0	179.00	.43	0	15.31	63.05	11.14	6	0	0	0	0
2	7	7	29	24	53	12.	4.3	4.3	6	11	12	14	.86	229.8	.593	2	12.14	43.54	12.	7	0	0	0	0
3	6	6	29	21	50	8.	93.3	6.1	6	22	20	21	.95	239.7	.294	0	8.54	57.53	9.64	7	0	0	0	1
4	7	7	27	21	48	20.5	21.1	2.3	7	24	20	30	.67	94.2	.568	0	11.54	59.78	16.98	7	0	0	0	0
5	7	7	29	24	53	14.5	86.2	3.8	7	28	16	40	.4	120.7	.326	0	8.17	56.33	9.45	7	0	0	0	1
6	6	6	31	24	55	37	101.	1.	6	14	28	20	1.4	192.8	.428	0	11.66	61.98	18.14	6	0	0	0	1
7	6	6	27	21	48	20.	65.8	2.5	7	29	28	30	.93	95.4	3.82	2	11.73	61.14	11.75	7	0	0	0	1
8	6	6	29	24	53	31.5	70.	1.2	5	25	27	25	1.08	103.2	.271	0	9.10	51.16	11.02	7	0	0	0	0
9	6	6	28	20	48	11.5	100.	4.6	6	24	22	18	1.22	104.3	.525	0	11.17	52.15	9.64	7	0	0	0	0
10	6	6	28	22	50	16.	25.8	3.3	7	13	26	22	1.18	90.1	.232	0	15.49	56.62	12.22	7	0	0	0	1
11	6	6	30	24	54	11.5	13.	4.5	6	23	25	20	1.25	170.8	.365	0	12.82	65.36	10.75	7	0	0	0	1
12	7	7	31	24	55	13.	50.	3.9	6	22	20	19	1.05	97.9	.607	0	13.63	48.33	18.92	7	0	0	0	2
13	6	6	29	21	50	15.	26.7	3.3	5	10	24	10	2.4	84.8	.533	2	16.34	55.85	15.64	7	0	0	0	0
14	6	6	30	22	52	14.	7.1	3.1	5	39	33	28	1.18	116.6	.827	2	24.11	65.19	22.8	7	0	0	0	0
15	6	6	30	24	54	27.5	50.9	1.8	7	21	22	22	1.0	146.5	.964	0	23.76	63.87	29.12	7	0	0	0	0
16	6	6	31	23	54	9.	100.	6.4	7	20	25	20	1.25	100.	1.45	0	12.54	61.69	15.86	7	0	0	0	0
17	6	6	25	22	47	*	*	*	6	16	17	25	.68	134.2	.340	2	15.65	49.72	17.11	7	0	0	0	0
18	7	6	31	24	55	13.	80.8	4.1	7	15	17	22	.77	114.7	1.2	0	9.14	53.87	9.29	7	0	0	0	0
19	*	*	30	23	53	21.5	72.1	1.7	*	15	18	9	2.	208.	2.89	*	20.28	67.62	17.82	7	0	0	1	1
20	6	7	28	24	52	12.	69.6	4.	7	16	15	19	.79	122.8	.381	2	8.59	45.39	7.28	7	0	0	0	0
21	7	6	29	23	52	19.5	105.6	2.5	7	28	27	30	.9	88.7	.867	2	14.54	55.86	14.26	7	0	0	0	0
22	6	6	30	24	54	9.	29.4	5.1	7	25	32	24	1.33	111.7	.338	2	13.57	46.25	11.76	6	0	0	0	0
23	7	7	28	23	51	14.	82.1	3.7	6	9	14	10	1.4	222.6	.371	2	10.72	50.64	7.3	7	0	0	0	0
24	6	6	26	22	48	15.	*	3.7	7	6	13	10	1.3	125.5	.798	2	28.99	68.17	26.36	7	0	0	0	0
25	7	7	28	23	51	18.	77.8	2.8	7	14	27	17	1.59	102.9	.219	2	14.43	33.29	13.74	7	0	0	0	0
26	7	7	31	24	55	23.	0.0	2.1	6	17	29	23	1.26	215.4	1.04	0	22.0	59.	29.83	7	0	0	0	0
27	7	7	28	24	52	12.5	48.	4.1	6	28	24	29	.83	99.	.651	0	8.19	56.54	7.48	7	0	0	0	0
28	6	6	31	21	52	33.	103.4	1.2	6	18	10	15	.67	140.1	.578	0	18.66	53.64	22.09	7	0	0	0	*
29	7	7	30	24	54	13.5	30.8	3.7	7	24	10	19	.53	171.8	.833	2	8.78	60.63	10.59	7	0	0	0	1
30	6	6	27	22	49	16.5	43.8	3.1	7	13	18	13	1.38	79.1	.588	0	7.19	53.05	7.33	7	0	0	0	0
31	6	6	30	23	53	17.5	17.6	2.1	7	13	32	18	1.78	195.8	.998	2	10.3	62.17	9.2	7	0	0	0	0
32	7	7	31	22	53	11.	95.5	3.8	6	29	41	32	1.28	103.1	.478	2	13.13	58.11	16.45	7	0	0	0	0
33	6	6	24	20	44	20.5	97.4	2.2	7	15	12	18	.67	117.3	.774	0	21.63	58.75	38.83	7	0	0	0	1
34	6	6	31	24	55	15.5	70.1	2.3	6	27	35	29	1.21	95.8	.953	2	9.96	58.34	10.79	7	0	0	0	1
35	6	6	30	21	51	14.5	100.	3.6	5	20	15	18	.83	207.5	1.26	-1	11.46	64.41	18.43	7	0	0	1	2

* Missing data point

APPENDIX H Follow-up Raw Data

Subjects	Speech Reading FCM	Speech Spontaneous FCM	OSMSE R Structure	OSMSE R Function	OSMSE R Total	Breath Groups Per Minute	Percent Sufficient Inhalation	Duration Of Exhalation (Secs)	Voice Perception FCM	Max Phonation Time (Secs)	Sustained S (Secs)	Sustained Z (Secs)	S/Z Ratio	Fo (Visipitch)	Jitter	Resonance Perceptual Scale	Zoo Passage Percentage	Nasal Sentences Percentage	Low Pressure Percentage	Liquid & Solid FCM	Change of Vocal Quality – Liquid	Change of Vocal Quality – Solid	Promptness of swallow- Liquid	Promptness of Swallow – Solid
1	7	7	31	23	54	13.5	7.4	3.1	6	16	9	10	.9	234.2	.395	2	11.2	59.13	11.75	6	0	0	0	0
2	7	7	29	24	53	8.	93.8	6.7	6	16	17	17	1.0	233.1	.233	2	11.13	49.13	11.46	7	0	0	0	1
3	7	7	29	23	52	7.	100.	7.7	6	24	25	22	1.14	213.8	.275	0	6.48	50.93	6.26	7	0	0	0	0
4	7	7	27	23	50	14.5	65.5	3.4	7	21	19	28	.68	101.3	.214	0	15.82	64.32	18.75	7	0	0	0	0
5	7	7	28	24	52	12.5	100.	3.9	7	36	14	38	.37	113.3	.324	0	7.31	56.31	5.61	7	0	0	0	1
6	6	6	31	24	55	27.	1.9	1.5	7	12	29	24	1.21	204.9	1.12	0	19.72	71.36	24.44	7	0	0	0	0
7	6	6	28	23	51	11.	86.4	4.7	6	29	24	23	1.04	95.1	.398	0	7.6	57.91	8.83	7	0	0	0	0
8	6	7	29	23	52	20	*	2.5	7	19	18	23	.78	143.5	.357	0	8.64	51.53	6.14	7	0	0	0	0
9	6	6	28	23	51	16.5	0.0	3.2	6	23	18	24	.75	122.8	.346	2	8.33	45.76	7.34	7	0	0	0	0
10	6	6	28	23	51	12.5	41.7	4.5	7	14	29	25	1.16	82.8	.179	0	12.9	58.49	12.77	7	0	0	0	2
11	6	7	30	23	53	11.	10.	4.6	6	26	19	26	.73	161.5	.168	2	5.09	58.49	5.14	7	0	0	0	0
12	6	6	31	24	55	15.	20.	3.5	7	17	17	17	1.0	103.7	.189	2	15.56	56.32	17.69	7	0	0	0	1
13	6	7	30	24	54	10.	100.	5.3	6	10	21	10	2.1	98.	.173	2	10.05	53.67	9.71	6	0	0	0	0
14	6	6	30	23	53	11.	13.6	4.7	5	35	37	39	.95	100.2	.581	2	19.43	64.92	19.65	7	0	0	0	1
15	6	6	30	23	53	21.5	46.5	1.8	6	20	13	22	.59	144.1	.221	0	25.61	65.44	36.21	7	0	0	0	0
16	6	6	31	22	53	11.5	82.6	4.5	6	29	20	29	.69	102.7	.472	1	18.42	65.41	21.02	7	0	0	0	0
17	6	6	27	22	49	*	*	*	6	18	13	26	.62	118.5	.539	2	12.13	54.12	16.63	7	0	0	0	0
18	6	6	31	24	55	18.	55.6	2.9	7	10	38	38	1.	138.4	.854	0	10.49	65.17	9.87	7	0	0	0	0
19	7	7	29	23	52	11.5	0.0	4.1	4	12	16	12	1.33	235.	2.2	2	26.34	70.03	23.59	7	0	0	0	0
20	6	7	28	23	51	12.5	0.0	1.1	7	19	22	19	1.16	108.5	.627	0	12.2	50.17	10.78	7	0	0	0	0
21	6	6	30	24	54	13.	75.	4.1	7	27	29	26	1.12	87.7	.317	0	9.98	61.14	11.7	7	0	0	0	0
22	7	7	30	24	54	7.	78.6	8.6	6	30	32	33	.97	113.1	.382	2	14.41	44.13	10.74	7	0	0	0	0
23	6	7	28	22	50	26.	*	1.6	7	8	10	12	.83	227.4	.368	2	12.94	67.98	10.53	7	0	0	0	0
24	6	6	26	23	49	14.5	13.8	3.5	7	11	10	10	1.	122.2	.714	2	22.68	68.82	19.14	7	0	0	0	0
25	7	7	28	24	52	20.50	80.5	2.3	7	12	23	18	1.28	105.0	.401	0	13.59	51.82	13.52	7	0	0	0	1
26	7	7	31	23	54	13.5	29.5	3.7	7	14	26	22	1.18	223.	1.35	0	11.44	49.66	10.0	7	0	0	0	0
27	7	7	28	24	52	13.5	61.5	3.7	7	21	15	22	.68	86.6	.864	0	4.94	48.07	4.36	7	0	0	0	0
28	6	6	31	17	48	43.5	147.4	.8	6	21	9	15	.6	128.	.889	2	11.12	51.12	26.77	7	0	0	0	0
29	7	7	30	24	54	12.	62.5	4.2	7	22	9	19	.47	183.4	.359	0	10.01	57.86	14.09	7	0	0	0	0
30	6	7	27	24	51	13.5	0.0	3.5	7	11	13	15	.87	92.	.191	2	11.37	54.77	12.38	7	0	0	0	0
31	7	7	30	24	54	17.5	34.	2.1	7	14	21	14	1.5	195.2	.917	0	8.72	67.16	6.71	7	0	0	0	0
32	7	7	30	24	54	13.5	84.	3.5	7	24	34	29	1.17	94.1	.557	0	20.7	66.9	20.19	7	0	0	0	0
33	6	6	24	22	46	21.5	102.4	1.1	7	9	19	16	1.19	124.6	.24	2	19.88	59.72	23.55	7	7	0	0	0
34	6	6	31	24	55	9.5	31.6	4.1	6	29	39	29	1.34	87.5	.501	1	7.78	58.98	10.14	7	0	0	0	0
35	6	6	30	19	49	17.	35.3	2.9	5	20	9	15	.6	221.7	1.19	1	21.78	75.72	32.47	7	1	0	1	2

* Missing data point

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