# EFFECT OF SOUR AND CARBONATED LIQUID BOLUS ON HYOLARYNGEAL ELEVATION DURING SWALLOW

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**MAY- 2019**

## CERTIFICATE

This is to certify that this dissertation entitled "**Effect of Sour and Carbonated Liquid Bolus on Hyolaryngeal Elevation during Swallow**" is a bonafide work submitted in part fulfillment for the Degree of Master of Science (Speech-Language Pathology) of the student (Registration No: 17SLP007). This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier for the award of any other Diploma or Degree to any other University.

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# CERTIFICATE

This is to certify that this dissertation entitled "**Effect of Sour and Carbonated Liquid Bolus on Hyolaryngeal Elevation during Swallow**" has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier for the award of any Diploma or Degree to any other University.

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## DECLARATION

This is to certify that this dissertation entitled "**Effect of Sour and Carbonated Liquid Bolus on Hyolaryngeal Elevation during Swallow**" is the result of my own study under the guidance of Dr. Swapna N, Associate Professor of Speech Pathology, Department of Speech-Language Pathology, All India Institute of Speech and Hearing, Mysuru and has not been submitted earlier for the award of any Diploma or Degree to any other University.

Mysuru

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*"Wherewith God guides all those who seek his good pleasure to ways of peace, and he brings them out of darkness by his will to light and guides them to the right way"*

*V:5:16*

*If not for your grace and blessings, I would not have reached this far. I owe it all to you, Allah.*

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# Chapter I

## Introduction

Food is one of the basic needs of living beings. Eating food is considered to be a pleasurable act, and at the same time, a life sustaining activity. Swallowing, a part of the process of eating, is one of most interesting and sophisticated physiological phenomenon involving multiple organ systems. Maintaining one's nutrition and health is primarily accomplished through swallowing. Even though swallowing takes place in a few seconds, it involves different sophisticated physiological processes starting from oral cavity and extending till esophagus. There are several physiological processes which accompany swallow which include preparation and transfer of bolus in oral cavity to pharyngeal cavity, closure of the glottis, closure of the laryngeal inlet, elevation of hyolaryngeal complex, opening of upper esophageal sphincter, and so on. Along with these, there are several airway protective mechanisms which ensure the safe transfer of the bolus into the esophagus during a swallow, which is critical in swallowing. These include approximation of the true and false vocal folds, medial movement of the arytenoids to the epiglottic base, anterior and superior movement of the hyolaryngeal complex, and the lateral leaning of the epiglottis to lid the laryngeal vestibule (Shaker, Dodds, Dantas, Hogan, & Arndorfer, 1990; Ohmae, Logemann, Kaiser, Hanson, & Kahrilas, 1995).

Superior movement of the hyolaryngeal complex is one of the crucial events among the above within the pharyngeal phase of swallowing. It is then followed by the transfer of bolus into the pharynx and precedes pharyngeal constriction. The hyolaryngeal complex consists of different structures such as, the hyoid bone, thyrohyoid membrane, and laryngeal cartilages which serve as a connection site for the cricopharyngeus that constitutes the upper esophageal sphincter. The hyolaryngeal elevation occurs by the contraction of various suprahyoid muscles as well as the thyrohyoid muscles. This in turn leads to the upper esophageal sphincter opening. These series of movements repositions the larynx from the course of an approaching bolus and directs the bolus to the upper esophageal sphincter, through which it enters the esophagus (Matsuo & Palmer, 2008).

The primary trigger for swallowing is initiated with sensory stimuli that originate at receptors situated in and around the sensory fields of mouth and pharynx. The central swallowing centers are activated in a coded manner by the input from these sources. In fact the sensory input is crucial in all the stages of swallow including oral, pharyngeal, and oropharyngeal stages. In the oral stage, neural control centers are informed by the sensory input regarding the process of mastication based on the texture, consistency and volume of the bolus. This helps the boluses to be prepared to a desirable consistency. And also, lingual propulsive forces play a major role in transporting the bolus adeptly into the pharynx (Takahashi, Miyamoto, Terao, & Yokoyama, 2007; Minato et al., 2009). The subconscious pharyngeal swallow is triggered by the sensory input. This sensory input modulates the motoric impulses which result in a sequence of muscle activities that aids in in the transfer of bolus across the pharynx (Doty, 1951; Doty & Bosma, 1956). Intensity of swallow at the esophageal level is also modified by the sensory input and it initiates secondary peristalsis as well (Dong, Loomis, & Bieger, 2001). In order to trigger swallowing, the sensory input synaptically manipulates multiple pathways, both cortical and brainstem. This modifies motor output and immediately activates ascending pathways. These, in turn, automatically modulate the motoric output all over the swallowing sequence (Lowell, Poletto, Knorr-Chung, Reynolds, Simonyan, &

Ludlow, 2008).

Any damage to the nervous system can lead to a dysfunction in swallow physiology which can in turn affect various aspects of bolus transfer from oral cavity to esophagus through pharyngeal cavity and can result in dysphagia. In some instances, the sensory input to the brain which is crucial in triggering a swallow is also interrupted. These patients may not be able to appreciate the sensory properties of food such as taste and temperature, which is an important aspect of swallow. Oropharyngeal dysphagia is often dealt using therapy procedures which are either compensatory and/or rehabilitative in nature. One of the strategies in dysphagia management is altering the sensory properties of the bolus to improve the sensory input to the brain and to trigger a quicker swallow.

Since altering sensory properties of the food is relevant to the management of swallowing disorders, this has been widely researched. Most discussed bolus properties include, taste, consistency, volume, viscosity, texture, temperature, etc. Past few decades of research have tried to investigate the influence of taste on swallowing physiology across different parameters. Studies have shown that different tastes have differential effect on the aspects of swallowing (Chee, Arshad, Singh, Mistry, & Hamdy, 2005; Miyaoka, Haishima, Takagi, Haishima, Asari, & Yamada, 2006; Leow, Huckabee, Sharma, & Tooley, 2006; Loret, 2015; Yamamura, Kurose, Okamoto, 2018). Most of them point to timing as the most likely aspect to display taste-dependent variation, based on the assumption that taste sensory input travels along afferent pathways to the cortical and brainstem areas involved in swallowing control, and may serve to excite these centers for the task of swallowing. Some among the studies have reported that the taste stimuli compared to water facilitated faster swallow timing measures (Logemann, Pauloski, Colangelo, Lazarus, Fujiu, & Kahrilas, 1995; Kajii, Shingai, Takahashi, Taguchi, Noda, & Yamada, 2002; Ding, Logemann, Larson, & Rademaker, 2003; Pelletier & Lawless, 2003; Palmer, Mcculloch, Jaffe, & Neel, 2005; Leow, Huckabee, Sharma, & Tooley, 2006). Faster swallow speeds (determined in volume per second) were reported for citrus, saline, and glucose solutions when compared to that of water (Chee, et al., 2005). However, other studies have found no differences in swallow timing measures (Butler, Postma, & Fischer, 2004; Hiss Strauss, Treole, Stuart, & Boutilier, 2004; Miyaoka, et al., 2006), while a few others have even found prolonged duration measures with tastants compared with water (Hamdy et al., 2003; Chee et al., 2005). One of the studies using bitter, sweet, and salty tastants found no effect on swallow apnea duration (SAD) (Todd, Butler, Plonk, Grace-Martin, & Pelletier, 2012). Certain studies have reported the strength of swallow, for example, salty bolus elicited more robust swallows (Ding et al., 2003; Miura, Morita, Koizumi, & Shingai, 2009) and sweet boluses resulted in stronger swallow (Ding et al., 2003).

Most of the research on taste perception shows that sour triggers the swallow better compared to the other tastes (Loret, 2015). Evidences show that sour boluses produced greater submental EMG amplitude and stronger swallows (Ding et al., 2003; Palmer et al., 2005; Leow, Huckabee, Sharma, & Tooley, 2007; Miura et al., 2009). Further investigations have reported that sour stimuli resulted in shorter latencies between events in the suprahyoid muscle contraction sequence in swallowing compared with those observed with water (Ding et al., 2003; Palmer et al., 2005; Leow et al., 2007). A recent study by Mulheren, Kamarunas, and Ludlow (2016) also reported that sour conditions increased swallowing frequency and cortical activation, whereas sweet stimuli as well as water did not.

Studies in patients with neurogenic dysphagia also showed that swallowing response can be improved using a sour bolus (Logemann et al., 1995; Pelletier & Lawless, 2003). Logemann et al. (1995) performed a videofluoroscopic swallow study (VFSS) using water and real lemon juice, and it was found that sour bolus helped in improving the oral swallow. Additionally, the patients also showed improvements like reduction in oral transit and pharyngeal transit time. Oropharyngeal swallow efficiency (i.e., the ratio between the percentage of food bolus entering into the esophagus and the total oral and pharyngeal transit time) was also found to have improved. They also noted reduction of aspiration in some patients. Pelletier and Lawless (2003) using Fiberoptic Endoscopic Evaluation Study (FEES), experimented with 2.7% citric acid in water (this was expected to be corresponding to the sourness of stimuli used in the study of Logemann et al., (1995) on a different sample of patients with neurogenic dysphagia. Citric acid (2.7%) helped in considerably reducing penetration as well as aspiration compared to that of water. According to Pauloski et al. (2013), regardless of whether a patient has suffered central or peripheral sensory damage, sour taste might help in improving the speed of pharyngeal transit. Sour stimuli resulted in reduced oral and pharyngeal transit time, reduced aspiration and penetration, high lingual pressure, in disordered (neurogenic) population, and stronger and shorter submental muscle contractions in healthy population (Loret, 2015).

However, there are a few other studies which report of no or delayed response to sour taste (Hamdy et al., 2003; Butler et al., 2004; Hiss et al., 2004; Chee et al., 2005; Miyaoka et al., 2006; Todd et al, 2012). Even though there is a lot of research generated with regard to the basic tastes, in real life, these different tastes are perceived as flavours. The flavour of food that we speak of, as defined by the sensory scientists, is the combination of a particular taste/s, retronasal aroma and chemesthesis. Chemesthesis results from different chemical reactions in the oral cavity and is responsible for the perception of coolness of mint candies or menthol and the heat or burn of extremely spicy foods (Pelletier & Dhanaraj, 2006). Even though the temperature within the oral cavity is not altered, the sensation of heat or cold owing to the chemical reaction inside mouth, supplements to the "flavor" experience (Todd, Butler, Plonk, Grace-Martin & Pelletier, 2012a). Olfactory receptors in the oral and pharyngeal cavity respond to the aromas of stimuli that are placed in the mouth (i.e., retronasal aroma), making it challenging to differentiate between the respective contributions of taste, chemesthesis, and aroma to the overall experience of flavour during swallowing (Auvray & Spence, 2008).

Citric acid and high salt are known to result in chemesthesis which is facilitated by the trigeminal nerve. Thus, it is regarded that chemesthesis might be playing a decisive part in swallowing physiology (Green & Gelhard, 1989; Pelletier & Lawless, 2003). The sensations in the oral cavity by the carbonated drinks are highly chemogenic in nature. Studies have correlated the oral perception of carbonation to the stimulation of trigeminal nerve. Studies done in rats and humans using carbonic anhydrase blockers, before presenting with carbonated stimuli, have shown reduced neural activity of chorda tympani and trigeminal neurons in the lingual nerve (Komai & Bryant, 1993; Simons, Dessirier, Carstens, O'Mahony, & Carstens, 1999). Chandrashekar et al. (2009) reported that carbonation is a blend of multisensory inputs and it has the ability to elicit a chemosensory as well as somatosensory response (Chandrashekar et al., 2009). If so, the possibility of including trigeminal irritants such as carbonation in dysphagia diet recommendations might be beneficial to individuals with dysphagia (Pelletier & Dhanaraj, 2006).

Some researchers have explored the influence of carbonation on different aspects of swallow. Ding et al. (2003) failed to establish a relationship between carbonation and intensity or time period of contact on submental electromyography. Miura et al. (2009) found that the sour taste, carbonated and cold stimuli could surge the high frequency content in the signals of swallowing submental electromyography.

Bulow, Olsson, and Ekberg (2003) reported that, in contrast to thickened thin liquid, carbonated liquid had the ability to decrease pharyngeal retention, lessen penetration/aspiration and cause a reduction in pharyngeal transit time. Nixon (1997) using VFSS, looked into four adult groups, on the effects of thin barium versus carbonated liquids with respect to swallowing measures. And three among the four groups, had dysphagia. He noted that, while using carbonated liquids, first two groups demonstrated significantly reduced oral transit times (OTT), pharyngeal transit times (PTT), pooling, as well as aspiration. Research has also shown that carbonated thin liquid is effective in considerably decreasing the occurrence of penetration as well as aspiration in individuals with neurogenic dysphagia (Sdravou, Walshe, & Dagdilelis, 2012). The temporal and descriptive measures considered in Sdravou et al. (2012) study was OTT, PTT, initiation of pharyngeal swallow, stage transition duration, pharyngeal retention, and penetration-aspiration scale. Even though carbonated liquids helped reduction in penetration and aspiration, it could not elicit any significant differences in other above mentioned parameters of bolus flow. A pilot study done in children by Lundine, Bates, and Yin (2015) revealed that carbonated thin liquid is an alternative for thick liquids in children with dysphagia.

It is stated that, peripheral sensory receptors are excited and sensory fibers in the nucleus tractus solitarius by (NTS) of the brainstem, which is considered as one of the main structure responsible for the initiation of swallow, is activated by chemesthetic stimuli (Carstens, Carstens, Dessirier, Omahony, Simons, Sudo, & Sudo, 2002; Green, 2004; Sasaki & Leder, 2008; Chandrashekar et al., 2009; Hewson et al., 2009). But, in order to see the functional aspect of this hypothesis, further research is required.

**Need for the study**

A systematic review of the existing literature revealed that various physiological aspects that accompany swallow have been studied using different tastes and chemesthetic stimuli. These studies revealed that different tastes affect swallowing physiology differently (Logemann et al., 1995; Kajii et al., 2002; Ding et al., 2003; Hamdy et al., 2003; Pelletier & Lawless, 2003; Butler et al., 2004; Hiss et al., 2004; Chee et al., 2005; Palmer et al., 2005; Miyaoka et al., 2006; Leow et al., 2007; Loret., 2015). Some of these studies have shown that compared to other tastes and neutral stimuli, sour elicited better swallow (Logemann et al., 1995; Ding et al., 2003; Pelletier & Lawless, 2003; Palmer et al., 2005; Leow et al., 2007; Miura et al., 2009; Loret, 2015). On the other hand, there are also studies which reported either no effect or delayed responses to sour taste during swallow (Butler et al., 2004; Hiss et al., 2004; Chee et al., 2005; Miyaoka et al., 2006; Todd et al, 2012). Similarly, among the chemesthetic stimuli, carbonated thin liquids have been researched on to see its effect on swallow and these studies have shown promising results in managing neurogenic dysphagia in both pediatric and adult population (Nixon, 1997; Bulow et al., 2003; Sdravou, Walshe & Dagdilelis, 2012; Todd et al., 2012).

These studies have extracted parameters such as amplitude and duration using EMG SAD, nasal measurements, lingual pressures, oral and pharyngeal transit times, tongue movement trajectories, hemodynamic measures (like fNIRS) (Logemann et al., 1995; Ding et al., 2003; Pelletier & Lawless, 2003; Palmer et al., 2005; Leow et al., 2007; Miura et al., 2009; Sdravou, Walshe & Dagdilelis, 2012; Ragland, Park, McCullough, & Kim, 2016). Though, the elevation of hyolaryngeal complex is one of the critical events in swallowing physiology, studies pertaining to the effect of taste on the extent of hyolaryngeal elevation are almost nonexistent. Hence, it would be interesting to investigate this, which will add to the existing literature about whether the sour taste or carbonation, as opposed to the neutral stimuli, has got better effect on the hyolaryngeal elevation during swallow.

Most of these studies on the influence of taste on swallowing were carried out using techniques like VFSS and FEES. Specifically, FEES is invasive in nature whereas, VFSS exposes the subjects to radiation. Hence, sometimes non-invasive method which does not expose the subject to radiation, like accelerometry, and which involves less cost and is portable, is preferred. The use of accelerometers offers further possibilities for the assessment of swallow sounds by transduction from the body surface. Accelerometer is preferred over other techniques like cervical auscultation using a microphone or a stethoscope, since it suppresses surrounding noise more effectively and is only activated from surface vibrations on the skin (Borr, 2012). The studies done using the accelerometry in investigating the effect of sensory properties of the bolus on hyolaryngeal elevation, is almost none. Keeping this in view, the current investigation was planned to examine the influence of sour taste as well as carbonation on hyolaryngeal elevation during swallow using accelerometry.

**Aim of the study**

The aim of the study was to investigate the effectof sour bolus and carbonated bolus on the hyolaryngeal elevation. The specific objectives of the study were

- To investigate the influence of sour and carbonated bolus, in comparison with a neutral stimuli on the duration and amplitude of hyolaryngeal elevation.
- To investigate the effect of two volumes of each stimuli on the duration and amplitude of hyolaryngeal elevation.
- To assess the differences across gender, if any, on the hyolaryngeal elevation during swallow in the different stimuli and volume conditions.

# Chapter II

## Review of Literature

Swallowing is an inescapable physiological phenomenon which aids us in sustaining health as well as well being. Even though it takes place in a few seconds, it involves different sophisticated physiological processes starting at oral cavity and extending till esophagus and is mediated by similarly complex neural mechanisms. Mostly acknowledged stages of swallowing involve oral, pharyngeal as well as esophageal phases. The oral phase of swallowing involves preparation as well as propulsion of bolus from oral cavity to the pharyngeal cavity. A well prepared bolus propels down to the pharyngeal cavity and initiates a pharyngeal swallow. Laryngeal inlet is sealed by the epiglottis and upper esophageal sphincter (UES) is opened so that the bolus can slide down the pharyngeal cavity to esophagus. Once the bolus is passed on to the esophagus, the UES is closed and the laryngeal inlet is open. In order for these events to occur coordinated and sequential, anatomical structures as well as neurophysiological mechanism should be intact. At times, due to hindrances in either anatomical or physiological aspects, this process is hindered.

### Phases of swallowing

Normal swallowing includes an integrated, interdependent group of complex feeding behaviours. These behaviours are supposedly emerging from cranial nerves of brainstem. They act together and are regulated by neural regulatory mechanisms within the medulla, as well as by sensorimotor and limbic cortical systems. Typical individuals are able to carry out the sequential sensory and motor configurations of mastication and swallowing in parallel with conscious awareness and minimal effort. There are four stages of swallow (Dodds, Stewart, Logemann, 1990): (1) the oral preparatory stage, in which the food is chewed and made into bolus, (2) the oral stage, in which the prepared bolus is transferred from oral cavity to pharyngeal cavity, (3) the pharyngeal phase, in which the bolus is transferred from the pharynx to esophagus, while the laryngeal inlet is occluded by epiglottis and the airway is protected, (4) the esophageal stage is marked by the entry of bolus into esophagus, which later is passed down to the stomach with the help of peristaltic movements. An additional stage, prior to the oral stage is considered by few authors and was proposed by Leopold and Kagel (1997). This stage explains the stimulation of saliva in the oral cavity as a result of the visual appreciation of the bolus which sends a cognitive message. The stage of primary concern in this study is the pharyngeal phase.

**Pharyngeal phase**

The initiation of this stage is marked by the entry of bolus into the pharynx and the elevation of the hyolaryngeal complex, after which the pharyngoesophageal segment (PES) is opened (Kendall, Mckenzie, Leonard, Gonçalves, & Walker, 2000). To safeguard the upper airway from the bolus, hyoid bone maintains its upward movement towards the edge of the mandible, slanting the larynx under the tongue base, which pulls back when the bolus enters the pharynx. Hence, in preventing the bolus from entering the upper airway, many mechanisms are active. These include

1. Pausing of active respiration
2. Adduction of the true and false vocal folds
3. Laryngeal aditus closure
4. Redirection of bolus over a rising larynx by the tongue base
5. Division of the bolus around the superior aspect of the airway entrance

Activation of superior, middle and inferior constrictor muscles are noticed with the entry of bolus into the pharynx. These muscles are activated sequentially to narrow and shorten the pharynx. This contributes to peristalsis-like movements in the posterior pharyngeal wall that aid in bolus propulsion into the esophagus. The forward movement of the hyoid bone is important in applying traction forces on the PES to achieve maximum opening (Ishida, Palmer, & Hiiemae, 2002). Muscles in the region of the PES that had been shut before swallow are relaxed by parasympathetic signal carried by CN IX to the brainstem, before bolus arrives in the pharynx. After relaxation, during hyolaryngeal movements the PES is pulled open. After the bolus passes the region of the PES, primary esophageal peristalsis begins as the PES closes. The airway revives and the hyoid bone returns to its resting position. These processes indicates the conclusion of hyolaryngeal elevation.

Shaker and colleagues (1990) examined swallowing mechanism in 8 individuals within the age range of 20 to 30 years, to quantify the temporal relationship between swallow-induced glottic closure and different parameters like signals of swallow initiation, (such as tongue base movement, hyoid bone movement, and mylohyoid electrical activity); pharyngeal peristalsis, laryngeal elevation, vestibular closure, and oropharyngeal barium bolus transit. Dry swallow, 5ml water and 5ml barium wet swallows were assessed using concurrent pharyngeal intraluminal manometry, transnasal video laryngoscopy, and submental surface electromyography. The authors found that vocal cord adduction was the initial event among events evaluated, during the swallowing sequence (shown in the figure 2.1). Another finding was that, the laryngeal kinetics during deglutition has distinctive features, and their close synchronization with other swallowing events implies that they are critical features of the swallowing program. Yet another finding was that the lack of coordination between the glottis closure mechanism and oropharyngeal bolus transport, or abnormal laryngeal kinetics may have a vital role in swallow-induced aspiration. The schematic representation of timing of different swallowing events is depicted in figure 2.1. Bolus transit via the pharynx and across the UES begins and ends, while the vocal cords are at maximal adduction. The events shown in the figure 2.1 are onset of tongue base movement (TB-O), onset of superior hyoid movement (SH-O), onset of submental myoelectrical activity(SM-O), and UES opening (UESO).

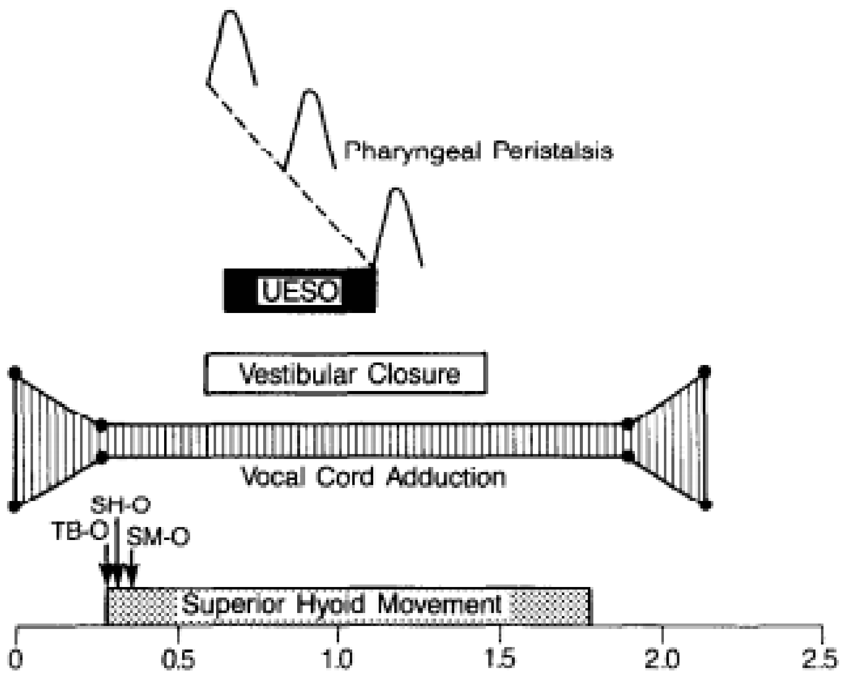


Figure 2.1. *The relation between the time of hyoid bone elevation and vocal fold closure, during 5 ml barium swallow. (Shaker et al., 1990).*

**Swallowing and hyolaryngeal elevation**

Hyolaryngeal complex plays an important role in airway protection, preventing aspiration and penetration. For PES opening, elevation of the hyoid and larynx are necessary. A vacuum is created by this movement that, along with gravity, will pull the bolus into the upper esophagus (Miller, 1982; Mcconnel, Cerenko, Jackson, & Guffin, 1988; Dodds, et al., 1990). In patients in whom the coordination of swallowing gestures is in question, the habitual evaluation of the timing of hyoid movements in dynamic swallow studies can be helpful. Consequently, the assessment of extent of hyolaryngeal elevation is included in the screening and assessment protocols of dysphagia. If the hyolaryngeal elevation is found to be reduced during the assessment, focus on increasing its movement becomes an essential component of management.

Pearson, Langmore, Yu, and Zumwalt (2012) suggested that a posterior and anterior sling of muscles suspends the hyolaryngeal complex and helps in elevating the structural complex during swallowing and thyrohyoid is found to aid it in the act. The submental muscles include anterior digastric, geniohyoid, and mylohyoid which are attached to the hyoid bone. Conventionally, they are thought to form the anterior sling. Along with that, the distal insertions of the remaining posterior digastrics, suprahyoid muscles and stylohyoid also contribute to the anterior sling (Kurt, Gürgör, Seçil, Yıldız & Ertekin, 2006). The long pharyngeal muscles consisting of different muscles like the stylopharyngeus, salpingopharyngeus, and palatopharyngeus, stabilized by the levator veli palatini, form the posterior sling. The distal attachments of these muscles merge together on the posterior edge of the thyroid cartilage and lateral pharyngeal walls, which is proximal to the upper esophageal sphincter (Okuda, Abe, Kim, Agematsu, Mitarashi, Tamatsu, & Ide, 2008), the thyrohyoid muscle which approximates the thyroid and hyoid, is intrinsic to the hyolaryngeal complex (Pearson et al., 2012).

Ishida et al., (2002) conducted a study in 12 healthy adults using videofluorography (VFG) to look into the factors affecting the hyoid elevation. Boluses of different consistencies (liquid, banana, chicken, cookie, peanuts) were considered. The authors concluded that the hyoid bone moved both forward and upward during swallowing, but the upward displacement was sometimes very small. No correlation was reported between the amplitudes of its forward and upward displacements during the same swallow. The amplitude of upward displacement was affected by initial food consistency and (for solid food) by swallow order within the masticatory sequence and was highly variable. The results suggest that during mastication and oral food transport, events in the oral cavity (with concomitant motions of the jaws and tongue) are the primary regulators of upward displacement of the hyoid bone during swallowing. Consistent with its known role in the UES opening, the amplitude of forward displacement was larger and less variable.

Kim and McCullough (2008) carried out a retrospective study of video-fluoroscopic swallowing exams in 40 normal subjects, who were divided into two groups (20 subjects each, within the age range of 21 to 51 and between the ages of 70 and 87 years). The aim of the study was to assess the maximal vertical and anterior displacement of the hyoid bone during oropharyngeal swallowing. On both 5-ml and 10-ml thin liquids descriptive statistics values (means and standard deviation) for both vertical and anterior displacement were analyzed. Age and gender differences were submitted to statistical analysis. Significant difference between younger and older subjects was reported for anterior displacement of the hyoid bone during the swallow. But no statistically significant result difference was obtained for vertical displacement. It was observed that there were no significant differences between male and female subjects. Anterior displacement of the hyoid bone shown negative correlation with age (that is, as the age increased, displacement decreased). This reduction may be related to muscle weakness. However, older people may adapt to preserve airway protection.

Ragland, Park, McCullough and Kim (2016) examined the speed of hyolaryngeal elevation in 37 healthy adults using VFSS. Subjects were divided into two different groups of younger adults  (within the age range of 21 and 51 years) and older adults (within the age range of 70 and 87 years)  The variables considered for the study was age, gender and bolus volume (5 ml and 10 ml) (within-subject). Maximum anterior and vertical displacement of hyoid bone was considered for measurements. The results obtained showed a significant difference for both the volumes between younger and older age group. It was revealed that older subjects had slower hyolaryngeal elevation. It was found that the speed of hypolaryngeal excursion increased in the younger subject group with the increase in bolus volume, where as the speed reduced in the older age group. No significant difference was observed for both 5ml and 10 ml liquid bolus between males and females. The reduced speed in older individuals was attributed to the overall slowing of all CNS functions.

**Assessment of hyolaryngeal elevation**

Hyolaryngeal elevation can be assessed by a number of ways such as direct observation and palpation. An estimate of hyolaryngeal excursion can be obtained using Logemann's four finger test (1998). The index finger is placed behind the mandible anteriorly, which tells about the initiation of tongue movement, middle finger at the hyoid bone to check its movement, third finger is at the top and fourth at bottom of the of thyroid cartilage to define the laryngeal movement when the pharyngeal swallow is triggered. In this way, sub-mandibular movement, hyoid movement and laryngeal movement can be assessed during the swallow. Comparing the time elapsed between the initiation of tongue movement and hyoid and laryngeal movement, a rough estimate of oral transit time and pharyngeal delay time or the time taken from the initiation of swallow by the tongue until the pharyngeal swallow triggers can be made.

There are several instruments to quantify the hyolayngeal elevation including tools like videofluoroscopic swallow study (VFSS), Fiberoptic endoscopic assessment of swallowing function (FEES), Ultrasound, Electromyography (EMG), Electroglottograph, cervical auscultation, or accelerometer. Videofluroscopic swallowing study (VFSS), also known as the modified barium swallow study (MBSS), is a commonly used procedure for direct visualization of oral, pharyngeal and upper esophageal function (Logemann, 1998). Various consistencies of food and liquid mixed with barium are introduced and visualized in real time. Asymmetry, stasis, cricopharyngeal dysfunction, aspiration before, during and after swallow can be detected. Various physiologies of different structures can be observed like lip closure, tongue control, bolus preparation and transport, any oral residue, initiation of pharyngeal swallow, elevation of soft palate, laryngeal elevation, anterior hyoid movement, pharyngeal contraction, UES opening, pharyngeal residue and esophageal clearance.

Fiberoptic endoscopic assessment of swallowing function (FEES) is a portable procedure that may be completed in outpatient clinic space or at bedside by passing an endoscope transnasally (Langmore, Kenneth, & Olsen, 1988) focusing on pharynx, from nasopharynx to oropharynx. Information on spillage before swallow, residue after swallow in valleculae, pyriform sinuses and pharyngeal wall, laryngeal penetration, aspiration and reflux can be obtained. Sensation of the hypopharynx and larynx can also be tested using FEESST (flexible endoscopic evaluation of swallowing with sensory testing) procedure. It is a two-channel scope to assess the sensory perception of larynx and to monitor the laryngeal adductor reflex, which is characterized by a brief closure of the true vocal folds. It provides information regarding the incomplete closure of larynx resulting in aspiration during aspiration. The lateral view also gives the movement of hyoid bone and the lifting of larynx.

Ultrasound uses high-frequency sound waves (2- 10 MHz) and receives the echoes which are then converted to real time images. It is typically used to assess the oral preparatory and oropharyngeal stages of swallowing. The kinematics of dorsal surface of tongue, oral transit time and the motion of hyoid bone can be studied.

Electromyography (EMG) is a non imaging technique which evaluates and records the electrical activity of the skeletal muscles. Commonly used procedure is Surface EMG (sEMG) where electrodes are placed under the chin and on muscles involved in hyolaryngeal elevation (digastric, stylohyoid, mylohyoid, geniohyoid, hyoglossus and genioglossus) and also on the thyroid cartilage. These muscles are activated once the swallow begins and hence used as a marker in the measurement of onset of swallow. sEMG has been used to measure the duration and amplitude of muscle contraction specific to muscles which move the hyoid during swallowing (Crary, Carnaby, & Groher, 2006). This can also be used as a biofeedback tool during therapy via the laryngeal elevators to explain the activation of hyolaryngeal muscles for a longer duration in the Mendelsohn maneuver.

Electroglottograph is used to measure the contact of vibrating vocal folds during voice production. This can also be modified to track laryngeal elevation. It provides bio feedback on extent and duration of laryngeal elevation during the swallows in which the patient is attempting to improve the swallow parameters. Perlman and Grayhack (1991) modified the frequency output response of the EGG and found that the EGG output can be used to identify maximum laryngeal displacement and the duration of laryngeal movement during swallowing.

The swallowing is associated with sounds which can be heard using listening device. Listeners hear the sound and interpret of what could be happening in the swallow or is there any impairment. For the same purpose cervical auscultation is used. It is non invasive, inexpensive, portable and can augment clinical assessment. It provides continuous monitoring of swallowing behaviours. Bolzan, Christmann, Berwig, Costa, and Rocha (2013) reported that in normal swallowing, there are three marked sounds in the pharyngeal phase, with two audible clicks corresponding to laryngeal elevation and the bolus transit through the UES and a third sound corresponding to expiratory murmur.

Swallowing accelerometry is a method to study of vibrations on the neck, believed to arise from hyoid and laryngeal movement during swallowing (Zoratto, Chau, & Steele, 2010). The accelerometer converts vibrations at the skin's surface into a voltage signal with frequencies within the audible range (Zenner, Losinski, & Mills, 1995).

**Swallowing disorders and the management options**

Swallowing disorders, also known as *dysphagia*, results from a wide variety of disease states and is often associated with the illnesses that results in anatomical abnormalities or neuromuscular dysfunction of the oral cavity, pharynx, larynx, and oesophagus. Any illness that results in weakness either from specific neurological or muscular pathology or from generalized debilitation is likely to have dysphagia related to it.

Sensorimotor impairment of the oral and/or pharyngeal phases of the swallowing because of a neurological disorder or insult results in neurogenic dysphagia. The three major types of neurogenic dysphagia may be categorized as transfer, transit, and obstructive. Transfer dysphagia represents a pathological variation in the neuromotor mechanism of the oropharyngeal phase of swallowing. This commonly results from stroke caused by cerebral vascular disease and other neurological disorders like myasthenia gravis, amyotrophic lateral sclerosis, polymyositis etc. Transit dysphagia results from a motor disorder of esophagus (for eg: achalasia), whereas obstructive dysphagia results from the intrinsic (for eg: lumen, tumour or stenosis) and extrinsic (a structure outside pharyngoesophagus compressing lumen) obstruction of esophagus.

Transfer dysphagia is the type which is commonly addressed by a dysphagia therapist. It affects functioning most of the structures in the oropharyngeal region, most significant and detrimental being the larynx. Airway being affected in an individual, poses a challenge of the presence of aspiration. Further, it is mandatory to predict and rule out the presence of aspiration and penetration, in order to prevent further complications like pneumonia from occurring.

Management of neurogenic dysphagia primarily involves the treatment of underlying neurological disorder whenever possible, swallowing therapy if oral feeding is practically safe to attempt, and gastrotomy if oral feeding is unsafe or insufficient (Foley, Martin, Salter & Teasell, 2009). There are different approaches to the management and treatment in dysphagia, which include compensatory and rehabilitative treatment.

Compensatory strategies focus on ensuring safety of oral intake and providing superficial kinaesthetic and sensory stimulation for the duration of rehabilitation process. Another aim of the compensatory management is to facilitate oral intake in those individuals for whom rehabilitation is unsuccessful based on aetiology, pathophysiologic features, or cognitive participation, or in those for whom rehabilitation is contraindicated or not advised, such as in some neurodegenerative disorders. Consequently, compensatory approach includes different sensory stimulation techniques, diet modification and simple postural techniques. Sensory stimulation is mainly achieved by altering the sensory and physical properties of the bolus. Most commonly altered sensory properties include temperature, taste, smell, texture, flavour etc. and the altered physical property is its volume.

**Sensory properties of the bolus**

The review by Loret (2015) discusses different sensory properties of food and their role in triggering swallow. The article lists evidences related to the role of taste, olfactory, chemesthetic, and texture perception. These sensory properties are important in deciding the diet, during the rehabilitation of individuals with dysphagia. Further, altering these properties have shown to improve the swallowing in terms of improved swallow response, hyolaryngeal excursion, strength of swallow, oral manipulation of the bolus, reducing penetration and aspiration, and so on.

***Temperature***

Ferrara et al. (2018) conducted a study on 9 preterm infants to assess the immediate effects of cold liquid on the pharyngeal swallow mechanism in preterm infants with dysphagia. The VFSS results revealed that compared to stimuli in room temperature, the cold stimuli helped in reducing airway compromise. Another study by Miyaoka et al. (2006) investigated the effect of temperature (5ºC, 20 ºC, 35 ºC, 50 ºC) on suprahyoid surface electromyography and perception of ease of swallowing in young healthy participants and found out that the suprahyoid muscle activity reduced at 50$^{o}$C, compared to all the other temperatures.

***Smell***

The presentation of an odourant or an olfactory stimulus, is considered as a compensatory option, if it is found to produce positive effects in the oral ingestion. Influence of swallowing is being researched to study the cortical modulation of swallowing. A randomised trial by Ebihara et al. (2006) was carried out on 105 post-stroke patients at a nursing home, who were medically stable, following 30 days trial of nasal odour inhalation. They investigated on the changes in swallowing reflex latency using submental EMG, regional cerebral blood flow (rCBF) and number of swallows per minute. Patients were given three different stimuli (lavender oil, black pepper oil, and distilled water) for inhalation 1 min prior to each meal. A significant reduction in latency of swallowing reflex in submental EMG and an increment in the number of involuntary swallows per minute, compared to their baseline, were noted in individuals who inhaled black pepper oil. In addition, single photon emission tomography (SPECT) scan results of the subgroup of 10 participants who breathed in black pepper oil revealed an increase in rCBF in the orbitofrontal and insular area, known to be activated during normal swallowing.

In another study conducted among 5 tube fed children with the diagnoses of neurogenic dysphagia due to different causes, it was found that inhalation of black pepper oil resulted in increased oral intake (Munakata et al., 2008). Even though there are evidences favouring the influence of smell, there are also few studies which show mixed findings. One such study is by Wahab, Jones and Huckabee (2010), who found no significant difference in motor-evoked potentials (MEPs) of individuals when different conditions of smell were presented separately from taste. Clinically, altering smell of the bolus is less sought compared to other procedures like that of temperature and taste.

***Taste***

Universally there are more than thousands of taste combinations. Based on the literature, there are five globally accepted tastes. They are bitter, sweet, sour, salty, and Umami (Savory) (Loret, 2015; Melis & Barbarossa, 2017) which are sensed by different taste receptors. The activation of taste buds develop approximately at 12 to 13 weeks' gestation and taste preferences begin to differentiate by at least 28 to 29 weeks after birth. It is also seen that the taste perception changes across the life span (Cowart, 1981). Taste plays an significant position in the event of food intake, in terms of, anticipation of bolus with respect to saliva production followed by the events in oral preparatory and propulsive phases of swallowing, in triggering a faster or stronger swallow, reducing and lengthening the swallow duration etc.

Further, individual discrepancies in taste perception, such as genetic taster status, may also mediate the influence of taste on swallowing. Based on genetic predisposition, the same stimuli can be perceived by non-tasters as weak and super tasters as strong (Smith & Davis, 2000; Bartoshuk et al., 2004). Swallowing apnea durations are found to be comparatively longer in super tasters (Plonk, Butler, Grace-Martin, & Pelletier, 2011). When swallowing taste-intense stimuli, supertasters were also noted to have higher values of linguapalatal pressures (Nagy, Steele, & Pelletier, 2014b), and larger submental electromyographic amplitudes (Pelletier & Steele, 2014) compared to nontasters. Inconclusive and limited evidence necessitates determining the influence of genetic taster status on swallowing function to swallowing taste boluses.

**Effect of taste on swallowing**

Ding et al. (2003) investigated on the effects of consistency and taste on swallow physiology in healthy individuals. They considered younger adults within the age range of 18 to 28 years old and older adults within the age range of 65 to 85 years, with 20 participants (10 men, 10 women) in each group. The study aimed to supply information on muscle contraction intensity variables and swallow timing variables across sweet, salty and sour tastes, along with carbonated stimuli. Surface electromyography was used to obtain respective measures of amplitude and duration, from three different sites, the orbicularis oris inferior region, the submental muscle group region and the infrahyoid muscle group region, which were thought to have involved in both the oral and pharyngeal phases of swallow. The study considered age, tastes and consistency as independent variables. They looked into the individual effects of taste, consistency and age, interaction effects of age and consistency, age and taste, and taste and constancy, and the interaction effects of all the three together. It was found that taste stimuli (sweet, salty and sour) elicited earlier submental and infrahyoid activation compared to the neutral stimuli. A significant effect of consistency was reported by the authors saying that the solid stimuli elicited higher values compared to the liquid stimuli. Across age, it was found that, the older adults had slower muscle activation compared to the younger adults, which is in convergence with the earlier studies.

Butler et al. (2004) examined the effects of viscosity, taste, and bolus volume on swallowing apnea duration (SAD) in 22 healthy adults (10 males). Nasal airflow during swallow conditions was assessed to measure SAD. Different conditions of viscosity, taste and bolus volumes were considered. Viscous stimuli included thin liquid, thick liquid, and puree. Taste stimuli consisted of water, apple juice, lemon concentrate. Nectar thick bolus volumes included 5, 10, 15, and 20 ml. the results revealed that only volume had a significant effect on SAD. Taste and viscous stimuli conditions did not show any effect on SAD.

Miyaoka et al. (2006) explored the effect of different temperatures (5°C to 50°C) and tastes (sweet, salt, sour, bitter, and umami) on EMG during swallow. The results revealed that there was no statistically significant effect of taste alone on the EMG measures during swallow. The authors suggested that combination is sensory stimulation (taste and temperature) better in eliciting easier swallows, rather than a single sensory modality.

Palmer et al. (2005) investigated intramuscular electromyographic activity of the mylohyoid, geniohyoid, and anterior belly of the digastric muscles during the swallow of sour and water boluses in 8 healthy participants within the age range of 21 to 37 years, using EMG. To compare between the sour and neutral stimulus, the measures considered were duration, strength, timing, and pattern of muscle activation. There were no statistically significant differences in the measures of muscle duration, swallow onset time, and pattern of muscle activation. When a sour bolus was used, it was noted that the muscle activation time was more firmly approximated across the onsets of the three muscles. Another finding reported was that the sour bolus also elicited a stronger muscle contraction which was indicated by greater EMG activity with regard to different measures (strength, duration, and timing of muscle activation).

Chee et al. (2005) conducted a study on 42 healthy (21 males and females each) adults with a mean age of 28 years, to see the influence of taste stimuli and anaesthesia on pharyngeal phase of swallow. They used quinine (for bitter), glucose (for sugar), citric acid (for sour) and saline (for salty) solutions and water (neutral) as taste stimuli and lidocaine as anaesthetic. 50 ml Water swallow test, based on the protocol by Hughes and Wiles (1996), for each stimuli, were used to derive the outcome measures, which included, swallowing capacity (volume per swallow), inter-swallow interval andswallowing speed (volume per second). The swallowing tasks were carried out for different doses of lidocaine. The doses included 0 (placebo), 10, 20 and 40 mg of lidocaine, which was randomized to different days. Two different studies were carried out dividing the participants into two groups. The first group comprised of 22 participants (11 females) and the taste modulation of swallowing was studied using different taste stimuli. They were given Visual Analog Scales (VAS) to rate the pleasantness and intensity of the tastes. Each participant underwent 15 water swallow tests with three different stimuli (three trials for five taste stimuli each). The second group (20 participants, 10 males) were studied based on a different experimental protocol which looked into the oral anaesthesia modulation of swallowing. Each participant underwent 4 anaesthetic conditions each with above mentioned lidocaine dosages. Water swallow test and sensory threshold assessment was done. It was found that, compared to the neutral stimuli, the taste stimuli reduced the swallowing speed. Inter swallow interval and swallowing capacity was found to be increased with bitter stimuli. 40 mg lidocaine resulted in decrease in swallowing speed, and increase in inter swallow interval without affecting swallowing capacity.

Pelletier and Dhanaraj (2006) conducted a study in 10 healthy adults within the age range of 18 to 35 years, to investigate the effects of moderate and high concentrations of different taste stimuli and barium taste samples on lingual swallowing pressure. Lingual arrays were used to measure peak amplitude and duration during swallow for each taste stimuli. Nine-point Quartermaster hedonic scale was used to note the liking or disliking of the stimuli immediately after the trials. It was found that high salt, moderate sucrose, and high citric acid elicited significantly higher lingual swallowing pressures compared with the pressures created by water. It was found that the higher taste concentration stimuli did not uniformly increase swallowing lingual pressures. Researchers explained this with respect to the changes in perception of taste intensities across individuals. Pelletier and Dhanaraj (2006, p. 125) commented that *"The upper range of taste concentration levels may not have been high enough to elicit the increased sensory input to the nucleus tractus solitarius (NTS) with subsequent activation of more motor neurons in the nucleus ambiguus to evoke stronger lingual swallowing pressures compared with water."*

Leow et al., (2007) investigated on the influence of taste on swallowing. They considered the parameters like swallowing apnea duration (SAD), oral preparation time and amplitude and duration of submental muscle contraction during swallowing. The study was carried out in two phases, across twenty three healthy female adults within the age range of 20 to 45 years. sEMG and nasal airflow measurement were used to acquire the swallowing parameters across four tastants (sweet, sour, salty, and bitter). A visual analog scale was used to measure the intensity of these tastes. The electrodes for sEMG were placed on submental muscle groups in order to measure the muscle contractions associated with hyolaryngeal excursion. It was found that the sour taste elicited the shortest duration of submental sEMG andoral bolus preparation time. Sweet stimuli also elicited shorter sEMG duration. And, the mean amplitude of submental EMG was found to be higher for sour taste compared to other tastants. No significant effects of taste were found on SAD. The authors attributed the better effects using sour taste to the activation of NTS and NA and also to the trigeminal stimulation. Authors suggested further investigation on effect of tastes, especially sour taste, on hyolaryngeal lift to come to a solid conclusion.

Miura et al. (2009) conducted a study in 20 healthy adults (11 females, 9 males) within the age range of 26 to 45 years, using EMG. One of the aims of the study was to investigate the effect of different taste solutions on the EMG measures during swallow. It was found that the salt and sour stimuli elicited the spectrum-integrated values of the total power components. The salt stimuli elicited an increase in the low frequency component, whereas the sour stimuli elicited in the high frequency component. Another aim of the study was to see the effects of carbonation and cold stimuli on the on the power frequency content of continuous swallowing sEMG for 60-ml solutions. Authors reported that the carbonation caused a significant increase in the high-frequency content, which further lead to a significant increase in the spectrum-integrated value of the total power components. On the other hand, cold stimulus also resulted in the increase in EMG signals, but in the low frequency component.

Wahab et al. (2010) looked into effects of taste and smell stimuli on MEPs. MEPs were recorded from the submental muscles which were evoked using transcranial magnetic stimulation. Sixteen healthy adult participants were given concentrated and diluted (25%) lemon concentrate, along with water. The smell and taste were presented separately. MEPs during volitional swallowing and volitional contraction were recorded in different time intervals post stimulation, with taste and smell stimuli separately and then in combination. Immediate and late effects of the stimuli on amplitude and latency of MEPs were studied. No differences were noticed in any conditions except for the gender effects. But it was reported that the combined effects of odour and taste influenced neural pathway excitability which was only evident in measures taken during 90 min post stimulation.

Steele, Pascal, van Lieshout and Pelletier (2012) investigated the effects of taste and trigeminal irritation (chemesthesis) on tongue movement timing in liquid swallowing. Tongue movements were traced using electromagnetic midsagittal articulography (EMMA) while the participants were asked to swallow 5 different stimuli. The stimuli included 3 moderate concentration tastants without odour (sweet, sour, sweet-sour), and a high concentration of citric acid (sour taste plus chemesthesis). Thirty three healthy subjects were considered for the study, and were divided into two age groups. One of the groups consisted of 18 participants (9 males) under the age of 50 years and the other group consisted of 15 participants (6 males) over the age group of 50 years. Transducer coils were attached to anterior, middle, and posterior regions of the outstretched tongue. The researchers found a statistically significant main effect of stimulus for perceived taste intensity. It was also found that the perceived taste intensity did not vary between age groups or gender. Scrutiny of movement sequence frequencies, by event (onset, peak onset, peak termination, offset) revealed no particular patterns. Parameters considered for assessing duration of the tongue movements included total movement-envelope duration (ms), ride-phase duration (ms), Temporal location of first movement peak vs. terminal movement offset (ms), and release-phase duration (ms). The researchers observed significant main effect of stimulus on total tongue movement envelope durations, with no main effects of gender or age group and no interactions. The authors suggest that a wide variety of tongue movement sequences might be used to achieve a common functional goal, such as that of tongue pressure generation for bolus transport. They concluded stating that the study found no significant effects of taste or chemesthetic stimuli on the durational measures of tongue.

Dietsch, Solomon, Steele, and Pelletier (2014) studied the effect of barium on the perceived taste intensity and palatability in different taste and chemesthetic stimuli in 80 women who were equally divided in to two age ranges, a younger age group (18–35 years) and an older age group (60+ years). They were subdivided equally into supertasters and nontasters based on the genetic taste status. The study found that the barium affected the perceived taste intensity by suppressing it and also reducing the palatability of the stimuli. chemesthetic stimuli like ethanol and the taste stimuli like sour were reported to be less palatable in Hedonic General Labeled Magnitude Scale (HgLMS).

***Sour taste***

Among other tastes, sour, has been researched most due to its positive effects on swallow function. Research has shown that sour stimuli cause a hike in the submental muscle activity (Leow et al., 2007; Miura et al., 2009; Pelletier & Steele, 2014). Sour stimuli, contrasted with water and other tastes in typical participants, also led to an increment in oropharyngeal pressure (Wahab et al., 2010; Pelletier & Dhanaraj, 2006; Dietsch, et al., 2014; Pelletier & Steele, 2014), as well as the frequency of swallow (Nederkoorn, Smulders, & Jansen, 1999). This further leads to rapid occurrence of swallowing events (Hamdy et al., 2003; Chee et al., 2005). A sour bolus can cause a change in swallow timing (Logemann et al., 1995; Pauloski et al., 2013) and enhance safety of swallowing on the Penetration-Aspiration Scale (Pelletier & Lawless, 2003), in patients with swallowing disorders. Research in this regard have suggested that, sour stimuli triggers intense inputs in the superior laryngeal, facial, trigeminal, and glossopharyngeal nerves. These in turn lead to an increased synaptic firing within the brainstem swallowing central pattern generators. (Lewis & Dandy, 1930; Breslin & Huang, 2006). Taste may also result in enhancement of cortical activation in the swallowing network, including the activation in the areas like primary sensory area (S1) and the supplementary motor area (SMA) (Humbert & Joel, 2012).

Gatto et al. (2013) explored the influence of sour flavour as well as cold temperature on oral transit time within swallowing. Fifty two subjects, within the age range 50 to 80 years, diagnosed to be having oropharyngeal dysphagia post ischemic stroke, were considered for the study. Swallowing times were assessed and analyzed for 5 ml bolus of four different stimuli (natural, cold, sour and sour-cold), using VFSS. Paste consistency was used. Oral transit time and total oral transit time were considered as parameters. The interaction of cold as well as sour stimuli resulted in a considerable reduction of oral transit time and total oral transit time. They explained it in terms of the greater perception of bolus, resulting in highly conscious act of swallowing, which will facilitate a better oral control and faster swallow.

Mulheren et al. (2016) probed in to find whether taste had an effect on cortical activation in the swallowing network as well as swallowing frequency and whether taster status affected responses. 3 ml boluses of sour, sour with slow infusion, sweet, water, and water with infusion were compared on swallowing frequency and hemodynamic responses. While sweet and water did not result in any change, sour conditions caused an increase in swallowing frequency. In 15 healthy adults, functional near-infrared spectroscopy (fNIRS) was used to measure changes in cortical oxygenated hemoglobin (hemodynamic responses). The areas considered were in the right and left motor cortex, S1 and supplementary motor area. Changes measured by fNIRS were averaged over 30 trials for each condition, for 30 s following bolus onset. The peak hemodynamic response 2–7 s after bolus onset did not vary by taste, cortical location, or hemisphere. The mean hemodynamic response 17–22 s after bolus onset was larger in the sour and infusion condition than in the water condition, and highest in the motor regions of both hemispheres. Enhancement in the cortical swallowing was due to sour taste, as sour taste considerably increased both cortical activation as well as swallowing alike with and without slow infusion.

**Effect of chemesthetic stimuli on swallowing**

Literature suggests that increasing the sensory input by altering the sensory properties of bolus might boost the excitability of the central pathway and thereby trigger a faster and effective swallow in individuals with oropharyngeal dysphagia (Loret, 2015). The effect of different sensory alterations (taste, smell, temperature etc) was discussed above. Most of these sensations are mediated by the facial nerve. There are also few stimuli which are capable of evoking different sensation in the oral cavity. For example, ingestion of capsaicin or menthol would result in the sensation of heat and cold inside the oral cavity without any change in the internal temperature. In addition to the taste and smell food, there are often other chemical sensations like 'fizzyness' (example, after drinking carbonated drinks), which an individual experiences. This is due to the stimulation of trigeminal nerve, and is often referred to as chemesthesis. As mentioned, sensations of chemesthetic stimuli are mediated by the CN V and nucleus ambiguous instead of CNVII and nucleus tractus solitarius. Effect of chemesthetic stimuli have been studied by different authors, and have a positive found effect of these in triggering the swallowing. Chemesthetic stimuli includes stimuli like menthol, capsaicin, chilli pepper, carbonation, different tastes in higher concentration (for eg: higher concentration of citric acid, salt, etc) etc. Different studies have found effects of chemesthetic stimuli on swallowing (Pelletier

& Lawless, 2003, Bulow et al., 2003).

Bulow et al. (2003) reported what he examined in 40 patients (36 patients had neurological impairment) during a therapeutic videoradiographic swallowing study using three different consistencies: thin liquid, thick liquid and carbonation. The three parameters used to analyse swallowing were: penetration/aspiration, pharyngeal transit time as well as pharyngeal retention. They concluded that, in contrast to thickened thin liquid, carbonated liquid had the ability to decrease pharyngeal retention, lessen penetration/aspiration and cause a reduction in pharyngeal transit time.

Todd et al. (2012) explored the effects of different chemesthetic stimuli (citric acid, carbonation and ethanol) mixtures with barium on SAD. The variables considered for the study were age, different chemesthetic stimuli and genetic taste differences. Eighty women within two age ranges (within 18 to 35 years and above 60 years) were divided into two groups of 40 participants each. These groups were again divided into two equally, based on their genetic taste differences, ie., super tasters and non tasters. Main effects of age and chemesthetic stimuli were found to be significant along with the interaction effects of chemesthetic stimuli and taste. SAD was found to be significantly longer in older women. Among the chemesthetic stimuli, ethanol elicited a significantly longer SAD. No effects of carbonation on SAD were found. The longer SAD in older adults was attributed to either slower swallow or the compensatory mechanism to protect the airway longer.

Rofes, Cola and Clave (2014) reviewed the effects of different types of sensory stimulations on neurogenic oropharyngeal dysphagia. Stimuli considered for the review included chemical, mechanical, thermal and electrical stimuli. Chemical stimuli included acid, pungency, menthol and carbonation. The review reported positive effects of these stimuli on triggering swallow.

A pilot study (Lundine et al., 2015) examined whether carbonated thin liquids caused an improvement in swallowing compared to noncarbonated thin liquids in children with neurogenic dysphagia. VFSS was used to evaluate twenty-four children admitted for acute neurological injury/disease. In the statistical analysis, it was found that pooling of barium within the valleculae and pyriform sinuses prior to the swallow for carbonated thin liquids was noted significantly less often when compared to noncarbonated thin liquids. When compared to the other for 10 out of 24 participants, it was also found that significantly less penetration/aspiration occurred often with noncarbonated thin liquids. Scores on the Penetration-Aspiration Scale (PAS) were also noted to be significantly lower (indicating improved swallow function) for swallows with carbonated thin liquids. The authors concluded that carbonation shows promise in reducing penetration and aspiration in neurogenic dysphagia. This might not apply only to children but may also be true for adults and adolescents.

Sdravou et al., (2012) explored the effects of carbonated thin liquids on measures related to oral and pharyngeal stages of swallow, in individuals with neurogenic dysphagia. The study aimed to compare the effects of carbonated thin liquid with noncarbonated thin liquid on oropharyngeal swallow. They also tried to assess the palatability of the carbonated thin liquid. Participants considered for the study were individuals were diagnosed to be having oropharyngeal dysphagia secondary to a neurological lesion of central nervous system origin. A total of 17 individuals (5 women) underwent VFSS. The stimuli used were 5 ml, 10 ml and 25 ml each of carbonated and noncarbonated thin liquids, depending on the presence of aspiration or penetration. The outcome measures considered for the study was oral transit time (OTT), pharyngeal transit time (PTT), stage transition duration (STD), initiation of the pharyngeal swallow (IPS), penetration-aspiration scale (PENASP), and pharyngeal retention (PR). Palatability of the stimuli was assessed using a modified Quartermaster Hedonic Scale (AQHS). It was found that carbonated thin liquids did not show significant effects on OTT, PTT, IPS and PR. But the penetration and aspiration was found to have significantly decreased for 5 ml and 10 ml of carbonated thin liquids compared to noncarbonated thin liquids. Only one participant disliked the carbonate liquid, revealed the palatability measure. The indifference in the temporal measures was attributed to the lack of a priori screening to check whether the measures are affected or not, and also to the heterogeneity in the etiology of the neurological lesions in participants.

Pelletier and Steele (2014) explored the effects of perceived taste intensity of the chemesthetic liquid boluses (a high intensity sour stimulus, carbonated stimulus, and diluted ethyl alcohol) on the lingua-palatal pressures and sEMG in swallowing. Study was conducted in 80 healthy women were equally divided in to two age ranges, a younger age group (18–35 years) and an older age group (60+ years). Genetic tester status were also considered for the study (ie., supertasters and nontasters). A significant difference in the taste intensity was found for the sour stimulus followed by ethanol and carbonated water, and finally the water. Super tasters reportedly perceived a greater taste intensity compared to the nontasters. It was also observed and noted that the high intensity sour stimuli elicited a significantly higher anterior palate pressures and sEMG amplitudes compared to other stimuli.

An extensive review of literature suggests that, even though there are several studies looking into effects of taste and chemesthetic stimuli on different aspects of swallow, none of them specifically point to the effects of taste and/or chemesthetic stimuli on the hyolaryngeal elevation. Hence, the current study is an attempt to examine effects of taste and chemesthetic stimuli on the hyolaryngeal elevation of swallow. Like how sensory properties of bolus (as described above) can affect different parameters of swallowing, the physical properties like volume can also influence the parameters.

**Effect of bolus volume on swallowing**

There is extensive research on how the bolus volume affects swallowing (Dantas et al, 1990; Logemann et al., 2000; Butler et al., 2004, Lin, et al., 2014, Nascimento, Cassiani, Santos, & Dantas, 2015). It is observed that the oral and pharyngeal cavities change its properties depending on the size of the bolus to accommodate it. Different studies have shown that the opening of UES is longer for a larger bolus (Dantas et al., 1990; Logemann, Pauloski et al., 2000). There are also findings showing that there are changes in tongue with respect to direction and speed, and velopharyngeal movements (Dantas et al., 1990; Kahrilas & Logemann, 1993; Tasko, Kent, & Westbury, 2002), laryngeal dynamics like elevation of hyoid, and hyolaryngeal complex (Nagy et al., 2014; Nascimento et al., 2015). In a study, it was found that larger boluses compared to relatively smaller boluses, elicited higher peak velocities across the hyoid movement trajectory (Nagy, Molfenter, Péladeau-Pigeon, Stokely & Steele, 2014).

In a study by Nagy et al., (2014), videofluoroscopic data of 20 (10 male and females each) healthy young participants were analyzed to determine the effect of liquid bolus volume 5 to 20 ml on different aspects of hyoid movement. The study looked into whether; the increase in bolus volume from 5 to 20 ml caused these aspects to vary systematically. The outcome measures considered were hyoid movement distance, duration, velocity, and peak velocity. The temporal correspondence between laryngeal vestibule closure and peak hyoid velocity was also investigated. It was revealed that there was a significant increase in maximum hyoid position and peak velocity for 20mL bolus volumes compared to smaller volumes. And also, to achieve laryngeal vestibule closure is closely linked timing of peak velocity. This result proposes that generation of hyoid movements with greater power is a tactic for managing larger volumes.

Nascimento et al., (2015) evaluated swallowing using videofluoroscopic evaluation in 30 healthy adult participants within the age range of 29-77 years. The subjects were instructed to swallow 5 ml and 10 ml of thick liquid barium and honey thick barium, twice. They computed the duration of oral transit, pharyngeal transit, pharyngeal clearance, oropharyngeal transit, hyoid movement, and upper esophageal sphincter opening. They also looked into the relation between pharyngeal clearance duration and hyoid movement duration. It was observed that a longer UES opening duration was caused by a larger (10 ml) bolus volume than a smaller (5 ml) bolus volume. This was observed for both consistencies. It was also observed that with both the volumes of 5 ml and 10 ml, there was a longer pharyngeal transit for honey thick bolus consistency than for thick liquid. When pharyngeal clearance was considered, there was only significant difference with the bolus volume of 10 ml. No difference was found associated with bolus volume or consistency in the relation between hyoid movement duration and pharyngeal clearance duration. The proportion between hyoid movement and pharyngeal clearance does not change with bolus consistency or bolus volume.

**Effect of gender on swallowing**

Research has shown that the swallowing physiology varies across gender. Alves, Cassiani, Santos, and Dantas (2007) found that the gender is having an effect on water swallowing dynamics, with men having a higher swallowing velocity and a larger volume capacity in each swallow than women. Dantas, Cassiani, Santos, Gonzaga, Alves, and Mazin, (2009) in their study using VFSS found that there were differences in swallowing between men and women. It was reported that, for a 5-ml bolus women had a longer oropharyngeal transit than men. Molfenter and Steele (2012) investigated variation in temporal measures of swallowing across volume andgender, using VFSS, and found no significant difference across gender, but bolus volume significantly affected the duration of UES opening. It also impacted laryngeal closure duration, the pharyngeal transit time interval, and the laryngeal closure-to-UES opening interval. But the hyoid movement duration or the stage transition duration interval was found to have no effect.

Alves et al. (2007) conducted a study among 111 healthy adults (75 women) within the age range of 24-77 years, to evaluate the gender effect on timed water swallowing test. Results revealed shorter inter swallow interval in women, where as in men, faster swallowing velocity and higher volume capacity. The authors primarily attributed the results to the anatomical variations between men and women (larger oral and pharyngeal cavity in men). Authors also postulated the possible involvement of differences in the coordination of swallowing and breathing, and other physiological aspects.

Dantas et al. (2009) investigated the effect of gender on swallowing by considering the swallow event duration using VFSS. The study considered 18 men and 12 women, who were provided with 5 and 10 ml of liquid and paste barium boluses. Women were found to have longer duration measures of swallow, compared to men. Time required for oral transit, pharyngeal transit and pharyngeal clearance was found to be longer in women, which was attributed to the anatomical and physiological differences between men and women. Wahab, et al., (2010) reported that males were found to have larger MEP amplitude compared to females, when taste stimuli were presented.

To summarize, the core anatomical structures involved in the airway protection are the hyolaryngeal complex and the related structures. A look into the literature suggests that sour taste exhibits positive effects in enhancing swallow physiology. There are also studies shedding light on the effects of chemesthetic stimuli like carbonation on improving swallow physiology. It can be noted that most of the studies done in this area makes use of techniques like FEES, VFSS, EMG etc. for the purpose of measuring outcome variables. It can also be noted that mostly studied anatomical structure is hyolaryngeal complex, for its primary importance in the airway protection. One could observe that the studies involving the use of a non-invasive method like digital accelerometry for swallowing imaging, which is more accessible and affordable for most clinicians, is comparatively lesser. There is a dearth of literature in the area of research which looks in to the effects of sensory properties of bolus, specifically with respect to taste and carbonation, with different volumes and across males and females, on hyolaryngeal elevation of swallowing, using such non-invasive procedure like accelerometry. Hence, the current study was planned to investigate the effect of different stimuli (sour, carbonated and neutral), in two volumes (5 ml vs 15 ml), across males and females, on the hyolaryngeal elevation of swallow.

# Chapter III

# Methods

The current study aimed at investigating the effects of different stimuli (sour, carbonated and neutral), and two volumes (5 ml and 15 ml) on the hyolaryngeal elevation of swallow in young healthy adults.

## Participants

Healthy adults within the age range of 18-35 years were considered for the study. Participants were recruited from in and around the campus of All India Institute of Speech and Hearing, Mysuru. Demographic details of the participants were collected using a Google form created for the same purpose. A total number of 60 participants (30 males and females each), with no history of neurological disease, psychological illness, cognitive communicative and sensory deficits, were considered for the study. These were ruled out using informal assessment and interview. Individuals diagnosed to be having dysphagia previously, individuals with pathological anatomical and physiological alterations, related to swallowing, were not considered for the study. Individuals reported to be having swallowing difficulties (including pain, slowness etc), and individuals with taste and smell disorders, individuals who were allergic to the taste stimuli were excluded. History of smoking and alcoholism was ruled out and those who were chronic smokers and alcoholics were not included in the study. Individuals who had chronic obstructive pulmonary disorder and individuals who had been under a diagnosis and/or management of reflux were not included. Different conditions like epilepsy or other eating disorders, neurological disorders, psychiatric disorders etc. were also ruled out. Individuals with history of intake of neuroleptic drugs/ toxins were not the part of study.

All ethical procedures were followed. Prior to the testing procedure, the study and its purpose were explained to the participants and a written consent was obtained individually from each one of them.

**Instrumentation and Materials**

Digital Accelerometry Swallowing Imaging (DASI$^{TM}$, Elixir Research, USA) was used to measure the hyolaryngeal elevation during the swallowing event. This instrument uses the accelerometric principles to track the movement of hyolaryngeal complex during swallowing. DASI$^{TM}$ is software which runs on MS-DOS. DASI has a flexible piezoelectric accelerometer sensor used to measure the movement of the hyolaryngeal structure of the participant. DASI$^{TM}$ is easy to use, flexible, provides a real time display and can be used for the purpose of assessment and intervention of persons with swallowing difficulty. This procedure is relatively easy, less time consuming and requires minimal response from the patient. Furthermore, this is a non-invasive procedure and does not expose the individual to any kind of harmful radiation.


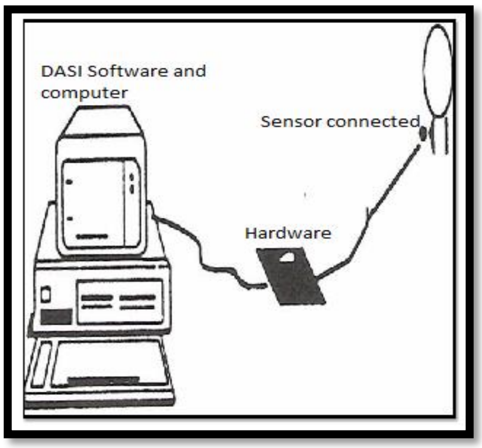


*Figure 3.1.* Instrument used for the study.

Eating Assessment Tool-10 (EAT- 10) (Belafsky, Mouadeb, Rees, Pryor, Postma, Allen, & Leonard, 2008) was used to screen for swallowing disorders. It is a self-administered, symptom-specific tool. A score of 3 or higher on this tool is indicative of dysphagia. Collection of demographic details and administering of EAT-10 was carried out by asking the participants to fill out a Google form made for the same purpose. All the individuals who obtained a score of three or less were included in the study.

Hedonic general Labeled Magnitude Scale (gLMS) was used to rate the perception of intensity and palatability of the stimuli. It is a combination of hedonic rating scale which measures palatability, and general Labeled Magnitude Scale (gLMS) (Bartoshuk et al., 2004) which measures the intensity of sensory stimuli. It is a visual analogue scale of 100 mm, which ranges from the scores -100 to +100 which have equal 10mm intervals, but the taste intensities are represented in unequal intervals. The -100 is “most intense displeasure of any kind ever experienced” and +100 is “most intense pleasure of any kind ever experienced”. This helped in looking into the perceptions and palatability of the test stimuli. Figure 3.2 depicts Hedonic general Labeled Magnitude Scale (HgLMS).

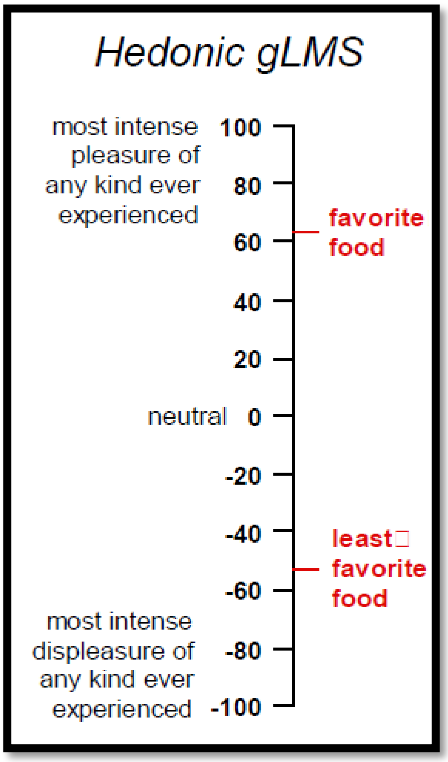


*Figure 3.2.* Hedonic general Labeled Magnitude Scale (HgLMS).

**Stimuli**

Different stimuli were presented based on the taste properties (Neutral: Water, Sour: Lemon juice concentrate, Chemesthetic stimuli: carbonated drink). The stimuli were chosen from commercially available, edible products. Lemon juice concentrate was diluted (50%) with water. Club soda of no specific taste was chosen for carbonated stimulus. Each stimulus was presented in two volumes, that is, 5 ml and 15 ml. This was measured in the measuring spoons shown in the figure 3.3.

*Figure 3.3.* Spoons used for measuring for 15 ml and 5 ml.

**Procedure**

Hyolaryngeal movements were recorded from the time of presentation of the bolus to the client's mouth to complete swallow of the bolus, using the DASI.

*Preparation of the participant:* The participant was asked to sit upright comfortably in a chair and the procedure was explained. All the recordings were made in a single sitting for all the participants. The participant was instructed prior to the experiment as follows "Be as relaxed as possible. Keep your head in normal position. Avoid any head or bodily movements and also avoid talking once the test begins. You will be given two liquids to drink. One is thin liquid which is purified water and the other is thicker liquid which is the yogurt. I will place this sensor on your neck and will also use a neck collar to tighten and also to ensure that the sensor is in place. The liquids will be given to you and you have to pour it in your mouth. Once I instruct you to swallow, you have to swallow and swallow the entire liquid as normal as possible. If you feel any kind of difficulty or if you are uncomfortable, indicate by raising your hand".

The piezoelectric sensor of the accelerometer was placed on the hyolaryngeal complex (specifically cricothyrotomy region between the thyroid and cricoid cartilages on the midline) and a neck collar was used to keep the sensor in place during the entire evaluation session. The area of sensor placement was cleaned using disinfectant, prior to the testing. The piezoelectric sensor used for the study has been shown in the figure 3.4.


*Figure 3.4* Piezoelectric sensor used for the study.

Initially the participants were asked to perform a dry swallow in order to locate the thyroid and hyoid. The hyolaryngeal space for the sensor placement was identified using Logemann's four finger test (Logemann, 1998), by placing the index, middle, ring and little finger, under the chin, hyoid bone, thyroid and below thyroid, respectively. The piezoelectric sensor was placed in the identified space (cricothyrotomy region), between thyroid and cricoid.

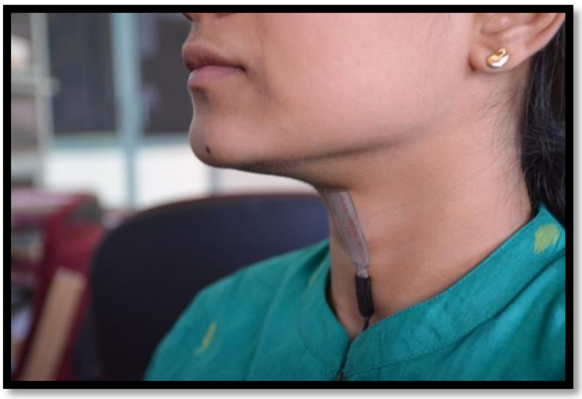

*Figure 3.5.* Placement of piezoelectric sensor in hyolaryngeal area.

Dry swallow was performed in the beginning to establish a baseline and to familiarize the test procedure. The test stimuli were presented through a small cup, in an ambient temperature, sitting erect in a chair. The participants were given 5 minute break-period between different stimuli and they were asked to rinse their mouth with water, during the end of that duration. The figure 3.6 depicts the paradigm used in the experiment.


*Figure 3.6.* Paradigm used in the experiment.

Randomization of stimuli: The stimuli were presented in random order to prevent the order effects. Six groups of stimuli orders were obtained using permutations and combinations. It included

- Group 1: Sour→Carbonated→Neutral
- Group 2: Sour→Neutral→Carbonated
- Group 3: Neutral→Sour→Carbonated
- Group 4: Neutral→Carbonated→Sour
- Group 5: Carbonated→Neutral→Sour
- Group 6: Carbonated→Sour→Neutral

**Reliability assessment**

In order to ensure test-retest reliability, the 10% of the samples were randomly selected and reanalyzed, after one week of the recording. Measures from 6 participants (3 each from both males and females) were randomly selected and retested.

**Analysis**

From the recorded data, measures of interest were derived. The measures that were considered for the study included the mean amplitude and the mean duration of hyolaryngeal elevation. The independent variables were the three stimuli (sour, neutral and carbonated bolus, two volumes (5 ml and 15 ml) and gender. The dependent variables were the amplitude and duration of hyolaryngeal excursion. The figure 3.7 shows a sample of recorded waveform of dry swallows performed on instruction, prior to the recording of wet swallows using stimuli. The wave form of dry swallow is presented because of the ease of depiction of measures of hyolaryngeal elevation considered for the present study.

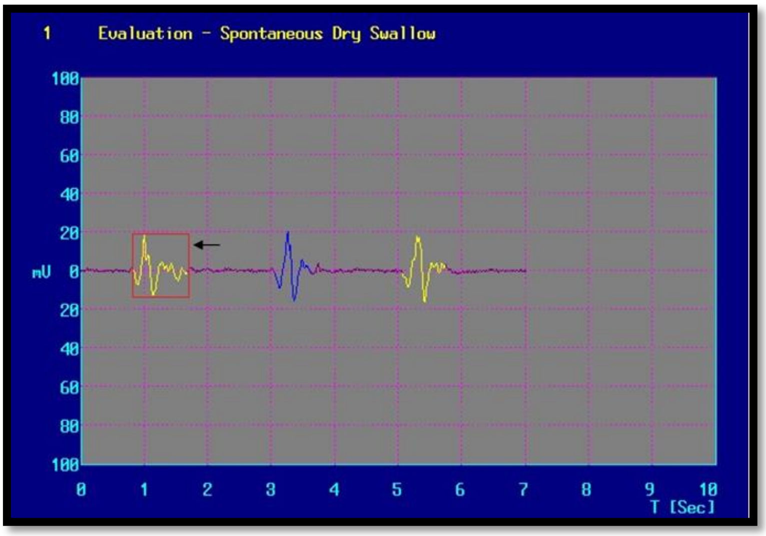


*Figure 3.7.* Three spontaneous dry swallows (the swallow in the red box is zoomed in the next figure).

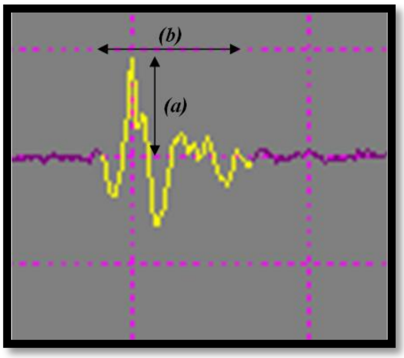


*Figure 3.8.* Parameters considered for the study (a) amplitude and (b) duration of swallow.

**Pilot study**

A pilot study was conducted prior to the study to check for the feasibility of measurement. Data was collected from two young healthy adults within the same age range specified for the study. Hundred percentage concentrated lemon juice and club soda was used as stimuli for sour and carbonated conditions respectively. Both the participants reported the sour stimuli (100% concentrated) to be highly unpleasant and uncomfortable and refused to test for further trials. Hence, it was decided to take the stimuli intensity for sour condition to be 50% concentrated lemon juice. It was noted that the whole procedure including preparation of the participant and testing took around 25 to 30 minutes.

**Statistical analysis**

Statistical analysis was performed using IBM SPSS Statistics Version 20.0 software. Cronbach's Alpha test was used to assess the test retest reliability of the data. Mean, median and standard deviation was obtained using the descriptive statistics. Normality was checked using Shapiro Wilk's test of normality. A non-parametric test (Mann-Whitney U test) was administered to compare between males and females. Within group comparison (taste and volume) was done using Friedman's test and when a significant difference was found between different groups, Wilcoxon's signed rank test was performed.

# Chapter IV

## Results and Discussion

The aim of the study was to explore the influence of sour and carbonated bolus on the hyolaryngeal elevation. The specific objectives of the study were to investigate the influence of sour and carbonated bolus, in comparison with a neutral stimuli and the effect of two volumes (5 & 15ml) of each stimuli on the duration and amplitude of hyolaryngeal elevation, and to assess the differences across gender, if any, on the hyolaryngeal elevation in different stimuli and volume conditions.

Data obtained from the three swallow trials for each participant was subjected to Shapiro-Wilk's test for normality. Since results revealed non-normal distribution, a nonparametric test (Friedman's test) was done to compare the trials in each task. The results revealed no significant difference across the trials. Hence, the average of three swallow trials was considered for the further analysis. Shapiro-Wilk's test for normality was performed for the averaged scores obtained for three trials, and the results revealed non-normal distribution. Descriptive statistics was performed to compute the mean, median and standard deviation. The following statistical procedures were used:

1. Cronbach's alpha test was administered to assess the test-retest reliability.
2. Non-parametric test (Mann-Whitney U test) was administered to compare the duration and amplitude values across gender.
3. Non-parametric test (Wilcoxon's Signed Rank test) was administered to compare the duration and amplitude values across volumes (5ml and 15 ml).

4. Non-parametric test (Friedman's test) was administered to compare the duration and amplitude values across three different taste stimuli (sour, carbonated and neutral).

The results obtained have been presented and discussed under each of the sections below:

## I. Test retest reliability

Test-retest reliability assessed using Cronbach's Alpha test, for amplitude and duration measures of hyolaryngeal elevation, for a randomly selected 10% of participants, revealed $\alpha$ values of 0.92 and 0.91 respectively, which indicated excellent test-retest reliability.

## II. Comparison of hyolaryngeal elevation between males and females

One of the objectives of the study was to compare the values obtained for measures of hyolaryngeal elevation between males and females. Males and females were compared for two different volumes (5 ml and 15 ml) across three different stimuli (sour, carbonated, and neutral) using descriptive statistics. The mean and standard deviation have been depicted in table 4.1. It can be seen from the table that the males had higher mean values for amplitude and duration across the different stimuli and volumes. The greater values were noted for males compared to females, in all the conditions, except for the duration values obtained for 5 ml carbonated stimuli.

Table 4.1

*Mean and Standard deviation (S.D) obtained for different measures (amplitude and duration) of hyolaryngeal elevation with respect to gender (males and females), volumes (5ml and 15 ml) and three taste stimuli (sour, carbonated and neutral).*

| **Taste** | **Measures** | **Volume** | **Female (n=30)** | | **Male (n=30)** | | **Total (n=60)** | |
|---|---|---|---|---|---|---|---|---|
| | | | **Mean** | **S.D** | **Mean** | **S.D** | **Mean** | **S.D** |
| **Neutral** | Amplitude | 5 ml | 19.04 | 11.26 | 24.17 | 13.45 | 21.61 | 12.57 |
| | | 15 ml | 19.26 | 9.24 | 22.02 | 12.76 | 20.64 | 11.13 |
| | Duration | 5 ml | 1.24 | 0.36 | 1.34 | 0.31 | 1.29 | 0.34 |
| | | 15 ml | 1.35 | 0.39 | 1.42 | 0.37 | 1.38 | 0.38 |
| **Sour** | Amplitude | 5 ml | 24.39 | 10.26 | 26.69 | 12.53 | 25.54 | 26.27 |
| | | 15ml | 24.81 | 10.37 | 27.72 | 10.19 | 11.41 | 10.30 |
| | Duration | 5 ml | 1.73 | 0.63 | 1.98 | 0.67 | 1.85 | 0.66 |
| | | 15 ml | 1.98 | 0.74 | 2.31 | 0.75 | 2.14 | 0.76 |
| **Carbonated** | Amplitude | 5 ml | 20.69 | 11.82 | 22.72 | 11.86 | 21.71 | 11.78 |
| | | 15 ml | 21.55 | 9.62 | 24.06 | 10.72 | 22.81 | 10.18 |
| | Duration | 5 ml | 1.42 | 0.44 | 1.37 | 0.38 | 1.39 | 0.41 |
| | | 15 ml | 1.42 | 0.46 | 1.59 | 0.46 | 1.51 | 0.46 |

Mann-Whitney Test was administered to compare the amplitude and duration values of hyolaryngeal excursion between genders. The results of the Mann-Whitney test has been depicted in table 4.2. The results revealed no significant difference in the amplitude and duration of hyolaryngeal elevation across gender. The mean values of amplitude and duration across gender in different stimuli conditions have been depicted in figure 4.1.

Table 4.2

*Results of Mann-Whitney test (/z/ and p value) in comparison of values obtained for males and females*

| | **Measures** | | **/z/ value** | **p value** |
|---|---|---|---|---|
| **Neutral** | Amplitude | 5 ml | 1.34 | 0.18 |
| | | 15 ml | 0.50 | 0.62 |
| | Duration | 5 ml | 1.37 | 0.17 |
| | | 15 ml | 0.84 | 0.42 |
| **Sour** | Amplitude | 5 ml | 0.50 | 0.62 |
| | | 15ml | 1.06 | 0.29 |
| | Duration | 5 ml | 1.61 | 0.11 |
| | | 15 ml | 1.66 | 0.10 |
| **Carbonated** | Amplitude | 5 ml | 0.48 | 0.63 |
| | | 15 ml | 0.84 | 0.40 |
| | Duration | 5 ml | 0.45 | 0.65 |
| | | 15 ml | 1.84 | 0.24 |

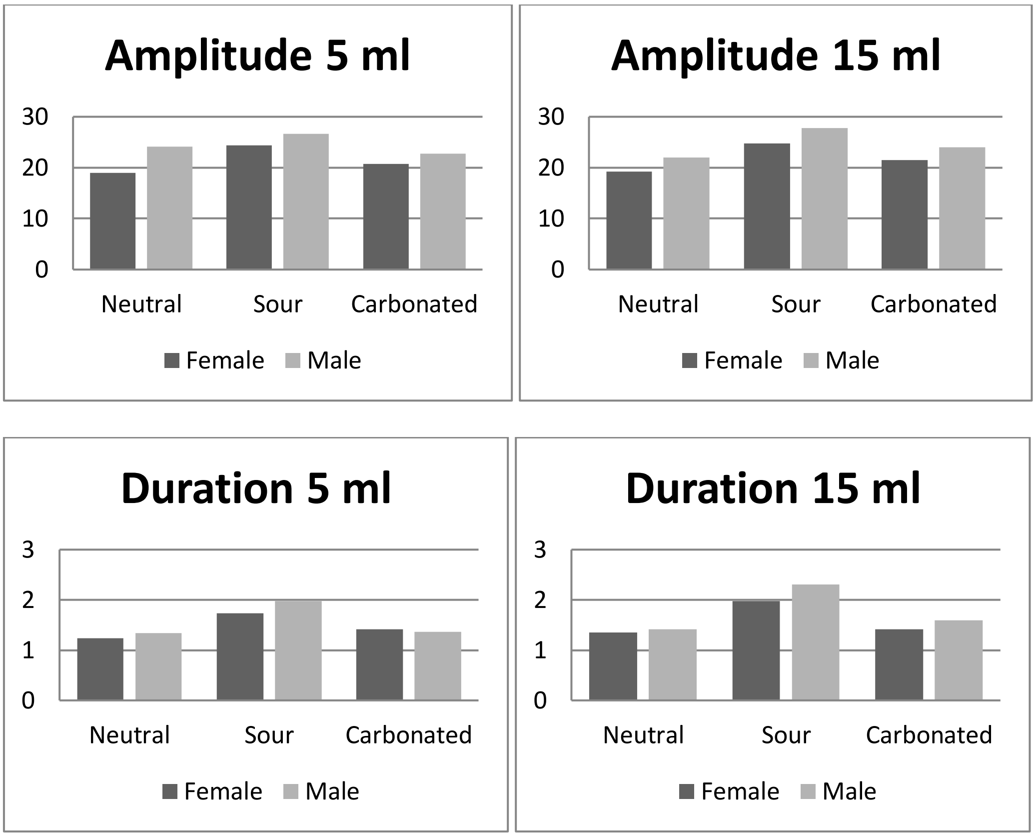


Figure 4.1: *Mean values of amplitude and duration across gender in different stimuli conditions.*

The result of the current study is in agreement with previous studies on the maximum vertical and anterior displacement of hyoid bone during swallow, using videofluoroscopic swallowing exams. The results of Kim and McCullough (2008)'s study revealed no significant difference across gender, when tested using 5 ml and 10 ml swallows, in the younger as well as older age groups. Yet another investigation (Ragland, Park, McCullough, & Kim, 2016) done on the speed of hyolaryngeal excursion revealed no significant difference between males and females. The same study reported a non-significant difference between young males and females with respect to volumes, that is, younger females exhibited higher mean velocity of hyoid movement for 10 ml stimuli, where as younger males observed higher mean velocity of hyoid movement for 5ml stimuli. Velocity being calculated by dividing displacement with duration, the current study can be said to be in concordance with the findings of Ragland et al. (2016).

There are also investigations showing mixed results. For example, a study by Logemann, Pauloski, Rademaker, and Kahrilas (2002) found significant difference between males (Logemann et al., 2000) and females in the measures of hyolaryngeal elevation for 10ml stimuli and not for 1 ml stimuli. In this study, the videofluoroscopic analysis of 8 young females within the age range of 21 and 29 years were compared with the previous research done with male subjects. Different measures of duration and range of movements were looked into. It was found that in the younger subjects, males were reported to have significantly greater movement than young females on laryngeal elevation, anterior laryngeal movement, and hyoid elevation at first cricopharyngeal opening, maximal laryngeal elevation, hyoid elevation, and anterior hyoid movement. But in contrast, females were reported to have long durations of swallowing events. This differences in results could be attributed to the methodological variations such as differences in age groups considered and the parameters looked into. The study by Logemann et al. (2002) did not investigate the amplitude and durational aspects of hyolaryngeal elevation with respect to different taste stimuli. Hence it becomes difficult to compare the findings of the present study with this study. Alongside that, there are not many studies done using accelerometry, making the comparison of the current study with the available literature, even complicated.

Additionally, research has shown that there was an effect of gender on different other parameters of swallow (Alves, Cassiani, Santos, & Dantas, 2007; Dantas et al., 2009; Humbert et al., 2018). For example, Alves et al. (2007) found that women had shorter inter-swallow interval, slower swallowing velocity and lower volume capacity compared to men, in 50 ml water swallow test, by observing the elevation of larynx. Dantas et al. (2009) also reported similar finding by analyzing videofluoroscopic examinations of men and women. They found that males had shorter oropharyngeal transit times compared to females for 5 ml bolus. Humbert et al. (2018) reported gender effects on different duration related kinematic measures. The study found that males had statistically higher duration values on different kinematic measures of swallowing. Thus, from these studies it can be seen that there are some differences between males and females on other swallow parameters, which could be attributed to the anatomical and physiological differences in the swallow mechanism. In the present study too, the males were found to have a higher mean amplitude and duration of hyolaryngeal excursion than females, though these were not statistically significant. This can possibly be explained by the anatomical differences (Alves et al, 2007; Dantas et al., 2009; Ragland, Park, McCullough, Kim, 2016; Humbert et al., 2018) with respect to hyolaryngeal elevation, for example, the resting position of hyoid (Ishida et al., 2002), presence of laryngeal prominence (Fitzpatrick & Siccardi, 2018) etc. The lower resting position of larynx in males allows greater displacement and range of motion in them compared to females. Having prominent larynx in males adds on to the advantage in males adds on to higher amplitude values. This is because the piezoelectric sensor picks up the movements better with a prominent larynx (the bending of the sensor is more when there is laryngeal prominence compared to when there is not). An ultrasonographic study assessing hyoid kinematics (Chi-Fishman & Sonies, 2002) found gender differences in the related parameters and found greater amplitudes in males compared to females.

An additional observation was that the males with notable thyroid prominence exhibited high amplitude negative peaks in the accelerometry signals. Since this negative amplitude is not considered by default for the computation of amplitude measure, this could have lead to the lack of significant difference between male and female groups (see figure 4.2).

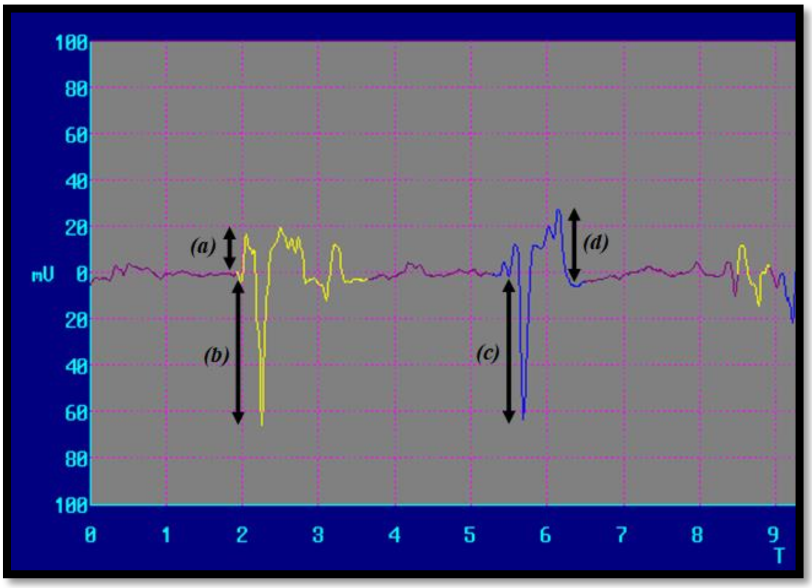


*Figure 4.2* Swallowing accelerometry signal with higher amplitude negative peaks, obtained for a male participant.

In the figure 4.2, *(a) and (d)* are the positive peaks, and (b) and (c) are the negative peaks. It can be seen that the negative peaks are prominent compared to the positive peaks. Since the instrument calculates only the positive values for amplitude measurement, these negative peaks are ignored. It can be assumed that the results would have shown a different story, if these peaks were considered.

Similarly Molfenter and Steele (2014) reported greater hyolaryngeal excursion in males compared to females, using videofluoroscopic analysis of 5 ml, 10 ml and 20 ml swallows. The study concludes that the hyoid excursion is dependent on the size of the person. According to them, the hyoid excursion during swallowing is dependent on a person's size (size-of-the-system). Taller individuals have longer cervical spine length and demonstrate greater superior displacement, hypotenuse displacement and maximal XY position of the hyoid. When measurements do not control for the influence of size-of-the-system, sex differences in hyoid excursion are observed.

### III. Comparison of hyolaryngeal elevation across stimuli

The primary aim of the study was to find whether there was any effect of different stimuli on hyolaryngeal elevation of swallow. Higher mean values of amplitude and duration were observed for sour stimuli in comparison to the two other stimuli. Also, carbonated stimuli were found to have mean values higher in amplitude and duration, compared to neutral stimuli (Table 4.1).

Friedman's test was done to check the difference in the measures of hyolaryngeal elevation across different stimuli (sour, carbonated and neutral). The chi-square values and *p* values have been depicted in the table 4.3. The results revealed that there was a high significant difference in both the amplitude and duration measures of swallow with respect to different taste stimuli. Significance difference was found for amplitude and duration measures across different tastes in both 5 ml and 15 ml volume conditions.

Table 4.3

*Results of Friedman's Test (comparing tastes irrespective of gender)*

| Measures | Volume | Chi-Square | /p/ value |
|---|---|---|---|
| **Amplitude** | 5 ml | 12.31 | 0.00** |
| | 15 ml | 26.67 | 0.00** |
| **Duration** | 5 ml | 26.95 | 0.00** |
| | 15 ml | 47.67 | 0.00** |

** p<0.01 indicates highly significant difference

The pair-wise comparisons of different taste stimuli using Wilcoxon signed ranks test revealed highly significant differences between sour and neutral as well as carbonated and sour in both 5 ml and 15 ml volume conditions for both amplitude and duration measures. No statistically significant difference was noted between the carbonated and neutral stimuli. Figure 4.3 depicts amplitude and duration measures across different taste stimuli with respect to two volumes (5ml and 15 ml). The /z/ and p value shave been depicted in table 4.4.

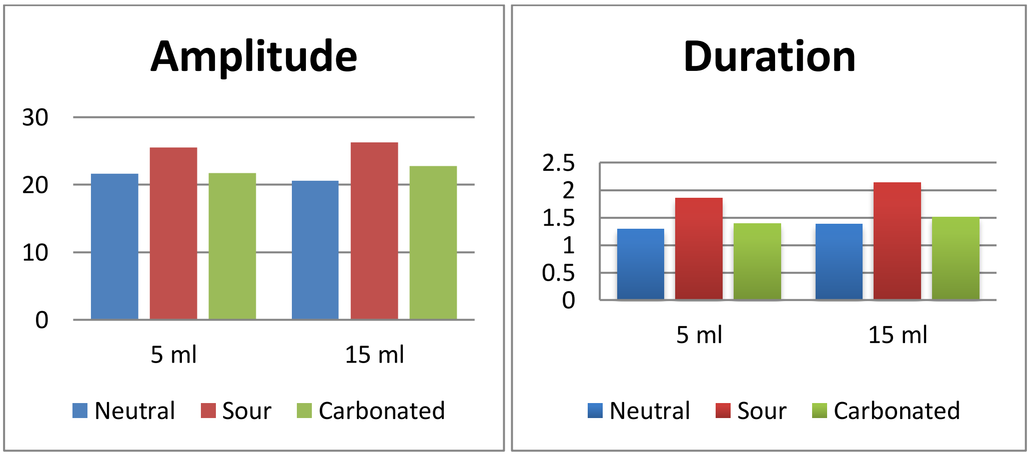


Fig. 4.3: *Graphical representation of amplitude and duration measures across different taste stimuli with respect to two volumes (5ml and 15 ml).*

Table 4.4

*Results of the Wilcoxon signed ranks test across different stimuli irrespective of gender*

| **Measures** | **Volume** | **Taste pairs** | **/z/ value** | **p value** |
|---|---|---|---|---|
| **Amplitude** | 5 ml | Sour vs. Neutral | 2.94 | 0.00** |
| | | Carbonated vs. Neutral | 0.41 | 0.69 |
| | | Carbonated vs. Sour | 3.18 | 0.00** |
| | 15 ml | Sour vs. Neutral | 4.23 | 0.00** |
| | | Carbonated vs. Neutral | 1.65 | 0.10 |
| | | Carbonated vs. Sour | 3.56 | 0.00** |
| **Duration** | 5 ml | Sour vs. neutral | 5.49 | 0.00** |
| | | Carbonated vs. Neutral | 1.65 | 0.10 |
| | | Carbonated vs. Sour | 4.51 | 0.00** |
| | 15 ml | Sour vs. Neutral | 5.98 | 0.00** |
| | | Carbonated vs. Neutral | 2.40 | 0.41 |
| | | Carbonated vs. Sour | 5.47 | 0.00** |

****** $p<0.01$ indicates highly significant difference

The current study found mean amplitude and duration of hyolaryngeal elevation for the sour stimuli to be significantly higher than carbonated and neutral taste stimuli, for both 5ml and 15 ml, irrespective of gender. Support for the results of the current study can be drawn from a few earlier studies which report that the taste stimuli has an effect on swallowing measures such as submental and infrahyoid muscle activation (Ding et al., 2003), swallowing speed, inter-swallow interval and swallowing capacity (Chee et al., 2005), peak lingual swallowing pressure (Pelletier & Dhanaraj, 2006), oral preparation time, submental sEMG amplitude, and duration

(Leow et al, 2007), oral transit time (Gatto et al, 2013), swallow apnea duration (Todd et al, 2012), and lingua palatal pressures and sEMG (Pelletier & Steele, 2014). Other studies report that the sour stimuli facilitate faster transit times (Gatto et al., 2013). Sour stimuli were found to have larger mean values for amplitude and duration measures of hyolaryngeal elevation, in the current investigation in comparison to other stimuli. Among the above mentioned studies, Chee et al. (2005) reported reduced swallowing speed for citrus (sour) stimuli. The authors explains this in terms of increased awareness of the bolus due to the presence of a strong flavour, which results in greater concentration and care while swallowing, thereby resulting in greater duration.

Leow et al. (2007) had reported that sour stimuli results in greater amplitudes of submental activation. This finding can be assumed to be related to the greater amplitude of hyolaryngeal elevation seen in the present study. The greater amplitude of muscle activation could be because of its involvement in laryngeal elevation. Literature suggests that the submental muscles like mylohyoid, geniohyoid, and anterior digastric plays vital role in hyolaryngeal elevation (Pearson, Langmore, Yu, & Zumwalt, 2012; Pearson, Langmore, Hindson, & Zumwalt, 2013).

Carbonated liquids, among other chemesthetic stimuli, is proved to show positive effects in facilitating faster and better swallows (Krival & Bates, 2012; Elshukri, 2012). But the present study found no significant difference between carbonated and neutral stimuli in amplitude and duration measures of hyolaryngeal elevation. This could be because of the variation in amount of carbonation. The way of presentation of stimuli (cup drinking) could have acted as the cause for lessening the “fizzyness” in the carbonated stimuli. If the taste aspect of different stimuli is considered, the carbonated stimulus is nothing but neutral stimulus (tasteless) with a little added fizzy sensation (chemesthesis). So, if the fizzy aspect is less, it could act like a neutral stimulus. The lesser intensity or amount of carbonation would have lead to the lack of significant difference between neutral and carbonated stimuli in the current study.

The results overall, suggest a positive effect of sour taste and carbonation on the hyolaryngeal elevation of the swallow. These findings are in consonance with the previous research. The sour (Mulheren, et al., 2016) and carbonated (Elshukri, Michou, Mentz, Hamdy, 2016) stimuli results in greater cortical activation resulting in triggering of a stronger and faster swallow. The presence of a strong taste and/or chemesthesis (sour and carbonation respectively, in the present study) causes a heightened perception there by increasing the sensory stimulation resulting from the bolus. An increased sensory stimulation leads to an enhancement in the awareness of the bolus in the oral and pharyngeal cavity. This, will in turn, possibly, result in greater activation of cortical centers mediating swallowing, leading to further alterations in the swallowing functions, in the present scenario, with respect to duration and amplitude of hyolaryngeal elevation of swallow. Elshukri et al., (2016) even suggested that presenting of these stimuli even leads to an increase in the corticobulbar excitability for around an hour and can even induce neuroplasticity.

However, the study done by Elshukri (2012) is in dissonance with the current study. He found that carbonated stimuli performed better than sour and neutral stimuli, in cortical excitation and successful swallows. This could be because of the variability in the stimuli used for the study, for example, with respect to the ‘fizzyness’ of carbonation and intensity of sourness.

Different studies on the palatability of taste stimuli (Pelletier & Dhanaraj, 2006; Pelletier & Steele, 2014) have not delineated any effects on the correlation between the perception of taste and the parameters of swallowing. The current study also did not find any trend in the perception of different taste stimuli. The HgLMS ratings for different stimuli revealed perceptual differences across different stimuli (Figure 4.4). It can be noted that taste of water (neutral stimuli) was perceived as "neutral" itself by majority of the participants, while rest of them perceived its taste to be pleasant. The perceptual reports of carbonated stimuli showed mixed findings, where some individuals found it to be either pleasant or neutral and a few individuals perceived it to be slightly unpleasant. On the other hand, majority of the participants reported sour stimuli to be unpleasant and intense. Also, there were a few participants who reported the sour taste to be pleasant and mildly intense. From these findings, it can be deduced that the perception of taste differs with respect to individual preferences. This could possibly affect the swallow physiology. The current study could not find any association between the perceptual differences and kinematic measures. Further research is required to look into the psychophysics related to the perception of different taste and chemesthetic stimuli and its relation to the swallowing physiology. Scatter plot presented in Figure 4.4 depicts the perceptual ratings of different taste stimuli on HgLMS.

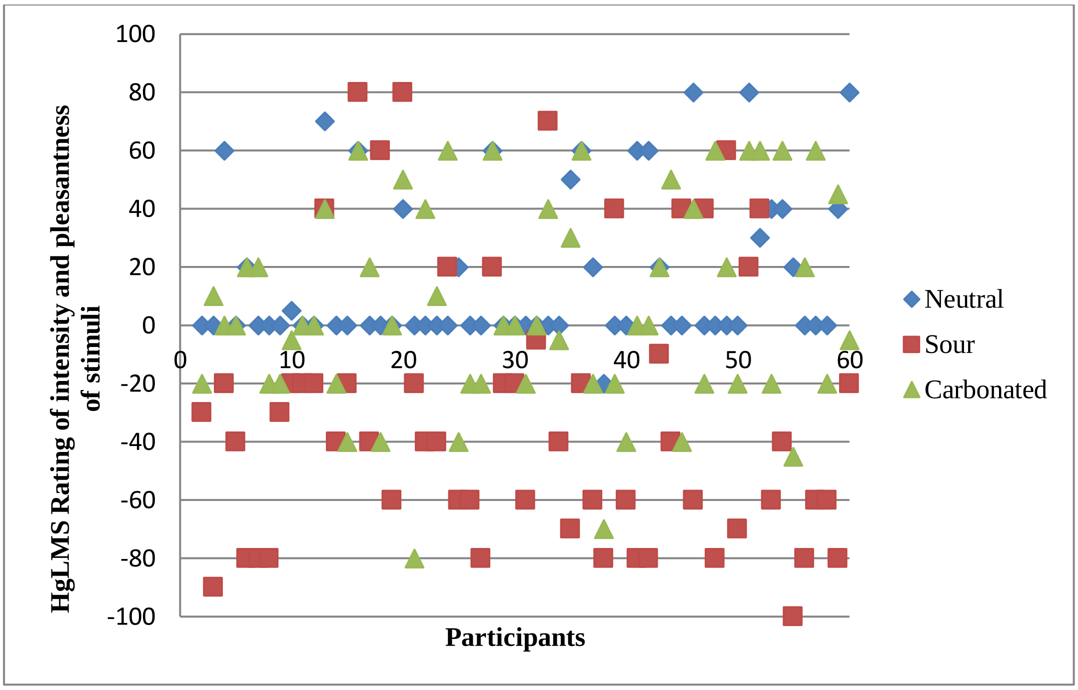


Fig. 4.4: *Scatter plot depicting the perceptual ratings of different taste stimuli on HgLMS.*

## IV. Comparison of hyolaryngeal elevation across volumes

Another objective of the study was to compare two volumes (5 ml and 15 ml) of different taste stimuli and to find whether there was any effect of volume on the parameters of hyolaryngeal elevation of swallow. Mean amplitude values (irrespective of gender) were higher for 15 ml stimuli in sour and carbonated conditions, but not in neutral condition. The mean duration values were also greater for 15 ml stimuli when compared to the 5 ml stimuli, in all the taste conditions (table 4.1).

In order to compare between volumes, Wilcoxon Signed Ranks Test was used. It was seen that there was a significant difference in mean duration for the sour and carbonated stimuli. The longer duration for higher volumes in the current study can be attributed to the multiple smaller swallows within a swallow complex. This can probably be attributed to the added taste and carbonation component in these stimuli as well. Even though the duration was longer for 15 ml bolus in neutral taste condition, it was not statistically significant. Amplitude parameters did not reflect any effect of volume on the hyolaryngeal elevation, that is, no statistically significant difference was found in mean amplitude measures across different volumes for the different stimuli. Table 4.5 depicts the comparison of hyolaryngeal elevation with respect to the stimuli, across volumes, irrespective of gender. Figure 4.5 depicts the mean values of bolus volumes with respect to different tastes.

Table 4.5

*Results of the Wilcoxon Signed Ranks Test for comparison of hyolaryngeal elevation across volumes for the three stimuli*

| **Parameters** | **Measures** | **/z/ value** | **/p/ value** |
|---|---|---|---|
| Neutral | Amplitude | 0.53 | 0.60 |
| | Duration | 2.32 | 0.20 |
| Sour | Amplitude | 1.17 | 0.24 |
| | Duration | 3.96 | 0.00* |
| Carbonated | Amplitude | 1.65 | 0.10 |
| | Duration | 2.63 | 0.01* |

***** $p<0.05$ indicates significant difference

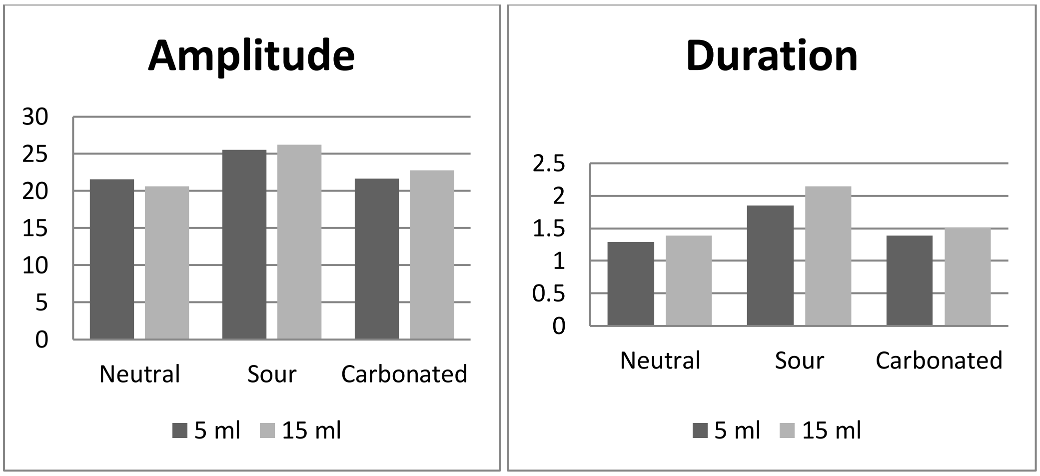


*Figure 4.5.* Graphical representations of amplitude and duration for two bolus volumes with respect to different tastes.

The finding of the current study is in concordance with the study by Honda et al. (2016) as well as in discordance with some other studies (Dodds, Man, Cook, Kahrilas, Stewart, & Kern, 1988; Chi-Fishman, & Sonies, 2002). Honda et al. (2016) explored the effects of volume on hyolaryngeal elevation, and reported a positive correlation between the duration parameters (similar to the current study) of swallowing sounds pertaining to the hyolaryngeal elevation. Dodds et al., (1988) found a direct correlation between volume of the stimuli and magnitude of hyolaryngeal elevation, however the present study did not find a significant effect of volume on amplitude measures. Their results implied that the neural program in the brainstem regulates the oral and pharyngeal phases of swallowing is not completely pre-set or stereotyped, but might rather be modulated by volume-dependent sensory feedback. In a study by Chi-Fishman and Sonie (2002), using ultrasonography with head and transducer stabilization to study different parameters of hyoid kinematics, the authors found that the larger volumes resulted in larger amplitude measures. Molfenter and Steele (2014) report a significant effect of volume on hyolaryngeal elevation.

But, the results of the current study did not demonstrate the differences in volume on the hyolaryngeal to be similar across different tastes and gender. An interesting finding in the current study is that, the differences with respect to the volumes are reflected only in the duration parameter, that too not consistent across tastes and gender. This points to the further exploration in this particular area.

The present study cannot essentially be compared with previous research because of the methodological differences. The present study is one of its kind because of the choice of stimuli conditions and their combination along with the instrument or parameters used for the outcome measures. No studies are available in the literature which used accelerometry to study the effects of taste to compare with the present study.

To summarize, the present study primarily investigated the effects of sour taste and carbonated liquid bolus on amplitude and duration of hyolaryngeal elevation. Significant effects of sour taste and carbonation was found in both measures of hyolaryngeal elevation. Pair-wise comparison revealed a significant difference between sour and neutral stimuli, as well as between the sour and carbonated stimuli. The study also compared these measures between males and females and found no significant difference. Comparison between two volumes (5 ml and 15 ml) revealed significant differences in the duration measures of sour and carbonated stimuli.

# Chapter V

## Summary and Conclusions

Hyolaryngeal elevation is one of the major physiological phenomenon in the pharyngeal phase of swallowing. It can be noted that hyolaryngeal elevation is essential in carrying out a swallow successfully, for its involvement in the airway protection, pharyngeal peristalsis and upper esophageal sphincter opening. Hyolaryngeal elevation can be assessed using different methods like FEES, VFSS, and EMMA etc. Most of these measures are either invasive or costs time as well as money. Digital accelerometry is one of the non-invasive and clinician-friendly assessment procedures for swallowing imaging by assessing the movements of larynx during a swallow.

Often, due to different pathologies affecting the swallowing, hyolaryngeal elevation could be affected, resulting in hazardous after effects like aspiration. Different approaches are opted to treat these disorders depending on the presenting signs and symptoms. When behavioural intervention approaches are considered, there are compensatory and rehabilitative strategies. Compensatory strategies primarily focus on different types of sensory stimulations. Sensory stimulation includes altering physical and sensory properties of bolus. Physical properties of bolus are consistency and volume or size, where as the sensory properties are temperature, taste, smell etc.

A systematic review of the existing literature revealed that there are no existing studies which specifically looked into the effects of different stimuli conditions (sour and carbonated) on hyolaryngeal elevation, especially using digital accelerometry. Hence, the present study aimed to find the effects of sour taste and carbonation (chemesthetic stimulus) on the hyolaryngeal elevation of swallow.

Alongside, effects of sour, carbonated and neutral stimuli were compared across two different volumes (5 ml and 15 ml). The current investigation also probed into finding whether there were any differences in the measures of hyolaryngeal elevation between males and females.

Sixty healthy young adults within the age range of 18 to 35 years were considered for the study. History or presence of different disorders which could possibly affect the parameters studied, were ruled out prior to the experiment. Informed consent was obtained individually from each participant. EAT-10 was performed to screen the presence of dysphagia. The participants were provided with different stimuli after instructing to sit upright comfortably in a chair. Triplicates of 5 ml and 15 ml stimuli of each stimuli were presented after randomization. Stimuli were presented in a cup. Digital accelerometry for swallowing imaging was performed to obtain the outcome measures (duration and amplitude of hyolaryngeal elevation). Participants were asked to rate the pleasantness and intensity of each taste of each stimuli in a visual analogue scale (HgLMS).

Since the data did not follow normal distribution, different non-parametric tests were administered. The results revealed that there was no statistically significant difference between males and females with respect to the amplitude and duration parameters of hyolaryngeal elevation. Effect of taste on hyolaryngeal elevation was studied, and it was found that the sour stimuli elicited significantly higher values in amplitude and duration measures of hyolaryngeal elevation, followed by carbonation and neutral stimuli. It was also found from the investigation that larger volumes elicited greater duration in different stimuli (sour and carbonation) conditions. Individual differences were seen across the perception of different stimuli on the

HgLMS scale.

It can be concluded from the study that compared to neutral stimuli, sour and carbonated stimuli have a possible role in producing significant sensory stimulation. Sour stimulus elicited significant higher amplitude and longer duration swallows compared to the other stimuli. This points to the possibility that sour stimuli can be used for the boluses to facilitate better swallows in individuals, particularly with dysphagia. Similarly, compared to smaller liquid bolus (5 ml), a larger bolus (15 ml) elicited longer swallow. The results of the current study suggest that altering the sensory (taste and chemesthetic) properties and physical properties (volume) would result in changes in hyolaryngeal elevation.

**Limitations**

There was a high variability in the measures of hyolaryngeal elevation of swallow across subjects. Measures of the hyolaryngeal elevation calculated by a method like accelerometry, can possibly be affected by different individual-specific physical characteristics like height, presence and absence of laryngeal prominence, position of larynx, thickness of skin or presence of fat layers over larynx etc. No scalars or correction factors were available in regard to these mentioned characteristics which can probably affect the measured parameters.

The testing was not done using a double blinded protocol, which could possibly have had an effect on the anticipation before swallowing. Both the participant and investigator knew the stimuli that were being presented, and hence they would have expected or anticipated to an extent, which would have inturn hindered obtaining a raw response to the different stimuli presented.

Another limitation of the study was with respect to the visual analog scale

(HgLMS) used to rate the intensity and pleasantness of the stimuli. Each point in the scale represented two aspects (pleasantness and intensity) and this resulted in some confusion in the raters, as they often required detailed explanation. For example, positive 100 represented extremely pleasant and intense taste, whereas negative 100 represented extremely unpleasant and intense taste. Also, sometimes taste stimuli could be less intense and highly pleasant or vice versa and it is not possible to represent this combination in the scale. Hence, it is better to use a separate hedonic rating scale and gLMS to rate pleasantness and intensity, respectively. Future studies can take these aspects into consideration.

**Clinical implications**

Cues from hyolaryngeal elevation helps in inferring the efficiency with which the bolus is transferred from pharynx to esophagus. It is also an indicator of whether there is aspiration and/or penetration or not. The findings from this study will help in distinguishing the differences in the physiology of this hyolaryngeal mechanism, with respect to the sour and carbonated liquid bolus across two different bolus volumes. The study also provides normative values, especially for water at 5 and 15ml, in healthy adults which can be used as a reference while testing patients with dysphagia. The results of the study will also provide an insight into the stimuli that has greater positive effects on hyolaryngeal elevation and the same information can be used during assessment and counselling of patients with swallowing disorders.

The results are also expected to help in the dysphagia rehabilitation, during choosing the stimuli for eliciting a healthy, faster or better swallow, depending on the client requirement. It also helps in selecting the right stimuli for stimulating sensory properties of multiple cranial nerves (ie, trigeminal, facial, glossopharyngeal and vagus). This would serve as a biofeedback, to show the differences across, tastes, chemesthetic stimuli, and volume, during dysphagia therapy.

**Future Directions**

Hyoid elevation associated with swallowing is observed to be in two directions, i.e., superior and vertical. The current study makes use of single axial accelerometry, and hence the movement directions are not specified. To be specific, the present study used a piezoelectric sensor to record the movements of the larynx. As it is known, a piezoelectric sensor converts all movements into potential differences, irrespective of the direction of movement. Hence, it is difficult to delineate specific movements of larynx from the recorded waveforms. Replication of the study using dual-axis accelerometry is required to see whether similar results can be obtained. Further studies can be carried out to study using taste stimuli of different intensities, would help in finding ideal concentration of different stimuli to elicit a better swallow. Testing different pathological population would also help in identifying the effectiveness of these stimuli in the treatment of oropharyngeal dysphagia of neurogenic or non-neurogenic origin.

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## APPENDIX I

## Informed Consent (Presented in Google form)

**Information regarding the study**

This Informed Consent Form is for healthy adults (men and women) within the age range of 18 to 35 years, and whom we are inviting to participate in the research on the effect of taste on swallowing. The title of the study is "Effect of Sour and Carbonated Liquid Bolus on Hyolaryngeal Elevation during Swallow"

**Purpose of the research**

Taste is an important part of the food we eat, and it is found to have effects on the swallow physiology. Our research is to find the effect of three different tastes (Neutral, Sour and Carbonated), on the swallow, based on a noninvasive method (accelerometry), across two different volumes (5ml & 15ml) and gender.

**Participant selection**

We are inviting all healthy adults who satisfy the selection criteria of the dissertation to participate in this study.

**Voluntary Participation**

Your participation in this research is entirely voluntary. It is your choice whether to participate or not.

**Procedures and Protocol**

Initially the participants will be asked to perform a dry swallow in order to locate the thyroid and hyoid. The hyolaryngeal space for the sensor placement will be identified by placing the index, middle, ring and little finger, under the chin, hyoid bone, thyroid and below thyroid, respectively. The piezoelectric sensor will be placed in the identified space, between hyoid and thyroid. Dry swallow will be performed in the beginning to establish a baseline and to familiarize the test procedure. The test stimuli will be presented through a small cup, in an ambient temperature, sitting erect in a chair. The participants will be given 5 minutes break-period between different stimuli and they will be asked to rinse their mouth with water, during the end of that duration. The participants will be instructed to avoid all the unnecessary movements during the testing. They will also be asked to swallow as normally as possible after the self presentation of the stimuli.

**Side Effects & Risks**

Some might find the stimuli used in the study, slightly uncomfortable.

**Confidentiality**

The information that we collect from this study will be kept confidential.

## Informed Consent (Presented in print format)

Title of the study:

Effect of Sour and Carbonated Liquid Bolus on Hyolaryngeal Elevation during Swallow

Statement by the participant

I have read the information, or it has been read to me. I have had the opportunity to ask questions about it and any questions that I have asked have been answered to my satisfaction. I consent voluntarily to participate as a participant in this research.

Print Name of Participant___________________

Signature of Participant ____________________

Date ____________________________

Day/month/year

Statement by the researcher taking consent

I have accurately read out the information sheet to the potential participant, and to the best of my ability made sure that the participant understands that the following will be done:

1. Three trials of testing using three different taste stimuli in 2 different volumes for each stimulus.
2. Carrying out Digital Accelerometry for Swallowing Imaging (DASI) for the same.
3. Rating different tastes on a rating scale.

I confirm that the participant was given an opportunity to ask questions about the study, and all the questions asked by the participant have been answered correctly and to the best of my ability. I confirm that the individual has not been coerced into giving consent, and the consent has been given freely and voluntarily.

Name of Researcher taking the consent_________________________

Signature of Researcher taking the consent___________________________

Date ____________________________

Day/month/year