PERFORMANCE OF TYPICALLY DEVELOPING CHILDREN IN THE AGE RANGE OF 4-5 YEARS FOR SWALLOWING SOUND USING CERVICAL AUSCULTATION MODULE IN DIGITAL SWALLOWING WORKSTATION

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June, 2011

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CERTIFICATE

This is to certify that the dissertation entitled ***"Performance of typically developing children in the age range of 4-5years for swallowing sound using Cervical Auscultation module in Digital Swallowing Workstation"*** is the bonafide work submitted in part fulfillment for the degree of Master of Science (Speech-Language Pathology) of the student (Registration No.09SLP016). This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other university for the award of any other Diploma or Degree.

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CERTIFICATE

This is to certify that the dissertation entitled ***"Performance of typically developing children in the age range of 4-5years for swallowing sound using Cervical Auscultation module in Digital Swallowing Workstation"*** has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier in any other University for the award of any Diploma or Degree.

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DECLARATION

This is to certify that this dissertation entitled ***“Performance of typically developing children in the age range of 4-5years for swallowing sound using Cervical Auscultation module in Digital Swallowing Workstation”*** is the result of my own study under the guidance of Prof. R. Manjula, Professor of Speech Language Pathology, Dept. of Speech-Language Pathology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier in any other university for the award of any diploma or degree.

Mysore
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In the name of Allah, the most gracious and the most merciful

O my Lord, all praises be to You as it should be due to Your Might and the Greatness of Your Power.

Thank you Allah for all the blessings you showered on me….. BEST FAMILY……BEST FRIENDS…& FOR A WONDEFUL GUIDE….

DEDICATED TO…..

Ippa…..For all those times I left it unsaid…..Thank You..Thanks for being there for me…For showing me the way…..For being patient with me even when I made it difficult for you…For believing in me & encouraging me to dream and being such a inspiring presence in my life……Love u ippa……

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They are my most beloved friends…my brothers….Bibu and Babu…..thank you so much dears….love u both…

And ……

Teachers are those who use themselves as bridges over which they invite their students to cross, then having facilitated their crossing, joyfully collapse, encouraging them to create bridges of their own

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INTRODUCTION

Swallowing is a complex task where the food is propelled from the oral cavity to the stomach. The process of swallowing involves the coordinated action of different systems including neurologic, respiratory and gastrointestinal system. The anatomic areas involved in swallowing include the oral cavity, pharynx, larynx and esophagus. The act of swallowing includes four stages: Oral preparatory phase, oral phase, pharyngeal phase and esophageal phase.

The food which is taken into the mouth is manipulated into a cohesive bolus, and held there momentarily as it is prepared for transport. In the oral stage, the bolus is propelled posteriorly toward the oropharynx. As the bolus reaches the oropharynx, a pharyngeal swallow response is initiated, setting into motion a series of airway protective and bolus-propulsive events associated with the pharyngeal stage. The pharyngeal phase is characterized by velopharyngeal closure, inversion of the epiglottis over the laryngeal entryway, anterior and superior displacement of the hyolaryngeal complex, closure of the false and true vocal folds, progressive pharyngeal contraction, and opening of the upper esophageal sphincter and all these together protect the airway from food penetration. The esophageal phase is initiated by relaxation of the upper esophageal sphincter at the top of the esophagus that allows the bolus to begin its descent toward the stomach.

There is coordination between swallowing and respiration. The glottis is well sealed during the deglutition period. That is, respiration is arrested in the exhalatory phase for a fraction of a second and this is called ‘deglutition apnea’. At this point, to avoid the penetration of food into the airway leading to consequences such as aspiration etc, the air within the respiratory system is trapped and partially pressurized. The release of this partially pressurized air produces a small puff of air that is released immediately after the glottis is opened post swallow. This explains the functioning of glottis in its role as a mechanical safeguard during swallowing. Eibling and Gross (1996) have reported that positive subglottic pressure is required for an efficient swallow.

Overall, this chain of anatomical events if captured through sensitive tools will enable one to measure the ‘swallow sound’ as an acoustic event. Swallowing sound is typically heard during the pharyngeal phase of swallowing. Sounds of swallowing as detected by a throat microphone have been used in the past primarily to mark the occurrence of swallowing .The source of these sounds and what information the signals might contain about function is relatively unknown.

“Cervical auscultation” is a non invasive assessment method to analyze the sounds of swallowing. At its most basic level, the cervical auscultation technique can be used to document that a swallow has taken place (Perlman, Ettema, & Barkmeier, 2000). Cervical auscultation involves the placement of a stethescope or an acoustic detector unit (eg, accelerometer or microphone) onto the cervical skin in the region of the larynx. The acoustic signals are perceptually scrutinized by an examiner, if a stethoscope is used, or recorded onto audiotape, videotape, or a computer with an acoustic detector unit for later analysis. It offers a method for screening the pharyngeal phase of swallow.

A typical glottal sound is reported to have three main components (Hamlet, Patterson, Fleming, Jones, 1992):

- The first is a weak signal associated with laryngeal elevation and bolus flow through the pharynx;
- The second and the strongest sound is associated with the upper esophageal sphincter opening; and
- The third a weak component associated with to the laryngeal downwards movement after swallowing

Need for the study

Cervical auscultation is an assessment technique which is non invasive and requires limited patient cooperation. It provides clinicians with information regarding the swallowing status which in turn helps in understanding the diagnosis and in monitoring airway protection act or ‘deglutition apnea’ during swallowing. This in turn will help in understanding the status of swallowing act. However before the technique can be applied to clinical population, it is required to see the performance of typically developing children for swallowing sounds in different age groups as there is no literature on this issue. Most of the clients who seek rehabilitation for poor swallowing and oral motor issue fall in the age range of 4 -5yrs, and hence in this study, typically developing children in the age range of 4-5yrs were selected. The norms established in this age group will facilitate comparison of paediatric clients in the same age group who have swallowing abnormalities. The swallow process is different in dry and wet swallow conditions especially during the developmental period. Hence, it is postulated that the ‘swallow sound’ would also vary in parameters with respect to dry and wet swallow.

Besides this, establishing norms for ‘wet’ and ‘dry’ swallow will help to understand which task [dry swallow or wet swallow, (5ml or 10ml)] can be used as a sensitive stimuli for the assessment of young children.

Aim of the study

To analyze and compare the ‘swallow sound’ elicited in two tasks (dry and wet swallow) in typically developing children across:

a) Two age groups (4.0 to < 4.6 yr & ≤ 4.6 to 5.0yr)

b) Gender (males and females)

c) Swallowing task (dry and wet swallow)

Method

Sixty typically developing children in the age range of 4 – 5 years sub- divided into two age groups with 6 months age interval participated for the study (4.0 to < 4.6 yr & ≤ 4.6 to 5.0yr). Each group consisted of 30 participants with an equal number of males and females (15males and 15females). ‘Acoustic module’ of Digital Swallowing Workstation using cervical auscultation method was used to obtain the measure of interest in the study. Children were compared across age group, gender and swallowing tasks. Mean values were obtained for all the variables.

Implications

The implications of the study are as follows:

- The results of the study will provide insight about the 'swallow sound' and establish normative values for typically developing children in the age range of 4-5yrs.
- The results obtained from typically developing children can be used to compare with the pediatric clients with swallowing abnormality.
- The results also provide insight to the difference in the swallowing process in terms of dry swallow and wet swallow

Limitations of the study

The placement of the stethoscope to detect the swallow sound was based on the literature survey and decided on the thyroid lamina. More studies are required in this direction to verify if the 'swallow sound' characteristics are more robust when placed in other sites in the thyroid region.

REVIEW OF LITERATURE

Swallowing is a semiautomatic motor action of the muscles of the respiratory and gastrointestinal tracts that propels food from the oral cavity to the stomach (Miller, 1986). Swallowing involves a complex series of events which requires good coordination of the neurologic, respiratory and gastrointestinal systems.

The act of swallowing includes four phases 1) The oral preparatory phase 2) The oral phase of the swallow, 3) The pharyngeal phase and 4) The esophageal phase. The duration and characteristics of each of these phases depend on the type and volume of the food being swallowed and the voluntary control exerted over it. The frequency of swallowing varies with different activity. Swallowing frequency is greatest during easting and least during sleep with other activities, taking an intermediate place. Mean frequency of swallowing is approximately 580 swallows per day in a normal healthy adult. Records during sleep have shown periods of 20 minutes or more when no swallow occurs.

Swallowing and respiration are reciprocal functions; that is respiration is arrested during the pharyngeal phase of swallowing in humans irrespective of the ages including infants. Because of the reciprocal function, swallowing is described as an airway protective reflex.

Oral preparatory phase of swallow: Sensory recognition of food approaching the mouth and being placed in the mouth is critical before any oral preparatory movements can be initiated. Movement patterns in this phase vary depending on the viscosity of the material to be swallowed and the amount of oral manipulation the individual uses in savoring a particular food. This part of the swallow is voluntary. It is a mechanical phase that can be by-passed by dropping liquid or food into the back of the throat. In this stage, the food is chewed into smaller pieces and tasted. It is also mixed with saliva from three pairs of salivary glands, which are innervated by the glossopharyngeal nerve. The food and saliva form a bolus of material. The bolus is kept in the front of the mouth, against the hard palate by the tongue. The front of the tongue is elevated with its tip on the alveolar ridge. The back of the tongue is elevated and the soft palate is pulled anteriorly against it to keep the food in the oral cavity (the airway is open and nasal breathing continues during this phase). Labial seal is maintained to prevent food from leaking out of the mouth. Buccal muscles are tense. This prevents pocketing of food.

Oral phase of swallow: This phase is initiated when the tongue begins posterior movements of the bolus. It involves manipulation of food bolus and can employ lips, jaw, tongue, soft palate, muscles of mastication, and buccal muscles. This phase can be divided into 2 phases: initial transport phase where the tongue moves the bolus posteriorly until it is placed between the molars and the second phase, reduction phase where the bolus is chewed until it is made into small pieces and mixed with sufficient saliva to be swallowed. In humans, the reduction phase can be subdivided into a fast opening, fast closing and slow closing phase of mandibular movements. The fast opening stage occurs when the mandible descends; as the mandible ascends, the fast closing stage occurs and when the teeth begins to make contact with the food in preparation of the grinding process, the soft closing phase begins. Once the bolus has been adequately prepared and positioned on the tongue, the oral transport phase begins. In this phase, the velum elevates, the lips and buccal muscles contract, the posterior aspect of the tongue depresses, and the remainder of the tongue presses against the hard palate as it propels the bolus toward the oropharynx. The oral stage of the swallow typically takes less than 1 to 1.5 seconds to complete (Logemann, 1989, 1998; Dobie, 1978). It increases slightly as the bolus viscosity increases.

Triggering of the pharyngeal swallow: As the bolus is propelled posteriorly, sensory receptors in the oropharynx and tongue are stimulated sending sensory information to the cortex and brainstem. When the edge of the bolus or bolus head passes between the anterior faucial arches and the point where the tongue base crosses the lower rim of the mandible, the oral stage of swallow is terminated, and the pharyngeal swallow is triggered. If it is not triggered on time, the pharyngeal swallow is said to be delayed. As the pharyngeal swallow is triggered, the pharyngeal stage of swallowing is said to begin. The sensory portion of the pharyngeal swallow is carried by cranial nerves IX, X and XI. The motor portion is carried by nerves IX and X.

Pharyngeal swallow: This phase is dependent on the consistency of the bolus, the size of the bolus, and a single or continues event of swallow. The pharyngeal phase of swallowing involves the complex interactions of the tongue, velopharynx and larynx. The pharyngeal phase is characterized by velopharyngeal closure, inversion of the epiglottis over the laryngeal entryway, anterior and superior displacement of the hyolaryngeal complex, closure of the false and true vocal folds, progressive pharyngeal contraction, and opening of the upper esophageal sphincter and all these to protect the airway from food penetration.

Pharyngeal transit time: the time taken for the bolus to move from the point at which the pharyngeal swallow is triggered through the cricopharyngeal juncture to the esophagus- is normally one second or less. During this transit, the bolus moves smoothly and quickly over the base of the tongue through the pharynx and into the cervical esophagus. The purpose of epiglottis is to direct the food around the airway rather than over the top of the airway.

Esophageal phase of swallow: Esophageal transit time can be measured from the point where the bolus enters the esophagus at the cricopharyngeal juncture or UES until it passes into the stomach at the gastroesophageal juncture or LES. This time varies from 8-10secs. The peristaltic wave, which begins at the top of the esophagus, pushes the bolus ahead of it and continues in sequential fashion through the esophagus until the lower esophageal sphincter opens to allow the bolus to enter the stomach.

Variation in normal swallowing

Normal swallowing consists of different types of swallowing. The characteristics of the food are a major factor in making systematic changes in the oropharyngeal swallow (Logemann, 1998)

Volume effects: In general, changes in bolus volume create changes in the orpharyngeal swallow. A small volume swallow is characterized by oral phase, then pharyngeal triggering, the pharyngeal phase and then the esophageal phase. Whereas a large volume swallow is usually characterized by simultaneous oral and pharyngeal activity.

Increasing viscosity: As bolus viscosity increases, valve functions such as velopharyngeal closure, and upper esophageal opening and laryngeal closure, increases slightly in duration. The pressure generated by the oral tongue, tongue base, and pharyngeal walls increases, and muscular activity also increases.

Cup drinking: If it is sequential, there will be early airway closure and pre elevation of the larynx as the cup is approaching the lips with airway closure extending across all of the sequential swallows. The duration of airway closure on cup drinking may last from 5- 10 seconds, depending upon the number of consecutive swallows produced (Martin, Logemann, Shaker, and Dodds, 1994). The upper esophageal sphincter opens repeatedly as each bolus approaches.

Straw drinking: Here, the bolus is brought into the mouth via suction created in the oral cavity. Straw drinking is simply a way to modify food placement into the mouth.

If the suction is timed with inhalation, it is likely that the patient is straw drinking inappropriately with the airway open.

Coordination of Respiration and swallowing

In humans, the pharynx serves as a common pathway for swallowing and respiration. Several mechanisms minimize the risk of laryngeal penetration or aspiration. Swallowing results in reflex closure of the glottis which acts as a protective valve against the aspiration of foreign materials into the respiratory tract. Strong adduction of the true vocal folds is supplemented by the closure of the false cords and approximation of the aryepiglottic folds, although adduction of true vocal folds can alone stop the penetration into the trachea. The epiglottis contributes to the deflection of the bolus away from the laryngeal aditus into pyriform sinuses, from which it passes into the esophagus.

During swallow, the airway closes for a fraction of second. The airway, closure period, during swallowing is known as the apneic period. The apneic period usually corresponds to the closure of the airway during the pharyngeal phase of swallowing and the cessation of chest wall movement. The duration of the airway closure tends to increase as bolus volume increases (Logemann, Kahrilas, Lin, Pauloski, Cheng, & Rademaker, 1992). There is a predominant pattern of swallow respiratory coordination. Swallow interrupts the exhalatory phase of the respiratory cycle. Usually the individual returns to exhalation after swallow. By interrupting exhalation and returning to exhalation, the normal individual has a slight airflow through the larynx and pharynx after the swallow, which may help to clear any mild residue from around the airway entrance.

Preiksaitis, Mayrand, Robind and Diamant (1992) reported that at larger volumes, more swallows were preceded by inspiration. Infants are reported to take approximately 2-3 months to stabilize their swallow-respiratory coordination like that of adult pattern of swallow interrupting the exhalatory phase of respiration (McPherson, Kenny, Koheil, Bablich, Sochaniwskyj, & Milner, 1992). Eibling and Gross (1996) reported that the maintenance of a closed subglottic system permits pressure elevation which is key to swallowing efficiency. Restoration of positive subglottic pressure during swallowing enhances the velocity of swallowing.

Swallowing sound: its origin and characteristics

Swallowing sound is typically heard during the pharyngeal phase of swallowing. Overall chain of anatomical events during the pharyngeal phase if captured through sensitive tools will enable one to measure the ‘swallow sound’ as an acoustic event. Sounds of swallowing as detected by a throat microphone have been used in the past primarily to mark the occurrence of swallowing .The source of these sounds and what information the signals might contain about function is relatively unknown. The acoustic signature of the swallow is presented in terms of the (1) duration of the signal (2) frequency characteristics of the signal, and (3) amplitude of the waveform.

Lear, Flanagan, and Morrees (1965) suggested that swallowing sounds may arise from apposition and parting of the mucous membrane while the bolus flows into the pyriform sinus. This function may well contribute to generation of swallowing sounds. Mackowiak, Brenman, and Friedman (1967) suggested that the third swallow sound, present in a wet swallow, may be caused by movement of the epiglottis at the end of deglutition, or to movement of the lower esophagus as fluid approaches the cardioesophageal sphincter. Hamlet, Nelson and Patterson (1988) presented a theory of the physiologic cause of swallow sounds. They indicated that the most prominent acoustic feature of the swallow sound corresponded to movement of the bolus through the upper esophageal sphincter. They also postulated that a periodic noise component, in close proximity to the major sound burst, may be of laryngeal origin, whereas the remainder of the signal was aperiodic in nature. Hamlet, Nelson and Patterson (1988) further stated that mechanical movement of the hyoid, larynx, or epiglottis may also contribute to the acoustic signature of the swallow.

Heinz, Vice, and Bosma (1994) concluded that the acoustic signature of the swallow is composed of components that are tied to specific physiological events. Cichero and Murdoch (1998) have not only hypothesized the sources of these sounds based on their model, but have found support from studies that have used other technologies, namely manometry and VFSS. They conclude that the simultaneous closing of the laryngeal valve and the pressure of the tongue as it makes its first movement against the posterior pharyngeal wall produce the first swallowing sound. As was shown by Takahashi, Groher and Michi, (1994), elevation of the hyolaryngeal mechanism may also contribute to this peak. They believe that the second movement of the tongue against the posterior wall and the pharyngeal clearing wave combine to produce the second peak, one that is stronger and one that lasts longer than the first. Perlman, Ettema, and Barkmeier (2000) found that this second sound does not occur until the bolus is well into the esophagus and should not be construed as being due to bolus passage through the pharynx. Rather, Hamlet, Nelson and Patterson (1990) proposed that this point in the waveform reflects the onset of a pressurized flow of the bolus into the esophagus. Finally, if a third peak is noted, it may be due to an "un-valving" of the system at the conclusion of the swallow.

Cichero and Murdoch (1998) postulated the probable cause of swallowing sounds based on cardiac sound propagation theory, that swallowing sounds are generated via vibrations set up by pump and valve systems within the vocal tract. The cardiac analogy hypothesis presented is dependent upon two models—the cardiac model and the vocal tract model. The cardiac model suggests that the sounds arise from vibrations within closed cavities. The vocal tract model suggests that the perceptual characteristics of swallow sounds may change in accordance with alterations of the configuration of the pharynx, such as occurs during swallowing. By applying the knowledge that a change in configuration of the vocal tract during phonation causes a change in frequency and formant structure, it was hypothesized that a similar phenomenon may occur during fluid flow through the pharynx. The hypothesis further suggested anatomical sites and structures within the pharynx and larynx that act as pump and valve systems, strengthening the cardiac analogy. The cardiac analogy hypothesis was found to provide an explanation for both the propagation of normal swallowing sounds and potential causes of abnormal, or dysphagic, swallowing sounds. Propagation of normal and abnormal swallowing sounds was linked to the mechanism of sound propagation of normal heart sounds and heart murmurs.

Hamlet, Nelson, and Patterson (1988) recorded swallowing signals from a miniature accelerometer taped to the throat were recorded simultaneously with video fluoroscopic data taken while normal subjects swallowed small amount of liquid barium suspension and barium paste. The progress of the barium" bolus" could thus be followed radio graphically, and physical events in swallowing related in time to accelerometer signal characteristics. The most prominent signal feature is a relatively brief (200-ms) broadband noise that corresponds to the rapid passage of the bolus through the lower pharynx and cricopharyngeal sphincter in to the esophagus. The spectrum of the noise contains stronger high-frequency components for a liquid than for a paste swallow. In close temporal proximity to this noise component, or even mixed with it, is often a periodic signal that is in the frequency range of high-pitched phonation (approximately 500 Hz) that may be of laryngeal origin. Other low-amplitude signal features corresponded to structural movement of the hyoid/ larynx or epiglottis.

Several investigators have examined various parameters of swallowing using acoustic procedures (Logan, Kavanagh, & Wornall, 1967; Mackowiak, Brenman & Friedman, 1967). Recording the sounds produced during the swallow by placing a small microphone or accelerometer on the surface of the patient’s neck at various locations has helped in the identification of some repeated sounds produced in normal subjects (Hamlet, Nelson, & Patterson, 1990; Hamlet, Patterson, Fleming, & Jones, 1992). The “click” sound associated with the opening of the Eustachian tube and the “clunk” sound associated with the opening of the upper esophageal sphincter appear to be the most reliable sounds produced during swallowing. Hollshwandner, Brenman, and Friedman (1975) studied some temporal measures of swallowing, such as the time elapsing from the final chew of the swallowing cycle to the first sound of swallow, by attaching a contact microphone to the skin surface paralaryngeally. Though a number of other sounds have been recorded, the source of their generation however is not yet clearly identified.

Cichero and Murdoch (2002) investigated the acoustic characteristics of normal swallowing sounds for individuals from 18 to more than 60 years of age over a range of thin liquid volumes using cervical auscultation. Subjects were divided into three groups; Group I (18 to 35 yrs), Group II (36-59yrs) and Group III (60+). A microphone attached to a preamplifier which was fed the acoustic signal directly into the computerized speech laboratory (CSL- 4300, Kay Elemetrics) was used. The subjects were given 5ml, 10ml, and 15 ml of cordial respectively. Results showed that the swallowing sounds were distinguishable at all times. They were distinct more than 70% of the time for all volumes and for all groups and were distinct 90% of the time or more for the 15 ml bolus swallows. The duration of the swallowing sound was found to be approximately 0.4sec. The swallowing sound duration also varied as a function of bolus volume. Duration decreased as bolus volume increased. They also found a significant age-by-volume interaction (5-ml volume only). The youngest group recorded a swallowing sound duration of 0.377 second. This value was significantly shorter than that of the middle group (0.485) and that of the older group (.524 second). Very little variability was found between genders for swallowing sound duration (5-ml: women-0.46 second, men-0.45 second; 10-ml: women- 0.46 second, men- 0.44 second; 15-ml: women-0.41 second, men-0.38 second). In addition to the duration there was one more variable "location of the swallow peak" which refers to the time at which the swallowing sound reaches peak intensity. It was found that the location of the swallowing peak occurred uniformly 0.993 second after the beginning of the acoustic signal and 0.193 second from the beginning of the swallowing sound. It was stable across ages, genders, and bolus volumes. Swallowing sound intensity was found to be stable at 43 dB and was insensitive to age, gender, or bolus volume. No significant difference was found between genders. The study reported maximum frequency range of swallowing sounds to be at 5,900 Hz, with a mean frequency range score of 2,200 Hz. The female frequency range scores were comparable across bolus volumes, with a mean value of 2,297 Hz. The male frequency range volumes, however, differed depending on the volume of the bolus swallowed. The male frequency range for the 5-ml volume was significantly higher than both the 10-ml and 15-ml values.

Hamlet, Patterson, Flemming, and Jones (1992) found that a paste swallow was much shorter, approximating 250 milliseconds. Youmans and Stierwalt (2003) found the duration of puree and soft solids are not significantly different from liquids.

Morinie` re, Beutter, and Boiron (2006), studied the sound component duration of 30 adults (20 males and 10 females) while they ingested 10-ml of barium suspension. By using the numeric acoustic recording technique during swallowing, authors were able to identify and quantify the duration of the swallowing sound and the three main sound components within this sound in healthy subjects. No statistically significant gender difference in total swallowing sound duration or in the duration of the three main sound components was observed.

Origin of the sound components during pharyngeal swallowing in normal subjects (n=15, 10 men and 5 women) was studied by Morinie`re, Boiron, Alison, Makris, and Beutter (2008) using an X-ray camera connected to a video acquisition card to obtain synchronized acoustic–radiologic data (25 images/ s). They reported of three sound components based on the position of the bolus and the anatomic structure in movement: (1) the laryngeal ascension sound (LAS) when the sound component occurred during the ascension of the hyoid bone when the bolus was located in the oropharynx and/or hypopharynx, (average duration- 106 ± 47ms) (2) the upper-sphincter opening sound when the sound component occurred during the opening of the upper sphincter and the bolus was going through the sphincter (average duration- 185 ± 103ms), and (3) the laryngeal release sound when the sound component occurred during the descent and the opening of the pharynx and the larynx and the bolus was located in the esophagus (average duration- 72 ± 38ms).

Cagliari, Jurkiewicz, Santos, and Marques (2009) analyzed swallowing sounds by cervical auscultation using Doppler sonar, in a population between 2 and 15 years (which was divided into three age groups, 2-5yrs, 5-10yrs, 10-15yrs) without oro-pharyngeal dysfunction. Five variables were measured for each saliva swallowing effort and for the liquid and pasty substances:

- Sound wave initial frequency (FI): frequency at acoustic signal onset, with the frequency window between 60 and 12000Hz;
- Sound wave peak frequency (FP): frequency at the point of highest acoustic signal shift, with the aforementioned frequency window
- Sound wave initial intensity (II): intensity at acoustic signal onset, with the window between 10 and 100dB;
- Sound wave peak intensity (IP): intensity at the highest point of the acoustic signal shift, with the aforementioned intensity window
- Swallowing time (T): time between the beginning and the end of the analyzed acoustic signal, measured by means of an audio signal, in seconds

The authors reported that significance related to gender was found in certain age groups and consistencies, under all the studied variables, except swallowing time.

Methods of detecting swallow sound

Swallowing sounds can be detected by different procedures. The standard clinical examination of swallowing employs videofluroscopy. Other methods are also used for swallowing research and clinical assessment (ultrasonic scanning, scintigraphy, manometry). Auditory or automated acoustic analysis of swallowing sounds could become a useful noninvasive aid in alerting a clinician to the presence of swallowing dysfunction, or tracking its course in dysphagia treatment.

"Cervical auscultation" technique is a non invasive assessment method to analyze the sounds of swallowing. At its most basic level, the cervical auscultation technique can be used to document that a swallow has taken place (Perlman, Ettema, & Barkmeier, 2000). Cervical auscultation involves the placement of a stethescope or an acoustic detector unit (eg, accelerometer or microphone) onto the cervical skin in the region of the larynx. The acoustic signals are perceptually scrutinized by an examiner, if a stethoscope is used, or recorded onto audiotape, videotape, or a computer with an acoustic detector unit for later analysis. It offers a method for screening the pharyngeal phase of swallow. Cichero and Murdoch, (2002) have shown that cervical auscultation is a good measure for detecting swallowing sounds and also in determining the presence of dysphagia and the likelihood of aspiration. The authors also investigated the best placement of the acoustic detector unit for the detection of swallowing sounds and reported that, placement of the acoustic detector unit on the midline of the cricoids cartilage presented as the optimal site of placement because it is a prominent anatomical landmark. The cricoids may also have resonatory characteristics that enhance the recording of swallowing sounds.

Almeida, Ferlin, Parente, and Goldani (2008) assessed swallowing sounds by digital cervical auscultation in children in the age range of 3-11yrs.The study was performed on 118 (56 boys and 62 girls) children using a piezoelectric microphone. An acoustic detector and a preamplifier with filter connected to a computer were used for the cervical digital auscultation. The children were given 5ml of liquid and yogurt to swallow. Data from the swallowing sound signals were analyzed on the basis of visual and acoustic parameters (perceptual acoustic analysis). The components of perceptual acoustic analysis were identified on the spectrogram as 1) a discrete initial signal (DIS) preceding the main signal; 2) a main signal (MS) regarding the peak of swallowing signal determined from the energy profile, corresponding to the strongest point of the swallowing sound; 3) a discrete final signal (DFS) following the main signal; 4) an expiratory return (ER) with the signal returning to the baseline. The objective parameter of the swallowing sound signal analyzed was the duration (seconds), defined as the time elapsed between the first and the last markers of the swallowing sound. Results showed that the main component of the swallowing sound was a signal with high-frequency components in all children (100%). Discrete initial signal (DIS) was observed in 98 (83%) children and a Discrete final signal (DFS) in 83 (70%) children. Both these showed a low frequency component and were used as markers of initiation and termination of swallowing. The pattern of a complete swallowing signal composed of discrete initial signal (DIS) - main signal (MS) – discrete final signal (DFS) – expiratory return (ER) could be observed in 71 children (60%), and the absence of DIS, DFS, or ER was found in 40%. The mean duration of swallowing sound signal was 0.73±0.16 for liquid and 0.75±0.15 for yogurt. There was no significant gender difference either for liquid or yogurt. There was no correlation between age and duration of the swallowing sound for liquid or yogurt.

Changes in swallow sound with age

According to Dellow (1976), swallowing begins in the fetus, with sucking movements, drinking of amniotic fluid, and occasional presentation of thumb in the mouth. Swallow physiology in infants is quite different from that of adults. When sucking from a nipple, the infant repeatedly pumps the tongue (initially the tongue and jaw together), expressing milk from the nipple with each pump and collecting this liquid at the faucial arches (in front of the anteriorly bulging soft palate) or in the valleculae. Each infant tends to use a pattern of a particular number of tongue pumps predominantly, with some variability. Normal infants may use anywhere from 2 to 7 tongue pumps (Burke, 1977).

The pharyngeal swallow in the infant is similar to that of the adult with two exceptions. Laryngeal elevation is much reduced, since the larynx is anatomically elevated under the tongue base and does not need to move upward. In normal infants, the posterior pharyngeal wall is often seen to move much further anteriorly during swallow than is observed in adults. Once the infant moves to discrete swallows of soft foods, the oral and pharyngeal swallow physiology is similar to that of an adult, except reduced laryngeal elevation.

Studies have examined the structure and function of swallowing in normal aging adults (Blonsky, Logemann, Boshes, and fisher, 1975) and shown that some small significant changes in the physiology of swallowing occur until an individual reaches 80s. Some significant changes in oropharyngeal swallow physiology have been noted in normal individuals over age 60 (Robbins, Hamilton, and Kempster, 1992). Older individuals tend to more frequently hold the bolus on the floor of the mouth and pick it up with the tongue tip as the oral stage of swallowing is initiated. This stage is slightly longer in older adults as is the normal delay in triggering the pharyngeal swallow.

There is dearth of studies on children for swallowing sound and hence the current study was taken up with the aim of recording the performance of typically developing children between 4-5yrs for swallowing sound.

METHOD

Swallowing is a combined coordinated act of the muscles of respiration and oral/pharyngeal muscles facilitating propulsion of food into the esophagus and stomach. During swallowing the airway closes for a fraction of second. This airway closure period when the respiration is arrested is called as ‘apneic period’. The predominant pattern of swallow-respiratory coordination involves the swallow occurring in the exhalatory phase of the respiratory cycle. “Cervical auscultation” is a non invasive assessment method used to analyze the sounds of swallowing. This assessment technique provides clinicians with information regarding the swallowing status which in turn helps in diagnosing a swallow related dysfunction and in monitoring airway protection act or ‘deglutition apnea’ during swallowing.

The study aimed to analyze the performance of typically developing children between 4-5yrs for swallowing sound on ‘Cervical Auscultation Module’ of Digital Swallowing Workstation, Model 7120 by KAY PENTAX.

Aim of the study

To analyze and compare the ‘swallow sound’ elicited in two tasks (dry and wet swallow) in typically developing children across:

- Two age groups (4.0 to < 4.6 yr & ≥4.6 to 5.0yr)
- Gender (males and females)
- Swallowing task (dry and wet swallow)

Participants

Sixty typically developing children in the age range of 4-5 years participated in the study. Children were sub grouped into two depending on their chronological age. Group 1 (4.0 to < 4.6) included 15 males and 15 females. Group 2 (≥4.6 to 5.0) included 15 males and 15 females. The distribution of males and females across different age groups are depicted in Table 1

Table 1
Distribution of subjects across different age groups

Group	Age range (years)	Males	Females
1	4.0 to < 4.6	15	15
2	≥ 4.6 to 5.0	15	15

Inclusion of the participant in the study was based on the criteria that there should be:

- No history of swallowing disorders (based on parental interview)
- No structural and functional abnormalities in the structure of the oral cavity (based on the oro-sensory- motor examination)
- No maxillofacial or congenital abnormalities in the face and neck (based on clinical observation)
- No history of epilepsy or recurring epilepsy (based on parental interview)
- No complaint of hearing impairment (hearing screening test)
- No speech language delays (based on "Assessment checklist for speech and language domain – Phase 2" by Swapna, Prema & Geetha, 2010)

Informed consent was obtained from the teachers and the parents of the children, before including them in the study.

Instrumentation

Digital Swallowing Workstation, Model 7120 by Kay Pentax was used. This is a powerful, multi-functional system containing a robust set of features that have been integrated into one platform for the assessment of dysphagia clients and for research purpose. The Digital Swallowing Workstation has a physiologic data acquisition and visual feedback system which provides real-time displays of critical parameters related to swallowing function. Figure 1 shows the picture of Digital Swallowing Workstation.

Figure 1: Digital Swallowing Workstation

'Acoustic module' of Digital Swallowing Workstation using cervical auscultation method was used to obtain the measure of interest in the study. The stethoscope of the cervical auscultation module was used to record the swallow sound. This module was connected to the computer to detect the swallow sound produced during ‘dry swallow’ and ‘wet swallow’. ‘Cervical auscultation’ is a non invasive examination that is useful in monitoring the swallowing. As a screening procedure, cervical auscultation can be used to determine the presence of oro-pharyngeal dysphagia and the likelihood of aspiration. Cervical auscultation procedure involves the placement of a stethoscope or an acoustic detector unit (accelerometer or microphone) on the thyroid lamina of the larynx. It offers a method of screening the pharyngeal phase of swallow.

Materials

The materials used to assess wet swallow was:

- Measuring cup
- Purified water (thin liquid)

Procedure

Preparation of the participant:

After an explanation of the procedure, the child was made to sit comfortably on a chair. The stethoscope of the cervical auscultation module was placed on the lateral side of the thyroid notch (reported to be the best site in literature) by the investigator. Initially the child was instructed to swallow the saliva to locate the best site for the placement of the stethoscope. Once the site was identified, it was cleaned with alcohol wipe. Child was also instructed not to move his head during the procedure. Child was told to raise his hand if he feels any discomfort while swallowing.

The specific swallowing tasks recorded for each participant were as follows:

Dry swallow: defined as the swallow that involves no ingestion of external food or liquid. Each participant performed one dry swallow. The child was instructed to swallow his/her saliva as normally as possible without any extra effort.

Thin liquid swallow (wet swallow): defined as swallow involving ingestion of water. Swallows were obtained for two volumes of purified water (5ml and 10ml) and for each volume two recordings were obtained.

Water was given through the measuring cup and the child was instructed to swallow as normally as possible. In both the dry and wet swallow phase of the data collection, the participants were requested to swallow in one complete action and only once per recording. Practice trials were given to the participants to familiarize with the task.

Recording:

After preparing the participant by placing the stethoscope of the cervical auscultation module on the lateral side of the thyroid notch, the module was activated for recording the swallow sounds on the computer of the Digital Swallowing workstation. The setting and window resolution was maintained for all recordings across participants, as 8 seconds on the time scale with a sampling rate of 1000 Hz and display scale of 0 to 100microvolt.

Child was given 5ml water in the measuring cup and instructed to swallow only when the investigator indicated to him/her to do so. The swallowing sound was recorded by activating the recording mode of this module and the waveform was saved. The procedure was repeated 2 times and then two waveforms were stored. At a later time the investigator chose the good recording which was free of artifacts and had non distorted wave morphology. For the 10 ml volume and the dry swallow, the same procedure was followed. The order of recording of wet and dry swallows was randomized across participants to counter the order effect. Figure 2 shows the waveform of sa single swallow sound

Figure 2: waveform of a single swallow sound

Analysis

Each of the 'swallow sound' recorded for each participant in two different conditions (wet and dry condition) at each volume was observed by the investigator by visualizing the acoustic waveform.

The following parameters of the 'swallowing sound' signal were noted and analyzed for each of the selected sample:

- Duration in millisecond from initiation to termination of the swallow/glottal sound.
- Minimum amplitude of the sample (in microvolt)
- The peak amplitude (microvolt) indicating maximum protective closure (as an airway protective act).
- Mean amplitude in microvolt
- The slope of the swallow sound in terms of microvolt/second.

- The area under the amplitude - time curve (microvolt/ssecond)

Statistical analysis

The raw data was treated statistically using SPSS version 17.0 and analyzed to compare the acoustic feature of ‘swallow sound’ across selected age groups and conditions of swallow.

RESULTS AND DISCUSSION

The study was undertaken to analyze the performance of typically developing children between 4-5 yrs for ‘Swallowing sound’ using ‘Cervical Auscultation’ module in Digital Swallowing Workstation. A total of sixty children participated in the study in the age range of 4-5 yrs which were subdivided into 2 age groups (4.0 to < 4.6 and ≤ 4.6 to 5.0). Each group consisted of 30 participants with 15 males and 15 females in each group.

Aim of the study

To analyze and compare the ‘swallow sound’ elicited in two tasks (dry and wet swallow) in typically developing children across:

- Two age groups (4.0 to < 4.6 yr & ≤ 4.6 to 5.0yr)
- Gender (males and females)
- Swallowing task (dry and wet swallow)

The results of the study are presented and discussed under the following headings for all the variables (Duration of swallow sound (s), Minimum amplitude (mV), Maximum amplitude (mV), Mean amplitude (mV), slope of the swallow sound (mV/sec) and area under amplitude- time curve (mV sec))

- Comparison across age groups (4.0 to < 4.6 yr & ≤ 4.6 to 5.0yr)
- Comparison across gender (males and females)
- Comparison across swallowing tasks (dry and wet swallow)

- Overall performance of typically developing children between 4-5yrs across different measures.

Mean and standard deviation was obtained for each swallowing tasks for both age group and for both males and females. The same is shown in Table 2

Table 2

Mean and standard deviation of swallowing tasks across age group and gender

Swallowing tasks	**Parameters**	**Male**		**Female**	
		Group 1 (4.0 to < 4.6)	Group 2 (≤ 4.6 to 5.0)	Group 1 (4.0 to < 4.6)	Group 2 (≤ 4.6 to 5.0)
		Mean (Standard deviation)			
Dry	Duration	0.13 (0.19)	0.08 (0.03)	0.07(0.04)	0.08 (0.02)
	Min. Amp[a]	-5.05 (3.48)	-7.21 (6.11)	-7.84 (7.61)	-6.75 (6.23)
	Max. Amp[b]	11.67 (27.40)	6.02 (6.88)	8.15 (6.52)	6.73 (8.12)
	Mean Amp[c]	-0.56 (1.00)	-0.79 (1.21)	-0.44 (1.97)	-1.22 (1.79)
	Slope[d]	-35.10 (59.60)	-28.19 (30.76)	-83.41 (79.63)	-15.91 (50.98)
	Area[e]	0.02 (0.09)	0.09 (1.44)	-0.09 (3.67)	-0.06 (0.10)
Wet (5 ml)	Duration	0.07(0.03)	0.07 (0.03)	0.08(0.03)	0.07 (0.01)
	Min. Amp[a]	-6.06 (3.82)	-8.54 (9.64)	-9.78 (7.03)	-10.10 (9.91)
	Max. Amp[b]	8.13 (8.05)	9.75 (7.79)	8.00 (5.94)	9.58 (8.82)
	Mean Amp[c]	-1.04 (2.08)	-1.44 (1.90)	-1.00 (2.56)	-1.27 (2.37)
	Slope[d]	-57.32 (98.91)	-10.19 (17.21)	-35.07 (65.07)	-28.17 (78.84)
	Area[e]	-0.02 (0.31)	-0.04 (0.21)	-0.07 (0.15)	-0.09 (0.17)
Wet (10 ml)	Duration	0.10 (0.09)	0.07 (0.03)	0.06 (0.02)	0.05 (0.02)
	Min. Amp[a]	-6.39 (6.24)	-9.25 (11.46)	-10.70 (9.37)	-12.60 (8.82)
	Max. Amp[b]	7.74 (5.12)	8.87 (6.52)	10.48 (10.04)	11.41 (8.74)
	Mean Amp[c]	-1.49 (1.37)	-1.14 (3.46)	-1.09 (2.01)	-2.23 (3.18)
	Slope[d]	-66.91 (98.64)	-35.49 (25.79)	-98.01 (56.07)	-73.48 (79.83)
	Area[e]	-0.05 (0.16)	-0.04 (0.15)	-0.01 (0.15)	-0.15 (0.17)

Note: a=Minimum amplitude. b=Maximum amplitude. c=Mean amplitude. d=Slope of the swallow sound. e=Area under the amplitude time curve.

In the dry swallow task, no difference in the duration of swallow sound in each age group across both genders was evident. In general however, duration of swallow sound was higher in males in group 1 (4.0 to < 4.6) compared to males in group 2 and females in both the group. In order to verify if the difference seen were statistically significant, two way analysis of variance was carried out and the difference obtained were not statistically significant (p=0.144). Table 2 shows that the values obtained for minimum amplitude, maximum amplitude and mean amplitude of the swallow sound doesn't show much difference between each. This was statistically verified using two way analysis of variance. Maximum amplitude was higher for males in Group1 compared to males in Group 2 in dry swallow task. But the difference obtained is not statistically significant (p=0.852). There was not much difference between two age groups in females and also when compared to males in both age groups. In case of area under amplitude curve, the mean scores obtained between males and females in both the groups and for all condition were slightly different.

Two way analysis of variance was performed to compare between wet swallow of 5 ml and 10 ml across age group and gender. In wet swallow task, for 5ml volume, the duration of swallow sound did not show any significant difference (p=0.144). The mean duration was 0.07(sec) for both males and females in each group. There is no significant difference between the scores obtained for minimum amplitude (p=0.070), maximum amplitude (p=0.700), mean amplitude (p=0.243), slope (p=0.067) and area (p=0.124) of the swallow sound. For 10ml volume also, there was not much difference between any of the parameters. (duration, minimum amplitude, maximum amplitude, mean amplitude, slope and area)

In both the swallowing tasks (dry swallow and wet swallow (10ml)) duration of the swallowing sound was higher in males of the Ist age group (4.0 to < 4.6). The general trend observed was that it was higher for dry swallow compared to wet swallow. In case of other parameters, scores were variable across age group and gender.

I. Comparison across age group

Children in both age groups (4.0 to < 4.6 and ≤ 4.6 to 5.0) were compared across swallowing tasks. Interaction of age group with gender and swallowing tasks were also carried out.

Two way repeated measure ANOVA was carried out to check the interaction of age group, gender and swallowing tasks for all the measures (Duration of the swallow sound, minimum amplitude, maximum amplitude, mean amplitude, slope of the swallow sound and area under the amplitude-time curve). Results of the statistical analysis revealed that there was no significant interaction between age group and gender, age group and swallowing and age group, gender, swallowing tasks for all the measures ($p > 0.05$). Hence the data was verified with MANOVA to compare between two age groups across the swallowing tasks [dry swallow and wet swallow (5ml and 10ml)] for all the measures. Results revealed that there was no significant difference between age groups for any the six measures ($p > 0.05$).

In the study, the age group considered was 4-5yrs with a six months age interval. Since the age group considered in the study is in the prepubertal period, there may not be any gross structural or functional changes/ growth happening in the oropharyngeal structure. So within the six months gap between each age group, there may not be any significant anatomical or physiological changes taking place in the swallowing mechanism which would probably be the reason why there is not much of a difference between the two age groups of 4.0 to < 4.6 yrs and ≤ 4.6 to 5.0 yrs.

Results of the present study is in consonance with the observation of Almeida, Ferlin, Parente, and Goldani (2008) where the authors have assessed the swallowing sounds using digital cervical auscultation method in children between 3-11 yrs of age (total 140 children participated in the study with 56 boys (mean age, 7.29 ± 0.26yrs) and 62 girls (mean age, 6.60 ± 0.25yrs). In their study they have compared the swallow sound between 5ml of liquid swallow and swallow for thick liquid like yogurt. Results of the study showed that there was no correlation between age and duration of the swallowing sound for 5ml of liquid ($p = 0.247$) and yogurt ($p = 0.351$).

Contradicting findings were reported in adult population by Cichero and Murdoch (2002) where they have compared across three different age groups (Group 1 included 10 men and 10 women in the age range of 18-35 yrs with a mean age of 25.2 yrs, Group 2 included 10 men and 10 women in the age range of 36-59 yrs with a mean age of 46.8 yrs and Group 3 included 10 men and 9 women in the age range of 60+ with a mean age of 67.3 yrs. Three volumes (5 ml, 10 ml, and 15 ml) were considered in this study. The authors noted age specific patterns in the study. In case of group 1, the duration for 10 ml was significantly longer than 5 ml or 15 ml scores. For group 2, the swallow duration for

15 ml was significantly shorter than either 5 ml or 10 ml trials and for the third group, the swallowing sound duration for 5 ml was significantly longer than for 10 ml or 15 ml. So there was a volume by age interaction noted in case of adults.

II. Comparison across gender

Two way repeated measure ANOVA was carried out to compare the 'swallow sound' measures between genders (male and female), to check the interaction between gender and age, gender and swallowing tasks and gender, age, swallowing tasks. Results of the statistical analysis revealed that there was no significant difference between gender for any of the measures. No significant interaction was also noted between gender, age and swallowing tasks. ($p > 0.05$).

No difference in the swallowing sound was observed for any of the parameters in case of males and females and this may be attributed to the fact that, the majority of facial growth and development of structures involved in swallowing does not occur during the prepubertal period. So there may not be any structural or functional differences in the swallowing mechanism for both males and females during their developmental period which will support the result of the present study.

Similar findings were noted in the study by Almeida, Ferlin, Parente and Goldin (2008) where they compared across gender for swallow sound and they found that there was no significant difference between genders for 5ml of thin liquid ($p = 0.327$) and semi thick liquid such as Yogurt ($p = 0.792$) in children. Cagliari, Jurkiewicz, Santos, and

Marques (2009) analyzed swallowing sounds using cervical auscultation method on children aged 2 to 15yrs who were subdivided into three age groups (Group 1: 2-5yrs, Group 2: 5-10yrs and Group 3: 10-15yrs) and each group included 15 males and 15 females. The authors had considered five variables (Sound wave initial frequency, sound wave peak frequency, sound wave initial intensity, sound wave peak intensity and swallowing time) and measured across three conditions, that is, for dry swallow, liquid and pasty substances. The authors reported significant differences between gender for each age group and for all variables except swallowing time ($p < 0.05$).

On similar lines Cichero and Murdoch (2002) investigated the acoustic characteristics of swallowing sounds on adult population and the authors noted very little variability between genders for swallowing sound duration (5-ml: women-0.46 second, men-0.45 second; 10-ml: women- 0.46 second, men- 0.44 second; 15-ml: women-0.41 second, men-0.38 second). Morinie're, Beutter and Boiron (2006) studied the sound component duration of 30 adults for 10ml of barium suspension. No statistically significant gender differences in total swallowing duration were noticed.

III. Comparison across swallowing tasks

Two swallowing tasks were considered in the study: dry swallow and wet swallow. In wet swallow two volumes were taken: 5ml and 10ml. The swallowing tasks were compared across each other using one way repeated measure ANOVA. The swallowing tasks were compared across each age group. Results of the statistical analysis revealed no significant differences between swallowing tasks and between two volumes (5ml and 10ml) ($p > 0.05$).

The result of the present study is in consonance with the study by Cichero and Murdoch (2002), in adults where the authors considered three volumes (5ml, 10ml, and 15ml) and findings revealed no significant differences between three volumes in terms of duration ($p>0.05$). Almeida, Ferlin, Psarente and Goldani (2008) reported a study in children of 3-11yrs where 5ml of liquid and 5ml of yogurt were given and the swallow sound duration for these food consistencies were compared. The authors reported no significant difference between food consistencies ($p=0.189$).

IV. Overall performance of typically developing children between 4-5 yrs across different measures

The difference between the age groups and gender was not statistically significant (Group 1: 4.0 to < 4.6 yrs, n=30 & Group 2 ≤ 4.6 to 5.0 yrs, n=30), the two groups were combined (n =60) for further statistical comparison and interpretation. Mean and standard deviation were obtained for all the six measures for all the participants in the age range of 4-5yrs and the same is shown in Table 3

Table 3

Mean and standard deviation of the test parameters of the swallow sound

Conditions	Duration	Min Amp[a]	Max. Amp.[b]	Mean Amp.[c]	Slope	Area
Dry	0.09	-6.71	9.91	-0.43	-33.59	-0.10
	(0.10)	(5.93)	(14.83)	(1.62)	(100.60)	(2.19)
5ml	0.07	-8.62	8.87	-0.42	-32.82	-0.04
	(0.03)	(7.94)	(7.57)	(2.37)	(105.01)	(0.214)
10ml	0.08	-9.74	9.62	-0.95	-28.68	-0.06
	(0.03)	(9.22)	(7.77)	(2.72)	(101.07)	(0.23)

Note: a=Minimum Amplitude. b= Maximum amplitude. c=Mean Amplitude

Mean amplitude

Mean values for amplitude of the swallow sound is shown in Figure 3 for both conditions swallowing tasks

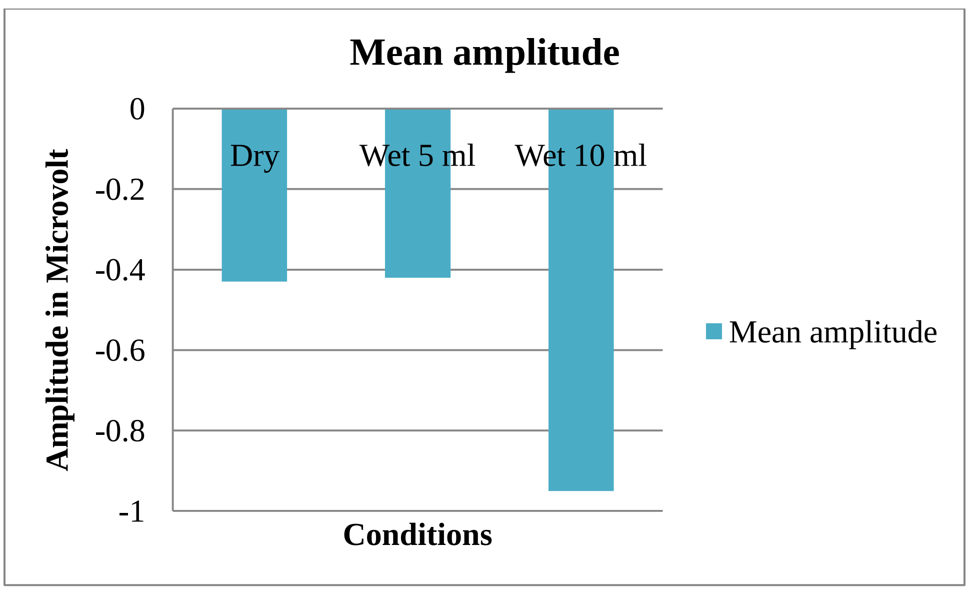

Figure 3: Mean values for the amplitude of swallow sound

The scores obtained for the mean amplitude of the swallow sound is shown in figure 6. The mean amplitude of swallow sound for dry swallow and 5ml water did not vary much. The scores obtained for mean amplitude for 10 ml of water was higher compared to 5 ml. As the volume increased, the mean amplitude also increased. This leads one to infer that probably a wet volume of more than 10 ml may elicit higher mean amplitude.

Minimum amplitude

Mean value of the minimum amplitude of the swallow sound is shown in Figure 4 for both swallowing tasks.

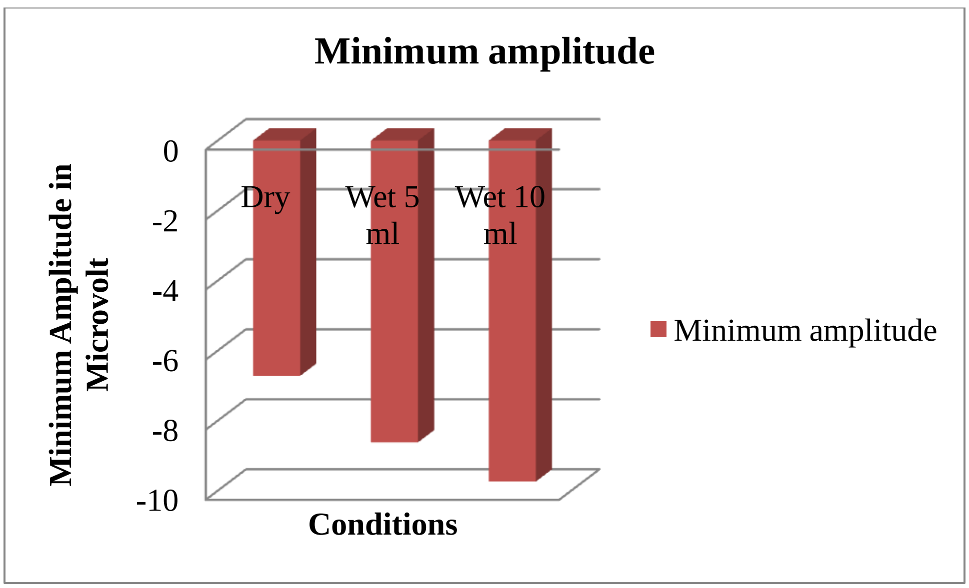

Figure 4: Mean value for the minimum amplitude of the swallow sound

Minimum amplitude reflects the initiation of the swallow process or the onset of the swallow sound. The values obtained for minimum amplitude of the swallow sound in dry swallow was less compared to 5 ml and 10 ml wet swallow. In case of two wet volumes, 10ml scores were higher compared to 5 ml. It can be inferred that, in case of dry swallow wherein saliva was swallowed, more effort was put into swallowing compared to the wet swallow condition. As there was no ingestion of food material, dry swallow seems to be a more effortful swallow. The lesser amplitude shown can be because of the longer duration taken to initiate the swallow. In case of wet swallow, the transition seems to be more quick compared to dry swallow and when the volume is larger (10ml), the initiation is much easier than in reduced volume (5 ml) condition.

Maximum amplitude

Mean value for the maximum amplitude of the swallow sound is depicted in Figure 5 for both swallowing tasks. Mean scores are higher for dry swallow compared to 5 ml and 10 ml wet swallow condition. In case of both the wet volumes, 10 ml swallow elicited greater value of maximum amplitude compared to 5 ml.

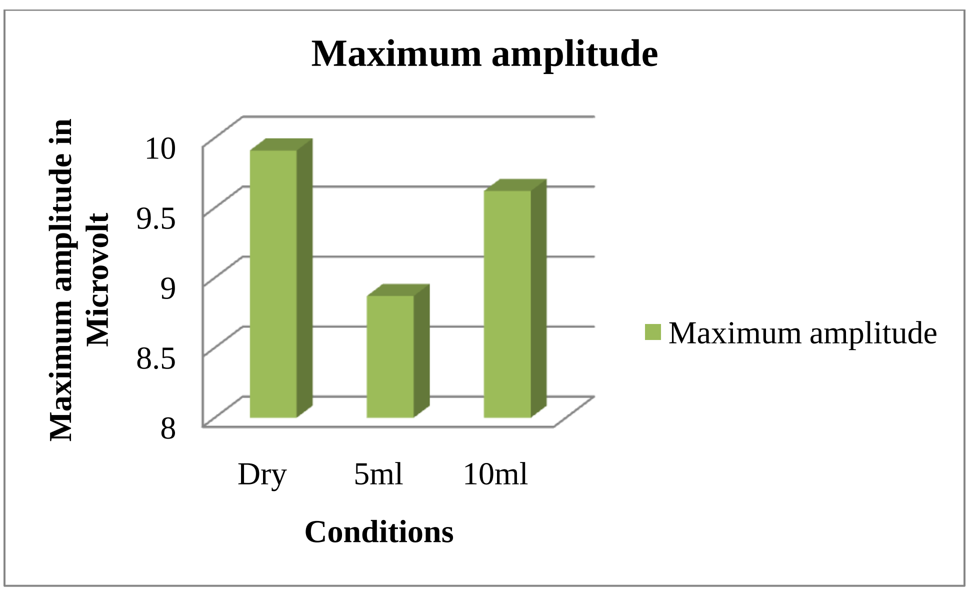

Figure 5: Mean values for the maximum amplitude of swallow sound

The maximum amplitude of swallow sound refers to the maximum protective closure of the swallowing mechanism. The higher scores as seen in figure 5 is obtained for maximum amplitude of dry swallow. As observed in case of minimum amplitude (figure 5), dry swallow seemed to take longer duration to initiate the swallow and it was noticed that during dry swallow, the effort was more compared to other conditions. So it can be inferred that the maximum protective closure seemed to occur for dry swallow. In comparison for wet volumes (5ml and 10ml), the values were higher for 10 ml compared to 5 ml. The greater the volume of wet swallow conditions, better is the protection act of swallowing mechanism as the mean maximum amplitude are higher in 10 ml compared to 5 ml volume.

Duration (seconds)

Mean and standard deviation for duration (from initiation to termination of the swallow sound) was obtained and is shown in the Figure 6

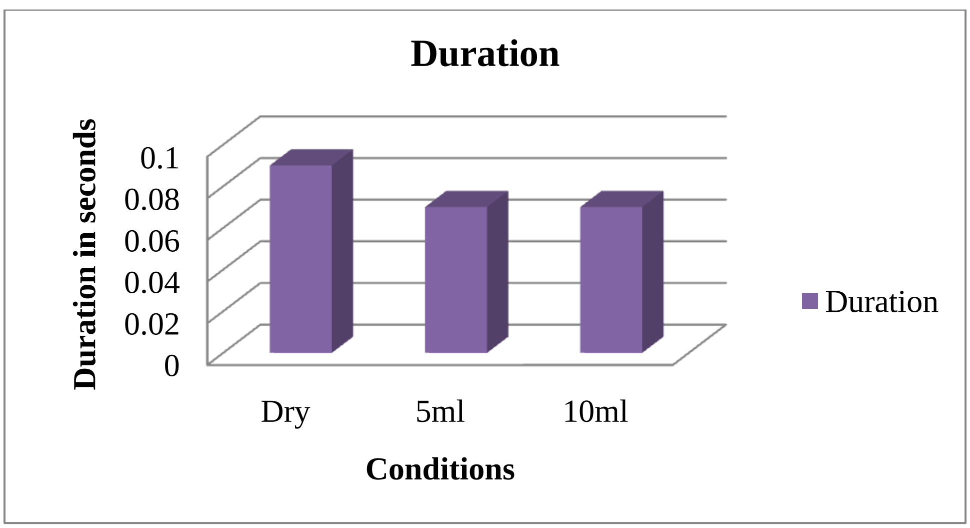

Figure 6: Duration of the swallow sound for all swallowing tasks

Duration in this study frame is considered as the time between initiation and termination of the swallow sound. The mean score obtained for duration of each swallowing tasks have been depicted in the figure 6. The mean values obtained for dry swallow is 0.09 s, 5ml of water is 0.07 s and for 10 ml of liquid is 0. 08 s. The scores obtained for dry swallow is higher than that of 5 ml and 10 ml water. There is no statistically significant difference between any of the swallowing tasks. In the wet swallow, for the different volumes (5ml and 10ml), the values obtained does not show any significant difference ($p > 0.05$).

As observed in the earlier section, when the swallow is more effortful, the duration taken for the swallow is also more which in turns affects the duration of the swallow sound. Dry swallow was more of effortful swallow compared to wet swallow and so the duration of the swallow sound for dry swallow was more compared to 5 ml and 10 ml wet conditions.

Cichero and Murdoch (2002) reported that the swallowing sound duration varied across bolus volume. The swallowing sound duration decreased as bolus volume increased (5ml, 10ml and 15ml). Contrary to their findings in the present study, there was no significant difference between two volumes but in case of wet swallow, the swallowing sound duration decreased compared to dry swallow.

Slope of the swallow sound

Mean values for the slope of the swallow sound is shown in Figure 7 for both swallowing tasks

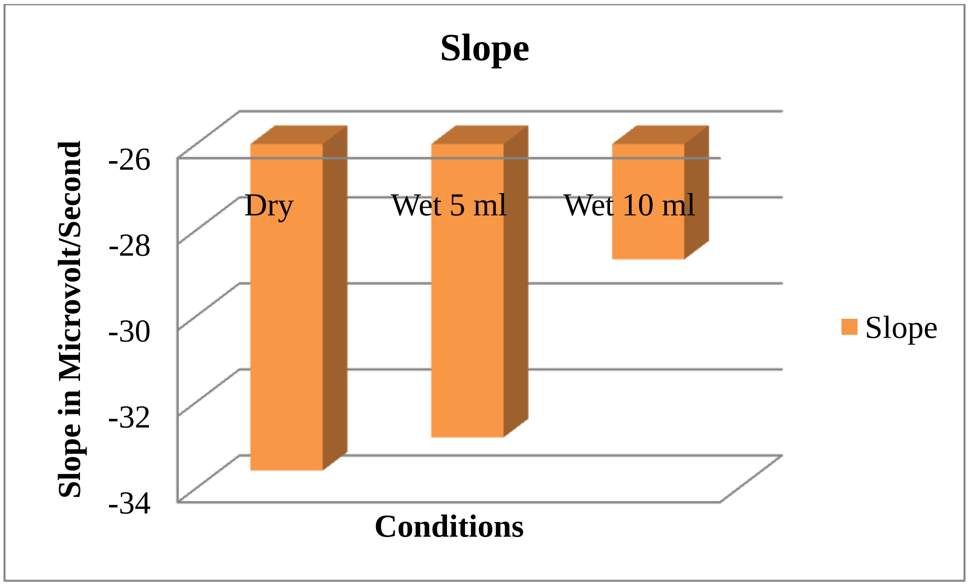

Figure 7: Mean values for the slope of the swallow sound

Slope of the swallow sound was found to be higher for dry swallow when compared to wet swallow condition. Similar findings were observed in parameters like maximum amplitude and duration of the swallow sound. Slope was less for 10ml swallow compared to 5 ml swallow

Area under the amplitude –time curve

Mean values for the area under the curve is shown in Figure 8 for both swallowing tasks

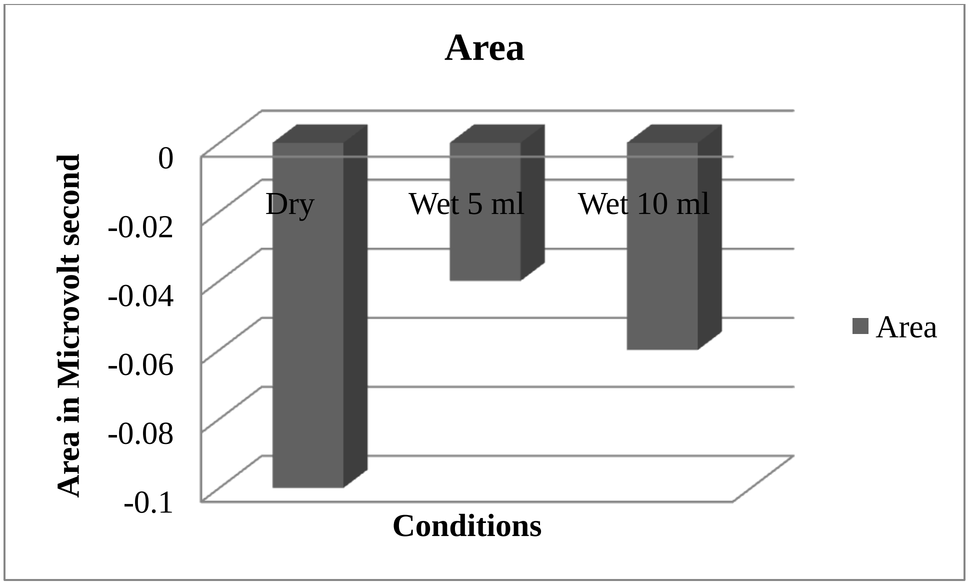

Figure 8: Mean scores for area under amplitude time curve

The mean scores for area were seen to be higher for dry swallow when compared to wet swallow. In case of two volumes, the duration was higher for 10ml and the same is reflected in the area under the curve.

Thus the values obtained for all the measures of the swallow sound in all the conditions shows a general trend. A trend was observed in case of dry swallow and for 10 ml swallow. There was no difference noticed between the age groups considered for the study. As the difference between both the groups was only of six months interval, there may not be any major anatomical or physiological changes taking place in the swallowing mechanism. Gender differences were also not observed for any of the parameters considered for the study. Since the age group considered was of prepubertal period, changes in males and females oropharyngeal structure may not show much difference.

In case of different swallowing tasks, even though not statistically significant, there were differences observed between dry swallow and wet swallow (as shown in figures). There was a general trend observed in dry swallow condition which varied across parameters. The mean scores obtained for dry swallow was higher compared to wet swallow for all the parameters. It is inferred that dry swallow seems to be more effortful swallow compared to wet swallow. Another reason could be, that generally the task is difficult to perform as not all children could swallow saliva, during the recording sessions and they were having difficulty following the instructions for dry swallow even after repeated instructions and modeling. Dry swallow in all probability may not be an important test for the younger age group to study the swallowing sound. In comparison to this, both wet volumes (5 ml and 10 ml), a clear trend emerged especially for 10 ml volume where the scores obtained were consistently high and robust for all the parameters of selected study of swallow sound. This suggests that 10 ml volume is better and may be recommended as an ideal swallow bolus volume for thin liquids such as water in children above 4yrs of age.

Thus, this study has yielded norms for the assessment of swallow sound in children between 4-5yrs. It also strongly pointed to the fact that ‘dry swallow’ may not be an ideal stimuli to elicit swallow sound. In comparison within the ‘wet swallow’ condition of 5 ml and 10 ml, 10 ml seems to be a sensitive measure with respect to volume which could be used as an ‘ideal’ measure to elicit ‘good’ swallow sound wave morphology using the ‘Cervical auscultation’ method of the Digital Swallowing workstation.

SUMMARY AND CONCLUSION

The study aimed at analyzing the performance of typically developing children in the age range of 4-5yrs for swallowing sound using “Cervical Auscultation module’ in Digital Swallowing workstation, Model 7120, by Kay Pentax, in two swallowing tasks (dry swallow and wet swallow) and was compared across the following:

- Two age groups (4.0 to < 4.6 and ≤ 4.6 to 5.0)
- Gender (Males and females)
- Swallowing tasks (dry swallow and wet swallow)

There were a total of sixty participants who participated in the study. Participants were sub grouped into two age groups depending on their chronological age. There was a six months age interval between both groups (4.0 to < 4.6 and ≥4.6 to 5.0). In each age group there were a total of 30 participants with an equal number of males and females (15 males and 15 females) in each.

The ‘Acoustic module’ of Digital Swallowing workstation using ‘Cervical Auscultation’ method was used to obtain the measures for dry swallow and two conditions of wet swallow (5 ml and 10 ml thin liquid i. e, water). The swallowing sound was recorded and analyzed. For dry swallow only one recording was obtained and for wet swallow, for each volume, two recordings were obtained of which only one with good waveform representation was later selected by the investigator for further analysis.

The following parameters of the ‘swallowing sound’ signal were analyzed for each of the selected sample:

- Duration in seconds from initiation to termination of the swallow/glottal sound.
- Minimum amplitude of the sample (in microvolt)
- The peak amplitude (microvolt) indicating maximum protective closure (as an airway protective act).
- Mean amplitude in microvolt
- The slope of the swallow sound in terms of microvolt/second.
- The area under the amplitude - time curve (microvolt second)

The data obtained were treated with suitable statistical analysis (Mixed ANOVA, two way repeated measures ANOVA, MANOVA and one way repeated measure ANOVA). The results of the study showed that there was no significant difference between the age groups and genders in the study.

Salient findings for the specific feature of the ‘swallow sound’ were as follows:

- ‘Duration of the swallow sound’ was found to be higher for dry swallow condition compared to wet swallow condition. There was no significant difference between age group and gender for the duration of the swallow sound.
- In terms of mean amplitude, it was observed that 10 ml wet swallow values were higher than 5 ml wet swallow and dry swallow. Dry swallow and 5 ml wet swallow did not vary much.
- Minimum amplitude was observed to be more for 10 ml wet swallow compared to other conditions. For dry swallow minimum amplitude was relatively less. This

implies that the time taken to initiate dry swallow was comparatively longer compared to wet swallow.

- Maximum amplitude for dry swallow was higher than two volumes of wet swallow. So, there is a maximum protective closure taking place during dry swallow. In terms of two volumes, 10 ml volume showed higher values compared to 5 ml volume. It can be inferred that higher the volume, better the protection act.
- Slope of the swallow sound was found to be higher for dry swallow when compared to wet swallow conditions. When comparing two volumes, slope was less for higher volume (10 ml) compared to lower volume (5 ml)
- Area under the amplitude time curve was also found to more for dry swallow than wet swallow condition.

Thus from the study, it can be concluded that the dry swallow tasks seems to have less potential in yielding adequate swallow sound wave morphology. On the other hand, 10 ml wet swallow (thin liquid-water) seemed to be yielding robust, clear swallow sound as per the outcome of the study using Cervical Auscultation module of the Digital Swallowing Workstation.

Future directions

Comparative studies between children and adults using different food consistencies would provide better insight in understanding the characteristic of swallow sound.

REFERENCES

Almeida, S. T., Ferlin, E. L., Maria, A. M. P., & Goldani, H. A. S. (2008). Assessment of swallowing sounds by Digital cervical auscultation. *Annals of Otology Rhinology and Laryngology, 117,* 253-258.

Blonsky, E., Logemann, J. A., Boshes. S., & Fisher, H. (1975), Comparison of speech and swallowing function in patients with tremor disorders and geriatric patients: A cineflurographic study. *Journal of Gerontology, 30*, 299-303.

Borr, C. M. A., Hielscher-Fastabend, M., & Lucking, A. (2007). Reliability and validity of cervical auscultation. *Dysphagia, 22,* 225-234.

Burke, P. M. (1977). Swallowing and the organization of sucking in the human newborn. *Child Development, 48*, 523–531.

Cagliari, C. F., Jurkiewicz, A. L., Santos, R. S., & Marques, J. M. (2009). Doppler sonar analysis of swallowing sounds in normal paediatric individuals. *Brazilian journal of Otorhinolaryngology, 75(5),* 706-15.

Cichero, J. A. Y, & Murdoch, B. E. (2002). Acoustic signature of the normal swallow: characterization by age, gender, and bolus volume. *Annals of Otology Rhinology and Laryngology, 111*, 623-632.

Cichero, J. A. Y, & Murdoch, B. E. (2003). What happens after swallow? Introducing the glottal release sound. *Journal of Medical Speech Language Pathology, 11,* 31-41.

Cichero, J., & Murdoch, B. (1998). The physiologic cause of swallowing sounds: Answers from heart sounds and vocal tract acoustics. *Dysphagia, 13*, 39-52.

Dellow, E., (1976). The general physiological background of chewing and swallowing. In B. Sessle & A. Hannan (Eds.), *Mastication and swallowing*. Toronto: University of Toronto Press.

Dobie, R. (1978). Rehabilitation of swallowing disorders. *American family physician 17*, 84-95.

Eibling, D. E, & Gross, R. D. (1996). Subglottic air pressure: A key component of swallowing efficiency. *Annals of Otology Rhinology and Laryngology, 105*, 253-258.

Hamlet, S., Nelson, R., & Patterson, R. (1988). Sounds of swallowing. *Journal of Acoustical Society of America, 83,* (Supp. 23).

Hamlet, S., Nelson, R., & Patterson, R. (1990). Interpreting the sounds of swallowing: Fluid flow through the cricopharyngeus. *Annals of Otology Rhinology and Laryngology, 99*, 749-752.

Hamlet, S., Patterson, R., Fleming, S., & Jones, L. (1992). Sounds of swallowing following total laryngectomy. *Dysphagia, 9,* 63-68.

Heinz, J.M., Vice, F.L. & Bosma, J.F. (1994). *Components of Swallow Sounds.* Presented at the Second Workshop on Cervical Auscultation, Ritz Carlton Hotel, Tyson's Corner, VA, October 13, 1994.

Hollshwandner C H, Brenman H S, & Friedman M H F. (1975). Role of afferent sensors in the initiation of swallowing in man, *Journal of dental research, 54 (1)*: 83.

Lear, C. S. C., Flanagan, J. B., & Morrees, C. F. A. (1965). The frequency of deglutition in man. *Archives of Oral Biology, 10*, 83-99.

Logan, W. J., Kavanagh, J. F, & Wornall, A. W, (1967). Sonic correlates of human deglutition, *Journal of applied physiology 23 (2),* 279-84.

Logemann, J. A. (1983). *Evaluation and treatment of swallowing disorders*, (1st edition), San diego, college hill press.

Logemann, J. (1998). *Evaluation and treatment of swallowing disorders* (2nd Edition). Austin, TX: Pro- Ed.

Logemann, J. A., Kahrilas, P. J., Cheng, J., Pauloski, B. R., Gibbons, P. J., Rademaker, A. W., & Lin, S. (1992). Closure mechanisms of the laryngeal vestibule during swallow. *American Journal of Physiology, 262 (Gastrointesintestinal Physiology, 25),* G338–G344.

Mackowiak, R., H. Brenman, & Friedman, M. (1967). "Acoustic profile of deglutition*." Proceedings of the Society for Experimental Biology, 125,* 1149-52.

Martin, B. J., Logemann, J. A., Shaker, R., & Dodds, W. J. (1994). Coordination between respiration and swallowing: Respiratory phase relationships and temporal integration. *Journal of Applied Physiology, 76,* 714–723.

McPherson, K. A., Kenny, D. J., Koheil, R., Bablich, K., Sochaniwskyj, A., & Milner, M. (1992). Ventilation and swallowing interactions of normal children and children with cerebral palsy. *Developmental Medicine and Child Neurology, 34(7),* 577-588.

Miller, M. (1986). Neurophysiological basis of swallowing, *Dysphagia,1*, 91-100.

Moriniere, S., Boiron, M., Alison, D., Makris, P., & Beutter, P. (2008). Origin of the Sound Components during Pharyngeal Swallowing in Normal Subjects, *Dysphagia 23*, 267–273

Moriniere, S., Boiron, M, & Beutter, P. (2006). Sound component duration of healthy human pharyngoesophageal swallowing: a gender comparison study. *Dysphagia 21*, 175–182.

Perlman, A. L., Ettema, S. L., & Barkemeier, J. (2000). Respiratory and acoustic signals associated with bolus passage during swallowing. *Dysphagia, 15*, 89-94.

Preiksaitis, H. G., Mayrand, S., Robins, K., & Diamant, N. E. (1992). Coordination of respiration and swallowing: Effect of bolus volume in normal adults. *American Journal of Physiology, 263*, R624–R630.

Robbins, J., Hamilton, J. W., Lof, G. L., & Kempster, G. B. (1992). Oropharyngeal swallowing in normal adults of different ages. *Gastroenterology, 103*, 823–829

Robbins, J., Hamilton, J. W., Lof, G. L., & Kempster, G. B. (1992). Oropharyngeal swallowing in normal adults of different ages. *Gastroenterology*, *103*, 823–829

Swapna. N, Prema. K. S, & Geetha. Y. V. (2010). *Developemnt of an intervention module for preschool children with communication disorders* – An unpublished ARF project undertaken at AIISH, Mysore.

Takahashi, K., Groher, M. E., & Michi, K. (1994). Methodology for detecting swallowing sounds. *Dysphagia*, *9*, 54–62.

Vice, F. L., Heinz, J. M., Giuriati, G., Hood, M., & Bosma, J. F. (1990). Cervical auscultation of suckle feeding in newborn infants. *Developmental Medicine and Child Neurology*, *32*, 720-728

Youmans, S. R., & Stierwalt, J. A. G. (2006). Measures of tongue function related to normal swallowing. *Dysphagia*, *21*,102–111.

Zenner, P., Losinski, D., & Mills, R. (1995). Using cervical auscultation in the clinical dysphagia examination in long-term care. *Dysphagia*, 27-31.