OBJECTIVE MEASURES OF STRENGTH AND ENDURANCE OF LIPS AND TONGUE IN TYPICALLY DEVELOPING INDIAN CHILDREN

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(Speech-Language Pathology)

University of Mysore

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April 2018

CERTIFICATE

This is to certify that this dissertation entitled ***"Objective Measures of Strength and Endurance of Lips and Tongue in Typically Developing Indian Children"*** is a bonafide work submitted in part fulfilment for degree of Master of Science (Speech-Language Pathology) of the student Registration Number: 16SLP030. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree**.**

Mysuru
April 2018

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CERTIFICATE

This is to certify that this dissertation entitled ***"Objective Measures of Strength and Endurance of Lips and Tongue In Typically Developing Indian Children"*** has been prepared under my supervision and guidance. It is also been certified that this dissertation has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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DECLARATION

This is to certify that this dissertation entitled ***"Objective Measures of Strength and Endurance of Lips and Tongue In Typically Developing Indian Children"*** is the result of my own study under the guidance of Dr.Swapna.N, Reader in Speech Pathology, Department of Speech-Language Pathology, All India Institute of Speech and Hearing, Mysuru, and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru Registration No.: 16SLP030

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Table of Contents

List of Tables

Sl.No	Title	Page No.

List of Figures

CHAPTER I

INTRODUCTION

Lips are a visible part of the oral cavity. They are soft, movable and serve as the opening for food intake and in the production of speech. The upper lip covers the anterior surface of the body of the maxilla. The lower lip covers the anterior body of the mandible. The primary muscle responsible for closing and puckering the lips is the orbicularis oris muscle which is innervated by the facial nerve (Gray, 1977; Zemlin, 2010). Appropriate lip mobility and strength is crucial for feeding, saliva control and speech production.

The tongue is a muscular organ in the mouth that manipulates food for mastication, moves during the act of swallowing and is important for the production of speech. It is an important part in the digestive system and is the primary organ of taste in the gustatory system. Adequate lingual mobility and strength is crucial directly for articulatory precision during speech production, bolus formation and food clearance in the oral phase and indirectly helps in the pharyngeal phase of swallowing. The tongue consists of two groups of muscles called intrinsic and extrinsic muscles. The intrinsic muscles help produce rapid, delicate, refined movements for articulation and also help in propelling the food to the back of the oral cavity. The extrinsic muscles tend to move tongue as single unit, sets general posture for articulation and alters the tongue's position during speech and swallowing (Seikel, Drumright, & King, 2015).The tongue is innervated by the hypoglossal nerve consisting of motor fibres, special sensory fibres for taste, and general sensory fibres for sensation.

Evaluating lip and tongue function is important in the assessment and treatment of chewing, swallowing and other speech disorders. Integrity of the lips and the tongue musculature can be examined through visual assessment of the concerned articulator at rest, during sustained posture and movement. Traditionally, measures of tongue and lip strength examinations are made subjectively, in the clinical practice during the oromotor assessment. This is obtained by having the patient press with the concerned articulator against a tongue blade, with resistance provided by the speech-language pathologists. The examiner rates the strength of the lip and tongue as normal or weak based on clinical experience, which is helpful for diagnosis and making recommendations for treatment in individuals with speech and swallowing disorders. However, this method raises concerns regarding the reliability of tongue and lip strength measurements due to an inability to eliminate the assessor bias and the variability among multiple assessors in most of the clinical environments.

Therefore objective evaluations play an important role in conjunction with subjective evaluations during clinical practice and research which could facilitate clinicians to document their observations in a standardised way. With recent advances in the field of speech and swallowing rehabilitation, various instruments have been made available for evaluation of lips - tongue mobility and strength such as KayPENTAX Digital Swallowing Workstation, the Madison Oral Strengthening Therapeutic device, lip force meter LF100, electronic dynamometer etc. One such easy, small, portable and a user friendly device is the Iowa oral performance instrument (IOPI) which measures the strength and endurance of lips, tongue and cheek.

A few studies have been carried out to measure the strength and endurance of lip and tongue in healthy children, adults and elderly as well as in the disordered population with speech and swallowing problems using IOPI. Tongue strength and endurance in typical individuals of different age groups from 19-96 years was studied using IOPI by Crow and Ship in 1996. The purpose of this study was to determine the relationship of increased age to tongue strength and endurance. The results revealed decreased tongue strength in older individuals (53.7 ± 13.3kpa) compared to younger individuals (75.7 ± 17.3kpa), and in females compared to males. There was no significant change in the tongue endurance with age and gender.

Youmans, Youmans, and Stierwalt (2009) identified tongue strength differences as a function of age and gender in 96 participants with normal swallowing in the age range of 20–79 years. They were divided into groups such as younger (20–39), middle (40–59) and older (60–79) age groups. Significant differences were found between the youngest (77.63kpa) and oldest groups (57.56kpa) as well as middle (69.63kpa) and oldest groups, however there was no significant differences between men and women.

Age and gender differences in oro-facial strength were evaluated by Clark and Solomon (2012) for individuals in the age range 18-89 years. Among them, 88 were males and 83 were females. Anterior and posterior tongue elevation strength measures were obtained using IOPI.

Cheek compression and lip compression were also studied. Measures of cheek strength were obtained with the bulb faced laterally toward the buccal surface and the participants were instructed to squeeze the cheek muscles against the bulb with maximum effort. Lip strength was assessed with the IOPI bulb sandwiched between two wooden tongue blades positioned between the lips at midline and the participants were instructed to squeeze the lips together with maximum effort. Lip and cheek strength measures were greater for men (33.8kpa) than women (22.4kpa), but tongue strength did not differ between genders (57.5kpa). The oldest participants exhibited lower anterior and posterior tongue elevation strength relative to the middle-age group. Cheek (33.9kpa) and lip (27.0kpa) compression strength demonstrated no age-related differences.

Oh, Park, Jo, and Chang (2016) measured and compared the maximal tongue strength and endurance of healthy young (aged 20 to 39 years) and older adults (aged 67 to 75 years) using IOPI. Maximal tongue strength was significantly higher in the young adult group than the older adult group. Maximal tongue endurance was longer in the young adult group than in the older adult group, but the difference between the groups was not significant. This study confirmed that older adults have a lower maximal tongue strength and endurance than young adults.

Maximal strength and endurance scores of the tongue, lip, and cheek in 120 healthy normal Korean adults were studied from 20-60 years age range. The mean maximal lip strengths in males ranged between 11.4kPa-14.5kPa and in females 11.1kPa- 11.7kPa. The mean lip endurance scores were between 24.9 seconds to 41.1seconds in men and 12.8seconds to 30.5seconds in women. Whereas the mean maximal cheek strengths were found between 25.2kPa-24.5kPa in men and 18.0kPa-21.2kPa in women. The mean cheek endurance scores were 21.7seconds - 47.8seconds in men and 17.2seconds - 43.9seconds in women. Further, the mean maximal tongue strengths was 35.2kPa - 46.7kPa in males and 32.1kPa-36.9kPa in females. The mean tongue endurance scores were between 15.8seconds-28.8seconds in males and 15.3seconds-20.8seconds in females. There were significant differences in maximal tongue strength, maximal cheek strength, and lip endurance by gender, men shown greater mean values than women. The study found significant correlations across age groups between maximal tongue and cheek strength and tongue, lip, and cheek endurance (Jeong, Shin, Lee, Lim, Choung, Kim, & Lee, 2017. A few studies have been carried out on typically developing children using IOPI. Maximal tongue strength in 150 typically developing children and adolescents in the age range 3–16 years was measured by Potter and Short (2009).The objectives of this study were to determine if commercially available equipment could be used to test young children, to examine the number of trials needed to determine maximal tongue strength in children and adolescents, to determine whether tongue strength was best compared by matching for age or weight and to provide comparative data for tongue strength in children and adolescents. The study revealed that maximum paediatric tongue strength can be reliably evaluated using commercially available equipment and provides a comparative database. Tongue strength measurements were elicited in blocks of three trials with a 30-s rest between the trials and a 20-min rest between blocks. Tongue strength (27kpa to 70kpa) increased with age (3-16years) with no consistent best trial across ages and participants. No significant correlation was found between tongue strength and weight across the age and gender. Males showed a slight increase in tongue strength over females at ages 14 and 16years.

Song (2015) examined the characteristics of maximal tongue and lip strength scores in 49 typically developing Korean children in the age range of 3-8 years. The mean scores for tongue strength was found between 24.29kpa to 47.43kpa and mean scores for maximum lip strength was between 5.43kpa to 10.48kpa from 3-8years respectively. The results showed that there were significant differences across age groups in maximal tongue and lip strength scores. They concluded that Korean children had stronger strength of lips and tongue as age increased.

A few studies have also been conducted in the past and recent years using IOPI, to identify lip and tongue strength and endurance in clinical population, both children and adults (Chigira, Omoto, Mukai, & Kaneko, 1994; Solomon, Robin, & Lushei, 1999; Stierwalt & Youmans, 2007; Choi & Sim, 2013).The results of these studies revealed a significant differences in the strength and endurance of the lip and tongue in comparison to the typical population.

Need for the study

An indepth review of the existing literature revealed that studies to measure the lip -tongue strength and endurance in the paediatric population are scanty. Most of the studies have been carried out in the healthy adults and elderly. Further a vast majority of the studies that have been carried out on the adults and elderly have addressed the strength and endurance of the tongue rather than the lips. A systematic review and meta-analysis done by Adams, Mathisen, Baines, Lazarus, and Callister (2015) on measurements of tongue and hand strength as well as endurance using IOPI, also revealed that IOPI was used primarily for measurement of tongue strength and endurance. Relatively few studies measured hand strength and endurance. Evidence was strongest for strength measurements and was best established for measurements of tongue strength. However, very few studies have measured lip strength and endurance. Therefore, there is a clear need to conduct studies to assess lip strength and endurance, particularly in the paediatric population.

Some of these studies conducted on adults, have developed norms using IOPI so that the same can be used for rehabilitation purposes. However, these norms cannot be used with children since the anatomical dimensions of their speech apparatus differ in comparison to the adult population. There is evidence that there is maturation of muscle physiology in the speech motor system in children. The diameter of human muscle fibre increases and the muscles increase in size and strength with age (Parker, Round, Sacco, & Jones, 1990). In addition, the speech motor skill undergoes a long period of acquisition in children. The subsystems of speech production undergo a number of changes such as increase in size, remodelling of the shape of individual structures, adjustments in the positional relationships between structures, changes in histology, alteration in biochemical properties, and adaptations in neural innervations. Though the development of the articulators particularly the tongue and the lips, begins before birth, it continues beyond age three (Bosma, 1986; Arvedson & Lefton-Greif, 1996). Further, during the period of maturation from 3 to 7 years, the overall oral system continues its gradual growth. From 7-10 years it undergoes a growth spurt. Rapid growth is seen in the tongue and lips between 9 and 13 years. According to Kent (1999), the growth of mandible, tongue and lips continues until 18 years of age. Sharkey and Folkins (1982) concluded that basic development in oromotor movements, especially in jaw and lower lip happen up to 4 years and in the late stages, the oromotor system will undergo a process of fine refinement. Cheng, Murdoch, Gooze, and Scott (2007) also reported that development was non uniform, with a refinement period from mid-childhood extending into late adolescence. These studies do indicate a clear need for establishing representative values across age, especially in children since the articulators are still in the developmental stage.

In addition, the studies carried out on children are in the western population. The norms provided as a part of these studies cannot be used with children from other ethnic/linguistic backgrounds as the developmental patterns and physiology could vary. Vanderwegen, Guns, Elen, and Bodt (2012) reported the mean maximum anterior tongue pressure in healthy Belgian adults in age range 20-96 years was 44.27kpa, which was significantly lower than those found in an American study by Stierwalt and Youmans (2012), who found a maximum anterior tongue pressure of 59.78kPa for individuals in the age range 19 to 91 years. Jeong, Shin, Lee, Lim, Choung, Kim, and Lee (2017) suggest that data need to be collected nationwide due to cross regional variations across age and gender. It is therefore necessary to develop normative values of strength and endurance for lips and tongue across different regions, age groups, gender, race and nationality. In the Indian context, no such studies have been done especially to develop norms.

There is a great need for objective quantitative measures of tongue and lips to aid in the assessment and management of feeding, swallowing as well as speech disorders in children. This data developed could be used for comparative purposes during the diagnostic process and also as targets during intervention.

Further, subjective evaluation of strength and endurance of lip and tongue can lead to a lot of variability in values due to several factors such as clinician's experience bias and inter clinician rating variations etc. Solomon, Clark Makashay, and Newman conducted a study (2008) to identify the validity of clinical assessments of orofacial weakness by comparing clinical (subjective) ratings to instrumental (objective) measures in 44 patients with dysarthria of age range 18 to 78 years using IOPI. Moderate correlation was found between the objective and subjective evaluations. This study reported that examiner bias is inherent to clinical assessment which necessitates the need to use instruments to improve objectivity and precision in strength and endurance related measurements. The data base developed through this study will also help in the objective verification of the efficacy of the treatment provided to the clients with speech and swallowing disorders and contribute towards the use of evidence based approaches.

Fatigability is also one of the important factor seen in individuals with motor speech and swallowing disorders. There is a need to quantitatively measure the lip and tongue fatigability through measuring endurance across the age and gender. Keeping this in view the present study was planned with the aim of investigating the lip and tongue strength and endurance measures in typically developing Indian children in the age range of 6-8 years using IOPI and thereby develop norms.

Aim of the study

The present study aimed at developing normative data of lip-tongue strength and endurance in the typically developing Indian children across the age range of 6-8 years using IOPI. The specific objectives of the study were

- To determine whether strength and endurance of the tongue and lips varies with gender.
- To investigate the changes in strength and endurance of the lips and tongue, if any, that occurs across different age groups.
- To assess the clinical validity of the data obtained from the typically developing children by comparing these with the strength and endurance measures of the lips and the tongue, in age matched children with cerebral palsy.

CHAPTER II

REVIEW OF LITERATURE

The act of speech production and swallowing necessitates precise and sequenced muscle movements of the respiratory, phonatory, resonatory and articulatory systems which are controlled by the central and the peripheral nervous system. These systems functions in coordination with each other to facilitate both these complex processes. The air from the lungs (respiratory system) escapes upwards and sets the vocal folds (phonatory system) into vibrations causing phonation through the adduction and abduction of vocal folds. Later this sound is modified into speech based on the shape assumed by the vocal tract due to movement of the tongue, cheek and lip muscles causing changes in its resonatory properties. Similarly during the process of swallowing when food is placed inside the mouth, the lips form a seal and with the movement of the tongue, food is lateralized and masticated with the teeth and pushed back to the pharynx with simultaneous protective mechanisms of velopharynx and larynx and later to the oesophagus, which directs the bolus into the stomach. Thus there are many similar structures involved in swallowing and speech production, among which lips and tongue are two of the important oral structures that play a major role.

The lip forms the orifice of the mouth and part of the external boundary of the buccal cavity. The muscles in the lips ensure good lip closure which is important to prevent oral contents from leaking out of the mouth. The opening and closing of the lips are highly correlated with the swallowing process and are important for the oral phase of swallowing and saliva management (Lespargot, Langevin, Muller, & Guillemont, 1993). The lips are also involved in the production of speech such as lip compression to form the phonemes /p, b, m/ and rounding of the lips to produce the phoneme /w/ (Pena-Brooks & Hedge, 2000; Seikel, 2005).

The lips are often described as being composed of four layers of tissue which, in order of depth, are cutaneous, muscular, glandular and mucus. The primary muscle responsible for closing and puckering the lips is the orbicularis oris muscle (superior and inferior) and is innervated by the facial nerve (Gray, 1977; Zemlin, 2010). When contracted together, they act in a sphincteric fashion to round the mouth opening and protrude the lips. Orbicularis oris aids to shape and control the size of the mouth opening, which is important for creating the desirable lip positions and movements during speech (Bentsianov & Blitzer, 2004).The labial approximation occurs for the bilabial consonants /p, b, and m/; lower lip elevation and retraction occurs during production of the labiodental phonemes /f and v/; and protrusion and rounding occurs for certain phonemes, such as /u, o, r, ʃ, Ɔɪ, and aɪ/. Lower lip elevation contributes to mouth closure by the action of the mentalis muscle. Other muscles that insert around the mouth generally act to widen the oral aperture by pulling the lips upward, downward, and sideways. One of these muscles is the risorius, a thin, superficial muscle that traverses laterally across the cheek and inserts at the oral angle. A deeper, wider muscle that forms the bulk of the cheek is the buccinator. Both of these facial muscles insert anteriorly into the lips near the oral angle. The risorius is considered as a muscle of facial expression because it retracts the oral angles. It also can act synergistically with the buccinator. The buccinator also can retract the lips, but its main function is to increase tension and bulk in the cheeks themselves. It creates the necessary pressure to prevent residue from settling in the buccal cavities (also called the lateral oral sulci).

The tongue is the most important oral structure for speech and swallowing which is innervated by the hypoglossal nerve consisting of motor fibres, special sensory fibres for taste, and general sensory fibres for sensation. It is composed of a complicated arrangement of extrinsic and intrinsic muscles. Each extrinsic muscle has at least one external attachment that affixes to cartilage or bone. Extrinsic muscles include the genioglossus, hyoglossus, styloglossus, and palatoglossus muscles, which help to move, position, and shape the tongue. The extrinsic muscles tend to move tongue as single unit, sets general posture for articulation and alters the tongue's position during speech and swallowing (Seikel, Drumright, & King, 2015). Vertical, transverse, inferior longitudinal, superior longitudinal are the intrinsic muscles whose muscle fibres terminate within the tongue itself. The intrinsic muscles help produce rapid, delicate, refined movements for articulation and also help in propelling the food to the back of the oral cavity. Furthermore, they are important for changing the internal tension characteristics of the tongue body (Slaughter & Sokoloff, 2005).

Tongue plays a major role during speech production as it varies its shape, movement pattern, and place depending on the speech sound to be articulated. For vowels, the tongue is described as being high or low, front or back in the oral cavity. Few consonants are classified based on the point of contact of tongue with respect to other articulators i.e. place of articulation such as lingua-palatal (sh, j, r) articulated by tongue touching hard palate; lingua-dental (th) for which tongue should be placed in between the upper and lower teeth; lingua-alveolar (t, d, s, z, ch, n, l, t) where the tongue is in contact with alveolar ridge; lingua-velar (k, g, ng) produced when back of the tongue touches soft palate.

Tongue is also an important part in the digestive system and is the primary organ of taste in the gustatory system. During oral preparatory phase of swallowing, the tongue moves in three dimensions within the oral cavity such as tongue flattening and grooving during suckling and sucking, spreading and shallow tongue cupping to accept spoon and for bolus formation. It may even protrude from the mouth to scrape food out of its container.

Thus for speech production and swallowing, adequate labial and lingual mobility, structural integrity, strength and endurance are crucial which develops from infancy, and continues throughout childhood to reach the adult level of performance.

Development of lip and tongue

Oral motor development refers to the anatomical and physiological changes that occur in the lips, tongue, jaw, teeth, and the hard and soft palates during childhood. Oral motor skills refer to the movement of muscles of the face (e.g. lips and jaw) and oral area (e.g. tongue and soft palate). It includes muscle tone, muscle strength, range of motion (distance), speed, coordination, and dissociation (Kumin, 2015). The movement and coordination of these structures are very important for basic survival, such as sucking and swallowing, speech development and growth and development of dental structures (Motion, 2002).

To develop normal speech and feeding abilities, proper functioning of central and peripheral nervous systems, appropriate and adequate muscle tone, strength and functionally appropriate oral and sensory motor systems are the prerequisites. The new born infant is reflex-bound and automatically makes certain oral motor movements. However over time, these reflexive movements of the newborn are gradually refined and incorporated into more voluntary movement patterns. At birth, the infant's anatomic structure dictates that the tongue move in an extension retraction pattern because of the limited room within the oral cavity. This in and out pattern is called suckling and resembles a lick-suck (Morris, 1987). The tongue begins to form cup shape which facilitates transfer of liquid to pharynx. A mixture of suck and suckle continues until 6 months of age. By 6 months of age the suck predominates where the body or dorsum of the tongue moves up and down and the lips close tightly around the nipple and a more negative pressure is created in the oral cavity. The upper lip moving downward to clean the spoon emerges at 6 months followed by lower lip involvement.

By 5 to 6 months the tongue begins to roll laterally (Bosma, 1985); by 7-9 months the upper lip becomes more mobile with refined lip movement parallel to tongue up and down movements and lateralization also occurs at the same time. By 10 to 12 months, the tongue begins to shift food laterally and diagonally (Alexander, Boehme, & Cupps, 1993; Green, Moore, & Ruark, 1997). Some form of refinement of lip closure appears at 12 months of age. Tongue tip elevation and matured tongue lateralization are seen by 1 and 2 years of age respectively and also the lip control improves and the corners of the lips actively move inward.

The overall size, shape and motor control of oral system such as jaw control, palatal width, teeth eruption, lips and tongue growth, begins before birth and it continues beyond age three (Bosma, 1986; Arvedson & Lefton-Greif, 1996). The gradual period of maturation takes place from 3 to 7 years following a growth spurt at 7-10 years. Precision of lip motor control in speech is markedly increased between 7-10 years (Watkin & Fromm, 1980).Younger children prefer biting the spoon than using their lips, and this behaviour was explained by a higher need for trunk stabilisation during feeding at an early age. These observations were made by quantitative measurements of the closing pressure of the lips during feeding, using a strain gauge embedded in a spoon (Chigira, Omoto, & Mukai, 1994). Lip pressure was found to increase steadily from 5 months to 3 years of age and to increase slightly from 3 to 5 years.

Anatomical changes during the development of lips and tongue

Lips during growth change in both size and shape especially in length and convexity. The neonates' lips are nearly circular when viewed in anterior perspective and an increase in width (angle to angle dimension) is major developmental feature. The lips have an early growth spurt between birth to 2 years and a later spurt occurs within the range of 10 to 17 years. This latter acceleration in growth may coincide with the growth acceleration of the mandible in boys (Walker & Kowalski, 1972). The lips also change in epithelial composition. Thach (1973) described epithelial zones such as hairy cutaneous, glabrous, and papillary. The papillary zone which has a flushed appearance in full-term infants, has a higher percentage papillae per unit area (12-15mm papillae). This high concentration of papillae helps to make the labial surface more mobile and adhesive, thereby facilitating the oral seal during suckle feeding.

The tongue of the new born is about 4 cm long, 2 to 3 cm wide and 1 cm thick (Crelin, 1973; Siebert, 1985). Siebert reported that by the age of 4 years, the tongue grows about 6 cm in length, 4 cm in width, 2 cm in thickness, and 23 g in weight. With the remodelling of the supralaryngeal airway that occurs in infancy and early childhood, the tongue changes in its orientation to other structures. In neonates, the tongue nearly fills the oral cavity and is oriented rather like a piston in the oral cavity cylinder. This anatomic design facilitates sucking, for the tongue can perform the reciprocating motions needed for suck. The root of the tongue lengthens during development as the larynx descends in the neck. Descent of the posterior third of the tongue has been noted to occur during the first year of life (Crelin, 1973; Laitman & Crelin, 1976). Consequently, the tongue root and associated pharynx increase in length. Because the tongue must perform its function within the oral cavity it seems reasonable, that its growth would parallel that of its structures, particularly the hard palate, mandible, and posterior pharyngeal wall. In fact, three conclusions have been advanced concerning growth of the tongue. Harris, Jackson, Paterson and Scammon (1930) believed that the tongue reaches nearly adult size by the age about 8 to 10 years, which conforms to the classic neural growth pattern. Seibert (1985) concluded that tongue weight increases 10-fold from birth continue to grow into adulthood. Brulin and Talmant (1976) and Kerr, Kelly, and Geddes (1991) concluded that lingual maturity is reached at the age of about 15 or 16 years.

An anatomical observation of vocal tract development using MRI has also been reported by Fitch and Giedd (1999). They studied a relatively large data set (129 subject's images) from 2 to 25 year olds and compared the elongation of the lip, tongue blade, tongue dorsum, velum and pharynx in the prepubertal (2.8–8.1yrs), pubertal (10.3–14.5yrs), and post pubertal (14.7–17yrs) periods. The results indicated that all of the five segments i.e. lip, tongue blade, tongue dorsum, velum and pharynx increased their length significantly across prepubertal and pubertal periods. The authors compared the growth rate of each structure and reported that lip, tongue blade, tongue dorsum, and velum segments increase in size by an average of 12% between childhood and puberty, and only 5% between puberty and adulthood.

Vorperian, Wang, Schimek, Durtschi, Kent, Gentry, and Chung (2011) documented that there were statistically significant gender differences in the anatomy of the prepubertal vocal tract approximately 3 and 7 years of age using 605 MRI and CT images in a horizontal region ranging from a line tangential to lips to the posterior pharyngeal wall. Another study by the same authors also indicated differences between the growth speeds in males and females. For example, the oropharyngeal width of males has grown to about 70% of its mature adult size by age 6, whereas that of females has grown to only about 50% of its mature adult size by the same age.

The complex growth of the articulatory apparatus from birth to adolescence been termed ‘anatomic restructuring’ (Vorperian, Kent, Lindstrom, Kalina, Gentry, & Yandell, 2005). They suggested that lip thickness (80% of adult mature size) and tongue length (70% of adult mature size) undergo a period of rapid spurt between birth and 18 months with no sexual dimorphism, followed by an interval of regular but slow growth in early and middle childhood, then a period of rapid growth during puberty and finally a period of slow but steady growth until they reach their adult mature size.

Craniofacial and oral growth continues into mid-puberty and is markedly different in boys and girls (Farkas, Posnick, & Hreczko, 1992). Kent and Vorperian (1995) reported that facial bones continue to grow until puberty or, in some cases, into adulthood. Accelerated growth of the tongue occurs between 11 and 14 years, and reaches maturity by about age 16 (Brulin & Talmant, 1976; Farkas, 1994; Kerr, Kelly, & Geddes, 1991). The mandible changes in size and shape between 8 and 17 years, with different growth curves occurring for males and females

(Bishara, Jamison, Peterson, & DeKock, 1981; Farkas, 1994). With respect to lip length and thickness, Mamandras (1984) recorded marked growth between 12 and 14 years, although females reached adult length and width earlier than males. According to Kent (1999) the growth of mandible, tongue and lips continues until 18 years of age. Rapid growth is seen in the tongue and lips between 9 and 13 years.

Physiological/ functional changes during the development of lips and tongue

The organization of motor responses in the orbicularis oris muscle following mechanically evoked perioral reflex from vermilion skin of the lips was sampled from a group of normal human subjects. The participants included a group eleven infants (1.63 to 7.7 months of age), five school-aged children (ages 3.33, 4.75, 6.08, 11.58, and 12.08 years), and ten young adults (17.67 to 26.75 years). A specially designed multi-point array skin contactor, coupled to a position-servo controlled linear motor was used for the study of the perioral reflex (R1). Overall, the evoked R1 response obtained from the infant was of variable amplitude relative to the children and adults, lacked response specificity, and longer latency. Thus brainstem mediated sensorimotor action appeared to take on several characteristic changes of the adult form by the age of 12 due to changes in nerve fibre diameter, axonal length (maxillofacial growth), myelination and synaptic efficiency. In general, the sensorimotor apparatus of the lower face speeds up as the organism matures thereby affording the nervous system with a higher degree of temporal resolution (Barlow, Finan, Bradford, & Andreatta, 1993).The emergence of each of these oral-motor milestones is also dependent on successful practice (Illingworth & Lister, 1964; Pinnington & Hegarty, 2000; Eicher, 2002).

Sharkey and Folkins (1982) studied the development of speech motor skill by measuring the variability of lower lip and jaw movements in groups of 5 adults, and children at ages 4, 7, and 10 years who produced (mae) and (bae) 20 times each. It was concluded that basic development in oromotor movements, especially in jaw and lower lip happen up to 4 years and in the late stages, the oromotor system will undergo a process of fine refinement. Cheng, Murdoch, Gooze, and Scott (2007) also reported that development was non uniform, with a refinement period from mid-childhood extending into late adolescence.

Green, Christopher, Higashikawa, and Steeve (2000) suggested that coordinative organization of the articulatory gestures studied shifted dramatically during the first several years of life and continued to be refined past age 6. The reduced lip and jaw spatial and temporal coupling observed in 1year old children suggest that the young child is not endowed with predetermined movement synergies (e.g., a widely distributed central motor program or shared neural control) among these articulators. Two year-old children exhibited rigid spatial and temporal coupling of upper and lower lips. The period between 6 years and adulthood reflected continued refinement of movement control and optimization of coordination. Between ages 2 and 6 years, lip and jaw spatiotemporal coupling continued to increase. Qualitative observations revealed that movement patterns exhibited by 6-year-olds were similar to those of adults, but were found to be more variable. The involvement of upper lip, lower lip, and jaw for oral closure was similar between 6-year-old and adult subjects. These findings parallel the continuous refinement of speech performance from mid-childhood to adolescence (Sharkey & Folkins, 1985; Smith & Goffman, 1998).

Murdoch, Cheng, and Goozeein (2011) investigated the developmental variability of lip and tongue movement in 48 children and adults (aged 6–7 years; 8–11 years; 12–17 years; and 28-32 years)using electromagnetic articulography during productions of sentences containing /t/, /s/, /l/, /k/ and /p/. The variation in distance, duration, speed, acceleration and deceleration of the articulators during single open–close speech movements was analyzed, and the stability of multiple movement sequences was examined using the spatiotemporal index. The experimental findings revealed a gradual developmental progression from 6 years to adulthood. At adolescence, speakers continued to exhibit significantly more variable speech motor output compared to adult speakers which reflect the developmental status of their neuromuscular system, and consequently ‘an index of maturation of motor control’ (Kent & Forner, 1980). The observed developmental pattern suggested that changes in the speech motor system occur from mid childhood, through adolescence to adulthood. These results are contrary to earlier beliefs that speech development reaches adult-like stability by age 11–13 years (Tingley & Allen, 1975; Kent & Forner, 1980; Chermak & Schneiderman, 1986; Smith, 1992). More recent physiological studies provided initial evidence that significant changes continue through, or perhaps extend past adolescence (Walsh & Smith, 2002; Smith & Zelaznik, 2004).

Variability of lip movements of phase and amplitude were examined (Susanne & Frid, 2012) across repetitions of the same utterance as a function of age in Swedish speakers using three-dimensional articulography. Subjects were 50 typically developed native Swedish children and adults (28 females, 22 males, and aged 5 to 31 years). Results show a decrease in both indices as a function of age, with a greater reduction of amplitude variability. There was no difference between males and females for either index. The results suggested that age related changes in speech motor control continue up until 30 years of age.

Impact of poor lip and tongue strength on speech and swallowing

In most children, the normal sequence of oromotor development takes place, however in certain others, due to the damage to the nervous system, this gets affected. Several disorders and conditions develop, under such circumstances, which are associated with oromotor deficits such as orofacial myo-functional disorders, cerebral palsy, developmental delays, intellectual disabilities, cleft lip and palate, autism spectrum disorders, dysarthria of speech and certain syndromes which may be of viral, bacterial, genetic, chromosomal, tetratogenic, or traumatic origin (Shipley & McAfee, 1992). These are confounded with different types of oromotor deficits such as poor tone, strength, endurance, range of motion, accuracy of movements, speed, timing, discoordination and dissociation between the structures, which in turn contribute to drooling, weak suck, reduced rate of speech, and affects the overall speech and swallowing related quality of life. Many research evidences emphasize that presence of speech and feeding deficits exist in association with oromotor weakness in different range of speech and language disorders, irrespective of age (Belmonte, Chandhok, Cherian, Muneer, George, & Karanth, 2013). The following issues would result due to poor structural and functional integrity of lips and tongue:

-Weakness in orbicularis oris muscle would result in a poor occlusal relationship, decreased force of bite, poor chewing ability and articulation difficulties.

-Poor lip closure causes a weak suck that makes breastfeeding difficult, difficulty in drawing food from spoon and poor gathering and coordination of the liquid or food in the mouth for the swallow.

-Persistent drooling is another early signal of oral motor dysfunction which is an indication of sensory or motor dysfunction (Evans-Morris & Klein, 1987; Mueller, 1974).

-Poor tone in the labial muscles could lead to food residue in the lateral and anterior sulci.

-More rapid rate of fatigue in the labial musculature could occur due to decline in maximum lip force (Thompson, Murdoch, & Stokes, 1995).

-Abnormal tongue function results in impaired mastication, poor bolus formation, abnormal bolus positioning, oral residue, disorganized oral transit and premature spillage of bolus into the pharynx, which might lead to dysphagia (Clay, 2005).

-Poor upward and backward rolling tongue motion results in poor bolus formation due to which posterior movement of bolus is affected, which could lead to poor initiation of pharyngeal stage of swallowing (Averdson & Brodsky, 2002; Matsuo & Palmer, 2008).

-Lack of rolling lateral motion of the tongue prevents picking up of food from the teeth, mixing it with saliva and rolling it back onto the teeth.

-Poor sweeping movement of the tongue prevents the bolus from reaching the anterior faucial pillars, due to which the swallow reflex is not triggered (Logemann, 1998).

-A weak tongue could also lead to dysarthria or poorly articulated speech, resulting from interference in the control of the muscles involved in speech.

-Reduced tongue strength and function may contribute to a slower swallow and longer duration of oral transit time (Robbins, Somodi, & Luschei, 1992).

- Reduced lip-tongue muscle strength increases the time required for a child to finish a meal, which should be no more than 30 to 40 minutes, regardless of age (Arvedson, 1993).

-Reduced control of labial and lingual musculature could result in poor speech intelligibility (Barlow & Abbs, 1984).

Hence adequate strength and endurance of lip and tongue are important for speech and swallowing functions as well as enhancing the quality of oral functions in health (Thompson, Murdoch, & Stokes, 1995; Goozee, Murdoch, & Theodoros, 2001; Stierwalt & Youmans, 2007; Steele, Bailey, Molfenter, Yeates, & Grace-Martin, 2010; Neel & Palmer, 2012; Clark & Solomon, 2012). Therefore clinicians need to determine the impact of reduced strength and endurance of lip and tongue in causing deficits in speech and swallowing during the process of rehabilitation.

Oromotor assessment

The ultimate goal of clinical oromotor assessment is to understand the underlying deficits in oro-motor abilities and its impact on the speech and feeding difficulties. It helps the clinician obtain information about the integrity of the speech mechanism. This process involves the evaluation of the oral structures and its functions through observation. Different aspects of oral motor function should be addressed in an oral motor assessment and certain muscle groups should be examined (Kenny, 1989; Bakke, 2007). The observed dysfunction should also be noted such as drooling, dry mouth, oral habits, tooth grinding (daytime), pathological reflexes, affected voice or breathing, mouth breathing and involuntary movements.

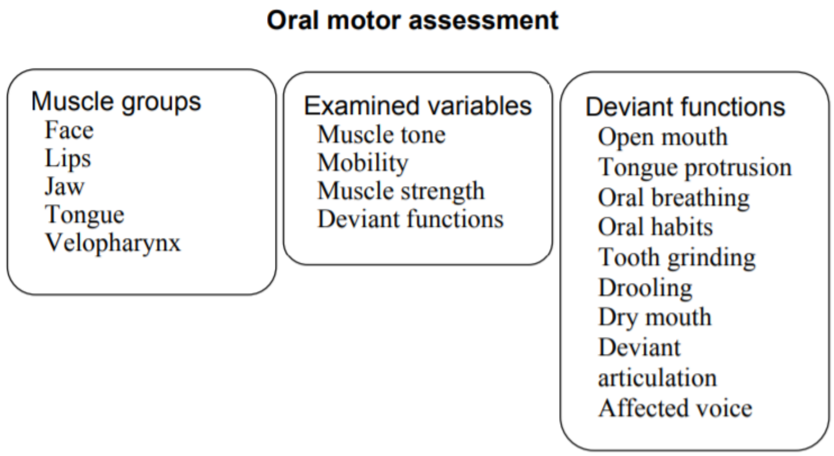

Figure 1.1: Muscle groups, examined variables, and deviant functions that are assessed during an oral motor examination (Bakke, Bergendal, McAllister, Sjogreen, & Asten, 2007).

During regular clinical practices, oral mechanism is examined to assess the strength, tone, speed, symmetry, range of movement, and steadiness of the jaw, face, tongue, and palate. According to Darley, Aronson and Brown (1975), these aspects are the 'salient features' required for neuromuscular function and form the foundation for all kinds of voluntary movements in the body. Generally the examination employs non speech and speech tasks. Non speech tasks focuses on how motor performance varies across nonspeech tasks at rest, during static postures, and movement (Duffy, 2013) and the speech tasks focuses on how motor performance varies across speech tasks. An example of a speech task is the Alternating and Sequential Motion Rates (AMR and SMR).

According to Hixon and Hardy (1964), non-speech movements would give important information even regarding the loci and extent of paresis, i.e., it provides information regarding the existence of neuromotor involvement of the musculature associated with those movements. The non-speech tasks have to be used because during speech tasks, the relative severity of the impairment is difficult to differentiate because of the complex interaction of the different subsystems. It is also important to examine each structure in isolation from others in order to estimate the relative contribution of impairment in various components. However they also concluded that the nonspeech behaviours would give limited clues for the magnitude of speech impairment.

Strength and endurance of oral structures

If a muscle required for speech production does not have adequate muscle strength, the person will not be able to perform the task adequately. Strength is the amount of tension or force a muscle can produce during single bursts or contractions of Type II motor units. Type II units are further classified as fast fatigable (FF) or fast resistant (FR) (Burke, Levine & Zajac, 1971; Barlow, 1999). FF motor units produce large tensions but are susceptible to fatigue. FR motor units have intermediate characteristics. They produce moderate tensions and are resistant to fatigue, so they will sustain the ability to produce force longer than FF motor units. The lips and tongue tip work as fast-moving articulators and consist of FR (type IIa) and (type IIb) fibers which are related to their functions (Saigusa, Niimi, Yamashita, Gotoh, & Kumada, 2001; Stal, 2003).

Subjective evaluation of strength of lips and tongue

One technique of muscle strength examination is instructing the individual to initiate contraction while the clinician applies resistance. Here the individual will have to resist/ hold against the pressure applied by the clinician. During oral facial examination to evaluate lip strength, certain tasks are performed by the examinee such as lip rounding by producing sustain exaggerated /u/ sound, lip spreading through voluntary smiling etc. Labial seal is evaluated by asking the participant to take a breath and use the air to puff out the cheeks not allowing air to escape while the clinician applies pressure on either side of the participants' cheek. To assess lip strength, the clinician places the tongue depressor horizontally between the lips of the examinee and asks to press the lips tightly against the depressor, while the examiner attempts to pull the stick against resistance of the examinees lips.

To evaluate tongue strength, a tongue depressor is positioned that barely touches the anterior surface of the person's lips and the examinee is asked to push the tongue depressor away by applying maximum resistance to check for strength of tongue protrusion. Whereas as to evaluate strength of tongue lateral movement, examinee is asked to push the tongue against the inside of his/her cheek against clinicians fingers/ a tongue depressor placed for resistance outside of the cheek (Love & Web, 2008).

Endurance is the amount of force that can be sustained over longer periods of time(Type I motor units).These type I units tend to be small, develop small tensions, and be resistant to fatigue which are recruited first, particularly for slow movements or those requiring small forces. As movements require increased speed or force, the larger Type II fatigue resistant units are recruited, followed by Type II fast fatigable units.

Endurance reflects the fatigability which is a failure to maintain required or expected force during an activity (Edwards, 1981). If the muscles involved in speech production are easily fatigable or has least endurance, then it affects the speech articulation and rate (Makashay, Cannard, & Solomon, 2015). Fatigue is generally considered as originating from the peripheral nervous system (PNS) or the central nervous system (CNS). Peripheral, or muscle, fatigue arises because of changes at the level of the neuromuscular junction or muscle, and central or mental, fatigue occurs when the CNS inadequately activates the PNS. Hence this is found as a prominent symptom in a variety of neurologic diseases such as Parkinson's disease, amyotrophic lateral sclerosis, multiple sclerosis etc that often are accompanied by dysarthria.

Endurance tests are usually evaluated subjectively by asking the patient to sustain a submaximal output level ormaintaining a target output of a task as long as possible (Robin, Goel, Somodi, & Luschei, 1992; Scardella, 1993).This task depends on the muscle strength.Clinical methods used to assess fatigue usually include interview, rating scales or questionnaires, and perhaps a speech "stress test" in which the patient required to talk for several minutes without resting. Duffy, (1995) recommends a counting task for the same. This test is used primarily to test for neuromuscular junction dysfunction, as in myasthenia gravis.

Another test is 'constant effort task/ an alternative fatigue assessment' which is based on the premise that effort increases as force is exerted (Enoka & Stuart, 1992), it follows that force (or pressure) will decrease if the sense of effort is maintained. When participants are asked to maintain a constant sense of effort, the force or pressure output may be interpretable as an indicator of fatigue. This task emphasize that effort must be kept the same for example, "If one held a 10-lb weight out to a side, where one could do it initially, but it would quickly become harder and harder to do until they couldn't do it anymore. Here the task is to do whatever one need to do to make sure that holding that weight doesn't get any harder so that the person should also concentrate on not letting it get any easier by keeping the effort the same.

In addition in the past, a few attempts have been made to develop checklists/test materials/questionnaires to assess the strength of oral structures. Some of these have been described below:

The oral motor activities for young children (Mackie, 1996):

The questionnaire is divided into part I and part II. Part I assesses the oral motor functions during the non-speech tasks. The assessment provides information about the stability, strength, mobility and differentiation of the oral structures. The sections are divided based on the characteristics it checks for. In the non-speech section, tasks are divided into 3 sections which includes positions at rest, strength and stability, mobility and differentiation. The articulators assessed include jaw, cheek, lips and tongue. Instructions to carry out the tasks, the observed / expected responses and the possible indication for each response are provided for each of the task. The section takes approximately 30 minutes to administer. The section for speech tasks (part II) have to be carried out in conjunction with other formal articulation test to evaluate the mobility, control, differentiation and stability of oral structures during the speech production. This section is further divided into 2 parts. The first section is based on the observations during speech production. The second part is based on the observation made from the specific tasks for the different articulators. The assessment is also done using various food textures.

Oral motor evaluation protocol (Beckman, 1997):

This protocol can be used to assess minimal competencies for range and strength for the lips, cheeks, jaw, tongue and soft palate with infants. It takes 7 minutes to administer the protocol. It can be used with individuals of all age groups who exhibit oral motor problems. It assesses both oral structure and oral function. The clinician needs to be trained to administer this tool. It examines specific muscle group function. It is a hands-on assessment tool in which the clinician has to physically examine the strength, muscle tone, and responses of the muscle groups which are responsible for each oral function. The strength and range of movement can be scored out of 3 and 5 respectively. The clinician can also observe for the response to pressure in different oral structures.

Oral Motor Assessment Scale (OMAS, Ortega, Ciamponi, & Mendes, 2009):

This protocol is used to evaluate lip closure and functions for its appearance, ability to close on utensil, during deglutition, control of food and liquid as well as during straw drinking in children from 3-13 years age. The descriptive scoring ranges from 0 (indicating more difficulty) to 3 (no difficulty).

All tasks of strength are rated traditionally as normal or abnormal according to a scale for weakness, such as the ordinal categories of mild, moderate, and severe. There are no norms for this test and ratings are based on the clinician's experience and internal representation of strength and fatigability. However, insufficient reliability of subjective scales is a recognized problem.

Instrumental evaluation of strength and endurance of lips and tongue

Clinicians and researchers working in the field of oral motor assessment and mimic muscle evaluation have underlined the need for objective, reliable and sensitive outcome measures as a supplement to more subjective assessments. Rarely instrumental measures are used in the clinic, although they are available (Robin, 1991; Thompson, 1995; Bu Sha, 2000; Hayashi, 2002). The details of some of the instruments are provided below.

Barlow and Abbs (1983) developed the force transducers, to evaluate labial, lingual and mandibular functions (representing multicomponent representation of the speech production system which measures force in terms of various response properties such as input/output linearity, frequency response, and phase shift.

Tongue Force Measurement System (TOMS) (Robinovitch, Hershler, & Romilly, 1991) objectively quantifies the tongue strength and endurance which requires highly sensitive beam transducer capable of measuring the magnitude of tongue thrusts in upward and lateral/sideward directions. This transducer is interfaced to a microcomputer which performs high-speed data acquisition and processing. Computer graphics provide instantaneous visual feedback which motivates the individual to maintain a predefined target level.

During the early1990s, new tools to measure the pressure generated by contact between the tongue and palate were developed, which offered speech-language pathologists an objective means of assessing strength and endurance of lip, tongue and cheeks. One such tool was Iowa Oral Performance Instrument (IOPI) developed by Luschei in 1992. It was originally developed to examine the relationship between tongue strength or endurance and speech motor control, and has subsequently been extended to examine relationship with swallowing. Later Madison oral strengthening therapeutic device (Hewitt, Hind, Kays, Nicosia, Doyle, Tompkins, Gangnon, & Robbins, 2008) was developed for evaluating the maximum force or pressure output at different locations on the tongue which quantitatively assess tongue muscle strength. The most widely used device for lip measure is lip force meter LF100 which is an electronic dynamometer (Hagg, Olgarsson, & Anniko, 2008) for the measurement of lip mobility and lip force which has a modified strain gauge for recording the ability of lips to withstand pressure (maximum lip force in newton's) that a subject is able to exert on an oral screen. While measuring the lip force, the pulling force must be applied perpendicular to the patient's mouth and the force exerted by patient is displayed on the device.

Among these devices IOPI is widely used because of purchase costs, sensors or bulbs which can be used commonly across individuals, extended durability because of limited low connective pieces, short calibration procedures, no change of the material properties with use, portability etc. Over time, a number of studies have been conducted using the IOPI in both healthy and clinical population. Some of these studies on typical individuals provide normative IOPI values for tongue strength and endurance (Potter & Short, 2009; Clark & Solomon, 2012).

Iowa oral performance instrument (IOPI)

IOPI is a portable hand-held device that uses an air-filled pliable PVC bulb (approximately 3.5cm long and 1.2cm in diameter with an approximate internal volume of 2.8ml), connected via an 11.5cm clear PVC tube to measure peak pressure exerted on the bulb. It contains pressure-sensing circuitry, a peak-hold function, and a timer. Researchers have used this device in many studies to measure tongue strength and endurance with excellent inter-rater reliability (Youmans & Stierwalt, 2006). Currently it is one of the most commonly used measurement techniques available to objectively measure even lip and cheek strength and endurance along with tongue (Steele, Bailey, Molfenter, & Yeates, 2009).

To measure lip strength, an IOPI bulb is placed inside the cheek just lateral to the corner of the mouth and the patient is instructed to squeeze the IOPI bulb against the buccal surface of the teeth by pursing the lips as hard as possible. Although the bulb is not directly between the lips, it is valid because the pressure developed in the bulb depends upon the strength of the circumferential muscle complex that surrounds the mouth, in particular the orbicularis oris. It is tension in these muscles that allows the lips to be compressed against one another.

The IOPI also measures the strength of the tongue at its anterior (air filled bulb placed at the level of alveolar ridge and pressed with the tip of the tongue) and posterior parts (places at the level of just at the end of hard palate and pressed with back of the tongue). It measures the maximum pressure that an individual can produce in a standard-sized air-filled bulb by pressing the bulb against the roof of the mouth with the tongue. The peak pressure achieved is displayed on a large, easy-to-read LCD. The units displayed are kilopascals (kPa).

The IOPI can be used to assess fatigability of lip and tongue by measuring its endurance, which is inversely proportional to fatigability. Low endurance values are an indicator of a high fatigability. Endurance is measured with the IOPI by quantifying the length of time that a patient can maintain 50% of his or her maximum pressure. This procedure is conducted by setting the target value in the Target Mode to 50% of the patient's maximum pressure and timing how long the patient can hold the top (green) light on.

IOPI device has clinical importance as it serves in deciding whether lip and tongue weakness is involved in oral stage swallowing problems and/or dysarthria. If the weakness is present, therapy could begin. If the strength is normal, clinician can eliminate weakness as a cause of the swallowing or speech problems, and thus concentrate on other more useful therapies. It helps in documenting that a patient's lip or tongue is weak, and therefore that strengthening exercises are justified. It also assists in assessing the results of lip or tongue strengthening therapy over time objectively. The device has a vertical row of lights (LEDs) on the front of the instrument. The higher the pressure, the higher the position of the light that is turned on. Producing a pressure that can turn on the top (green) light can be thought of as "winning" ("I hit the target!"). It acts as a biofeedback and motivates patients by showing them their progress from muscle exercise therapy as patient is visually reinforced for hitting their target. The pressure is required to illuminate the green light at the top of the IOPI's light array can be adjusted using the 'Set Max' arrow buttons. The clinician determines what target value is appropriate for exercise therapy purposes and provides specific instructions to the patient for a particular exercise protocol. A protocol should include the target value to set, the number of times to illuminate the green light and, for each repetition, how long the green light should be illuminated before releasing pressure on the bulb. Setting the target value can be expressed algebraically: $T = Pmax \times (E/100)$ where T= Target value; Pmax = maximum tongue pressure; E = Effort (%).

Studies using IOPI in typical population

A few studies have been conducted in the past and in the recent years using IOPI to identify lip and tongue strength and endurance in young, adult and elderly healthy and clinical population (Chigira, Omoto, Mukai, & Kaneko, 1994; Solomon, Robin, & Lushei, 1999; Stierwalt & Youmans, 2007; Choi & Sim, 2013).

Some of these studies have been carried out in children. Potter and Short (2009) measured maximal tongue strength in 150 typically developing children and adolescents in the age range 3–16 years. The objective of this study was to determine if IOPI could be used to test young children, to examine the number of trials needed to determine maximal tongue strength in children and adolescents, to determine whether tongue strength was best compared by matching for age or weight and to provide comparative data for tongue strength in children and adolescents. The study revealed that maximum paediatric tongue strength can be reliably evaluated using IOPI and provided a comparative database. Tongue strength measurements were elicited in blocks of three trials with a 30-s rest between the trials and a 20-min rest between blocks. Tongue strength (27kpa to 70kpa) increased with age (3-16years) with no consistent best trial across ages and participants. No significant correlation was found between tongue strength and weight across the age and gender. Further, there was no overall difference in tongue strength across gender for children ages 3–14 years In post-hoc analysis, there were slight differences in tongue strength between males and females at ages 10, 14, and 16 years. At age 10, girls tongue strength was slightly, but not significantly greater than boys. At age 14, boys tongue strength was slightly, but not significantly, greater than girls. At age 16, boys tongue strength was significantly greater than girls.

Song (2015) examined the characteristics of maximal tongue and lip strength scores in 49 typically developing Korean children in the age range of 3-8 years in an effort to develop normative data. The children were enrolled who had no issues on cognitive, language development and swallow functions that were screened through interviews with kindergarten and local community children's centre teachers. All assessments (i.e., lips and tongue strength assessment) were done three times and subjects had at least more than 30 seconds break after each session due to avoid the effect of fatigability. The mean scores for tongue strength was found between 24.29kpa to 47.43kpa and mean scores for maximum lip strength was between 5.43kpa to 10.48kpa from 3-8years respectively. The results showed that there were significant differences across age groups in maximal tongue and lip strength scores. Hence the authors concluded that Korean children tended to have stronger maximal strength scores of lips and tongue as they are getting old.

Certain other studies using IOPI have been carried out on adults and elderly typical individuals. Tongue strength and endurance was studied by Crow and Ship (1996) in typical individuals of age groups from 19-96 years including 52 males and 47 females. The purpose of this study was to determine the relationship of increased age to tongue strength and endurance. The results of this study revealed decreased tongue strength in older individuals (53.7 ± 13.3kpa) compared to younger individuals (75.7 ± 17.3kpa), and in females compared to males. There was no significant relationship between tongue endurance and age as well as gender. Based on the literature evidences authors suggest that, in healthy aging individual subclinical decreases in tongue strength appear to have no adverse effects on speech or swallowing. Normal aging changes in swallowing appear mostly in timing sequences, with increase in the duration of the total swallow. Hence the age-related changes in strength and endurance measures of tongue appears to have no clinical significance in normal aging, it could potentially cause a problem in association with other pathology.

Youmans, Youmans, and Stierwalt (2009) identified tongue strength differences as a function of age and gender in 96 participants with normal swallowing in the age range of 20–79 years including 48 males and 48 females. They were divided into groups such as younger (20–39), middle (40–59) and older (60–79) age groups. The results shown significant differences between the youngest (77.63kpa) and oldest groups (57.56kpa) as well as middle (69.63kpa) and oldest groups. However there were no significant differences between men and women. Authors concluded that, the information provided by findings of the study can be used for future comparisons of the tongue strength of persons with dysphagia during non-swallowing tasks. This knowledge could potentially improve clinician's ability to diagnose oral phase dysphagia more efficiently.

Effects of dining on tongue endurance and swallowing-related outcomes were studied on 22 healthy adults who were enrolled into two groups (ages 20-35 years and ages 65-82 years; 5 males and 6 females each). Maximum tongue strength (P max) and endurance were measured using IOPI, twice at baseline and once post meal. Subjects consumed half of a bagel with peanut butter, carrot sticks, and milk between measures. All subjects demonstrated reduced tongue strength and endurance post meal. Young adults showed a greater decline in anterior tongue endurance compared to older adults. There was no evidence that changes in tongue strength, perceived effort, or meal duration varied by age or gender. The three oldest subjects reported the highest effort and displayed signs of difficulty swallowing while dining (Kay, Hind, Gangnon, & Robbins, 2010).

Age and gender differences in oro-facial strength were evaluated by Clark and Solomon (2012) in healthy individuals from age range 18-89 years including 88 males and 83 females. Lip compression, cheek compression and anterior and posterior tongue elevation strength measures were obtained using IOPI. Lip strength was assessed with the IOPI bulb sandwiched between two wooden tongue blades positioned between the lips at midline and the participants were instructed to squeeze the lips together with maximum effort. Measures of cheek strength were obtained with the bulb faced laterally toward the buccal surface and the participants were instructed to squeeze the cheek muscles against the bulb with maximum effort. The oldest participants exhibited lower anterior and posterior tongue elevation strength relative to the middle-age group. Cheek (33.9kpa) and lip (27.0kpa) compression strength demonstrated no age-related differences. Lip and cheek strength measures were greater for men (33.8kpa) than women (22.4kpa), but tongue strength did not differ between genders (57.5kpa). Authors predict these differences in men and women could be due to, facial muscles in men generate greater pressures because of their larger size and it is also possible that despite of provided instructions to prevent participants from using their teeth to assist with lip compression, some participants, particularly men, may have done so. Thus authors concluded that clinician's should be conscious about various performance factors, and it is important to identify orofacial strength in persons with dysphagia for more informed interpretations of orofacial weakness.

Potter (2013) conducted a study on 16 trumpet playing individuals (younger than 27 years of age) (older than 45 years of age) and 16 non-trumpet playing individuals to assess cheek strength and endurance, tongue strength and endurance, and/or lip strength and endurance. It was found that the trumpet players differed significantly from the non-trumpet playing individuals on all the aspects. The trumpet players had greater cheek strength and greater lip endurance than the controls; however the tongue strength and endurance did not differ between the trumpet players and the controls. The findings indicated that a functional activity, such as trumpet playing, can increase facial strength and/or endurance and this increase can be objectively measured using a commercially available equipment.

Oh, Park, Jo, and Chang (2016) measured and compared the maximal tongue strength and endurance measures using IOPI device in 30 healthy young (aged 20 to 39 years) and 30 older adults (aged 67 to 75 years) with equal distribution of females and males. The maximal tongue strength was significantly higher in the young adult group than the older adult group which could be due to a reduction in muscle size and motor units due to aging. Maximal tongue endurance was longer in the young adult group than in the older adult group, but the difference between the groups was not significant. The authors hypothesised that it was associated with fibre type transformation due to aging. As aging progresses, skeletal muscle fibres may be subject to a transformation, involving type 2 fibres shifting to type 1 fibres. Hence the study confirmed that older adults have a lower maximal tongue strength and endurance than young adults.

Maximal strength and endurance scores of the tongue, lip, and cheek in 120 healthy normal Korean adults of three different age groups i.e., young (20-39 years), middle aged (40-59 years) and older (over 60 years) were studied. The mean maximal lip strengths were: young men (11.6kPa) and women (11.4kPa), middle-aged men (11.4kPa) and women (11.1kPa), and older men (14.5kPa) and women (11.7kPa). The mean lip endurance scores were: young men (41.1seconds) and women (22.4seconds), middle-aged men (24.3seconds) and women (30.5seconds), and older men (24.9seconds) and women (12.8seconds). The mean maximal cheek strengths were: young men (24.5kPa) and women (20.5kPa), middle-aged men (25.2kPa) and women (21.2kPa), and older men (22.4kPa) and women (18.0kPa). The mean cheek endurance scores were: young men (47.8seconds) and women (43.9seconds), middle-aged men (27.3seconds) and women (20.0seconds), and older men (21.7seconds) and women (17.2seconds). Mean maximal tongue strengths were as follows: young men (46.7kPa) and women (32.1kPa), middle-aged men (40.9kPa) and women (36.9kPa), and older men (35.2kPa) and women (34.5kPa). The mean tongue endurance scores were: young men (28.8seconds) and women (20.8seconds), middle-aged men (17.0seconds) and women (15.3seconds), and older men (15.8seconds) and women (17.9seconds). Study found significant correlations across age groups between maximal tongue and cheek strength and tongue, lip, and cheek endurance. There were significant differences in maximal tongue strength, maximal cheek strength, and lip endurance by gender.Authors also address that more data need to be collected nationwide due to cross regional variations across age and gender (Jeong, Shin, Lee, Lim, Choung, Kim, & Lee, 2017).

Studies using IOPI in clinical population

IOPI has also been used in individuals with different disorders. A study was conducted to identify tongue strength and endurance in 16 persons with mild to severe Parkinson disease (PD) in the age range of 54 to 84 years (Solomon, Robin, & Luschei, 2000). Tongue strength and endurance measures were obtained using IOPI device. Speech samples for picture description and monologue were recorded for approximately 10 min and evaluated perceptually by 8 SLPs for articulatory precision, accuracy, voice, prosody on a 7- point equal-appearing-interval scale (1 = normal and 7 = severe deviation from normal; Darley, Aronson, & Brown, 1975). The tongue strength (48.1kPa) and endurance (22.8seconds) of participants with PD were lower than tongue strength (55.5kPa) and endurance (36.9kPa) seen in healthy participants group. No significant correlations were found between tongue strength and endurance, interpause speech rate, articulatory precision, and overall speech defectiveness for the participants with PD, bringing into question the influence of modest degrees of tongue weakness and fatigue on speech deficits in individuals with Parkinson disease.

Muscle weakness and speech in oculopharyngeal muscular dystrophy (OPMD) was examined by Neel, Palmer, Sprouls, and Morrison (2013). Twelve individuals in the age range of 50-69 years with OPMD and 12 healthy age-matched controls underwent a comprehensive assessment of the speech mechanism including spirometry (respiratory support), nasometry (resonance balance), phonatory measures (pitch, loudness, and quality), articulatory measures (diadochokinetic rates, segment duration measures, spectral moments, and vowel space), tongue-to-palate strength measures using IOPI device and speech like tasks, quality-of-life assessment, and perceptual speech ratings by listeners. Individuals with OPMD had substantially reduced tongue strength (11–37kPa) compared to the controls (48–69kPa). However, little impact on speech and voice measures or on speech intelligibility was observed.

Weeks, Dzielak, Hamadain, Bailey, and Elgenaid (2013) examined the relationship between stroke and labial strength among four groups: a control group of 42 healthy adults, 3 experimental groups of 31 individuals who had experienced a stroke. The experimental groups were characterized according to the following features: labial weakness only, dysarthria, and dysarthria and dysphagia. All participants performed an oral motor evaluation, diadochokinetic rates, clinical swallow evaluation, and bilateral measurements of labial strength using the IOPI. Results showed significant differences in labial strength on the side affected by the stroke among all of the experimental groups. Surprisingly, smaller yet significant differences in labial strength of the unaffected side were also discovered between the control and experimental groups. Because the orbicularis oris is a sphincter muscle, it is possible that the right and left sides are unable to act independently of one another (Nakatsuka et al., 2011). As such, muscles on the affected side may influence labial strength on the unaffected side. This study contributes to the body of knowledge regarding labial strength required for conducting particular tasks such as producing precise bilabial sounds for purposes of intelligible speech and maintaining adequate labial seal while drinking. Oral strength (lip strength, tongue strength and tongue endurance) in 25 subjects with unilateral cleft lip and palate (CLP) in the age range of 6 to 17.9 years (mean age of 10.6 years) was measured using IOPI. The mean lip strength of subjects with CLP was 21.6kPa, while for the control group, it was 20.7kPa. Mean anterior tongue elevation strength was 37.2kPa for subjects with CLP and 43.0 kPa for the control group. The tongue endurance was 3.7seconds and 3.9seconds for CLP and control group respectively. The results of IOPI showed no significant differences between the subjects with a unilateral CLP and the age and gender matched control group without a CLP (Van Lierde, Bettens, Luyten, Plettinck, Bonte, Vermeersch, & Roche, 2014).

Starmer, Pike, Ishii, and Patrick (2015) quantified the labial strength and function in facial paralysis and evaluated the effectiveness of targeted lip injection augmentation in twenty-two patients with unilateral facial paralysis including 14 women and 8 men with a mean age of 57 years (range, 33-84 years). A complete oral motor evaluation was performed. The IOPI was used to measure inter-labial pressures from left, central, and right lip locations. Inter-labial pressures measured with the IOPI revealed reduction in the paralyzed, central, and non-paralyzed sides of the lip. The patients were evaluated for anterior bolus spillage and bilabial sounds. Hyaluronic acid–based filler was then injected intramuscularly into the deficient sites until the inter-labial gap and air escape were corrected. All patients were noted by the speech pathologist to have improved articulation of plosive sounds and decreased anterior spillage after the injection. The effect lasted at least 6 months. Therefore the study concluded that labial strength was reduced across the lip in patients with unilateral facial paralysis and that the IOPI was an effective tool for measuring labial strength, which can be used to evaluate the effectiveness of facial reanimation procedures.

Efficacy of IOPI in strengthening the lip and the tongue

Some studies also assessed the efficacy of IOPI in improving the lip and tongue strength and endurance. Steele, Bailey, Polacco, Hori, Molfenter, Oshalla, and Yeates (2013) measured treatment outcomes in a group of six adults with chronic dysphagia following acquired brain injury of age range 32-54 years, who completed 24 sessions of tongue-pressure resistance training, over a total of 11 – 12 weeks. The treatment protocol emphasized both strength and accuracy. Biofeedback was provided using the IOPI. Amplitude accuracy targets were set between 20 – 90% of the patient's maximum isometric pressure capacity. Single subject method were used to track changes in tongue strength (maximum isometric pressures), with functional swallowing outcomes measured using blinded ratings of a standard pre- and post-treatment video fluoroscopy protocol. Improvements were seen in post-treatment measures of tongue pressure and penetration-aspiration. No improvements were seen in pharyngeal residues, indeed worsening residue was seen in some patients.

Park, Kim, and Oh (2015) examined effectiveness of a structured program of resistance training for tongue using IOPI device, in order to improve swallowing function in stroke patients with dysphagia. Twenty-seven stroke patients with dysphagia were randomly divided into two groups. The experimental group participated in a resistance-training program involving a 1-repetition maximum, with an intensity of 80%, along with 50 repetitions per day each for the anterior and posterior regions of the tongue. Both groups received conventional therapy for dysphagia for 30 min per day, 5 times per week, for 6 weeks. The experimental group showed statistically significant improvements in both, the anterior and posterior regions of the tongue. In contrast, the control group showed significant improvements only in the anterior region of the tongue. In the video fluoroscopic dysphagia scale evaluation, improvement was noted at both, the oral and pharyngeal stages in the experimental group, whereas significant improvements were only noted in the oral stage and total score in the control group. This study confirmed that tongue resistance training is an effective intervention for stroke patients with dysphagia, offering improved tongue muscle strength and overall improvement in swallowing.

Park and Taeok (2015) examined the effects of 4 weeks of oropharyngeal strengthening exercise (OSE) on (a) maximum tongue pressure as measured by the IOPI, (b) peak amplitude of submental surface electromyography (sEMG), and (c) swallowing quality of life as measured by the SWAL-QOL in 27 healthy older individuals who had a mean age range 58-85 years old. The results of this study showed that the OSE had statistically significant and positive effects on increasing maximum tongue pressure and swallowing quality of life, but there was no difference in peak amplitude of submental surface EMG after a 4-week OSE. Maximum tongue pressure increased from 41 kPa to 47 kPa after a 4-week OSE. On the swallowing quality of life questionnaires, participants perceived that physical symptoms related to swallowing were statistically significantly improved after a 4-week OSE. Particularly, frequency of choking during eating was statistically significantly reduced after a 4-week OSE. The authors concluded that OSE swallowing intervention had a positive effect, because strengthening exercise for swallowing muscles increased muscular and swallowing reserve in older individuals. The OSE combined two swallowing exercises: tongue strengthening exercise and effortful swallow. The conceptual framework of the OSE is based on neuro-adaptation, which implies the adaptive modification of the neurological system through training. The OSE may lead to neuromuscular adaptive modifications of swallowing physiology in older individuals. Specifically, changes through the OSE may include increases in the firing rate of motor units with increasing strength related to oropharyngeal swallowing muscles such as the tongue.

A systematic review and meta-analysis was conducted by Adams, Mathisen, Baines, Lazarus, and Callister (2015). They examined the evidence for the use of the IOPI in measuring strength and endurance of the tongue and hand in healthy population and those with medical conditions. A systematic search of the scientific literature published since 1991 yielded 38 studies that addressed this purpose. The IOPI was used primarily for tongue strength (38 studies) and endurance (15 studies) measurement and relatively few studies measured hand strength (9 studies) or endurance (6 studies). The majority of the studies used the IOPI as an evaluation tool, although four used it as an intervention tool. Half the studies were conducted in healthy people, primarily adults. Most of the other participants had disorders with dysphagia, primarily Parkinson's disease or head or neck cancer. Age and gender, as well as a number of medical conditions, influenced the values of tongue and hand strength. There is sufficient evidence to support the use of the IOPI as a suitable tool for measuring tongue strength and endurance and as an assessment tool for intervention studies, and there is growing support for its use to assess hand strength and endurance in healthy and clinical population.

Adequate muscle movement, strength and endurance must exist for standard speech clarity to develop. Strength is rated traditionally as normal or according to a scale for weakness, such as the ordinal categories of mild, moderate, and severe. There are no norms for this test and ratings are based on the clinician's experience and internal representation of strength and fatigability. Though instrumental measures are available, they are not used, especially in the Indian scenario.

Protocols are also available for evaluation of strength of the oral structures. When we record data on a protocol, we can detect a configuration or certain regularities that lead us to identify certain categories of known problems. The data of an evaluation can be recorded by means of detailed description or by semantic qualitative analysis, however quantification of the data may be necessary especially for both clinical and research purposes.

IOPI is an instrument which allows the assessment of lip-tongue strength and endurance. Several studies have been conducted in the west in different age groups, both in typical and atypical individuals using IOPI. Some of these have attempted to develop norms, however these may not be applicable to the Indian population. Such studies in the Indian context are scarce. Further, clinicians seeking to determine whether reduced lip-tongue strength and endurance contributes to speech and swallowing deficits, must have access to normative data for lip-tongue strength and endurance in males and females across the life span. Thus the objective of the present study was to develop norms among healthy children of 6-8 years for strength and endurance measures of lip and tongue.

CHAPTER III

METHOD

The present study aimed at developing normative data of lip-tongue strength and endurance in typically developing Indian children across the age range of 6-8 years using Iowa oral performance instrument (IOPI).

Participants

A total of 110 typically developing Kannada speaking children in the age group of 6-8 years were selected for the study. These participants were further divided into two different age groups 6-7 years (mean age 6.10 years) and 7-8 years (mean age 7.5 years). Each group consisted of 55 children with, 28 males and 27 females in 6-7years age group and 27 males and 28 females in 7-8 years. The typically developing Kannada speaking children were selected from the regular schools of Mysuru. All the participants were screened using WHO Ten-question disability screening checklist (Singhi, Kumar, Malhi, & Kumar, 2007) to rule out the presence of speech and language disorders, neurological, oromotor, psychological, physical and sensorimotor disorders. Only those participants without any of these problems were included. Participants belonging to low, middle and high socio-economic statuses were be included which will be ascertained using the NIMH socioeconomic status scale developed by Venkatesan (2011). The scale has sections such as occupation and education of the parents, annual family income, property, and percapita income to assess the socioeconomic status of the participants.

Data was also obtained from 10 children with cerebral palsy in the age range of 6-8 years to assess the clinical validity of the data obtained from the typically developing children. These participants were considered as the clinical group. The children with cerebral palsy who reported to the Department of Clinical Services, All India Institute of Speech and Hearing, Mysuru were considered for the study. Only those children diagnosed as ‘Delayed speech and language or developmental dysarthria secondary to cerebral palsy’ by a qualified team of professionals including speech-language pathologist, paediatrician, physiotherapist and a clinical psychologist were included. All children of CP were of spastic type with topographic distribution of hemiplegia in 6 children and diplegia in 4 children, they were attending for speech therapy for a duration range from 10days to 6months period. Those children with associated problems such as sensory impairment, seizures, malocclusion (misaligned teeth), high arched palate, etc. were excluded from clinical group, however children with mild intellectual disability were included for the study.

The oromotor abilities were assessed by administering the Assessment of Oral Motor, Oral Praxis and Verbal Praxis Skills in Persons with Down syndrome (Rupela & Manjula, 2008). The Oral motor assessment protocol has 4 sections for assessing the motor and sensory behaviours. This includes the Posture (11 items, scoring ‘1’- Yes and ‘0’- No), oral structures at rest (8 items, scoring pattern - 2 for ‘a’, 1 for ‘b’ and ‘0’ for ‘c’), function of the oral mechanism for speech (6 items, scoring pattern 1 for ‘adequate’ and 0 for ‘inadequate) and oral sensory behavior (19 items, 4 point rating scale where in 0 indicated Never, 1 indicated ‘Occasionally’, 2 indicated ‘Frequent’ , 3 indicated ‘Always’, 0 indicated ‘Not applicable’). The mean scores for each domain was analysed i.e. for domain one (posture) the mean score was 9, for the second domain (oral structures at rest) mean score was 8, for the third domain (function of the oral mechanism for speech) mean score was 26.5 and the fourth domain (oral sensory behaviour) the mean score was 3.5 indicating the presence of oromotor deficits in all the participants (clinical group). Hence they were considered for the further objective evaluation using (IOPI). Only children with oromotor deficits were included in the validity testing. The details of the participants with CP are provided in the Table 3.1.

Table 3.1

Details of children with cerebral palsy

Participant	**Age/ Gender**	**Type of CP**	**Topographic distribution**
1	6.2 years/Female	Spastic	Hemiplegic
2	6.4years/ Male	Spastic	Hemiplegic
3	6.8yeras /Female	Spastic	Diplegic
4	6.4 years / Female	Spastic	Hemiplegic
5	6.8yeras / Male	Spastic	Hemiplegic

6	7.2years/ Male	Spastic	Hemiplegic
7	7.6years / Female	Spastic	Diplegic
8	7.2years / Female	Spastic	Diplegic
9	7.6years / Male	Spastic	Diplegic
10	7.8years / Male	Spastic	Hemiplegic

The children with a history of structural or neurologic impairments, presence of fever, cold, seizures, oral infections, dentures, pain in jaw and lips, oromotor sensory deficits, malocclusion (misaligned teeth), high arched palate, poor oral hygiene, respiratory disease, cognitive and language deficits, major head or neck surgery or any kind of health issues at the time of data collection were excluded from the experimental group. All ethical standards were met for participant selection and their participation. Prior to testing, a written consent was obtained from the parents/caregivers/teachers of the participants after explaining the purpose of the study.

Instrumentation

Iowa Oral Performance Instrument (IOPI model 2.2) was used for the study. This instrument objectively measures strength and endurance of lip and tongue.

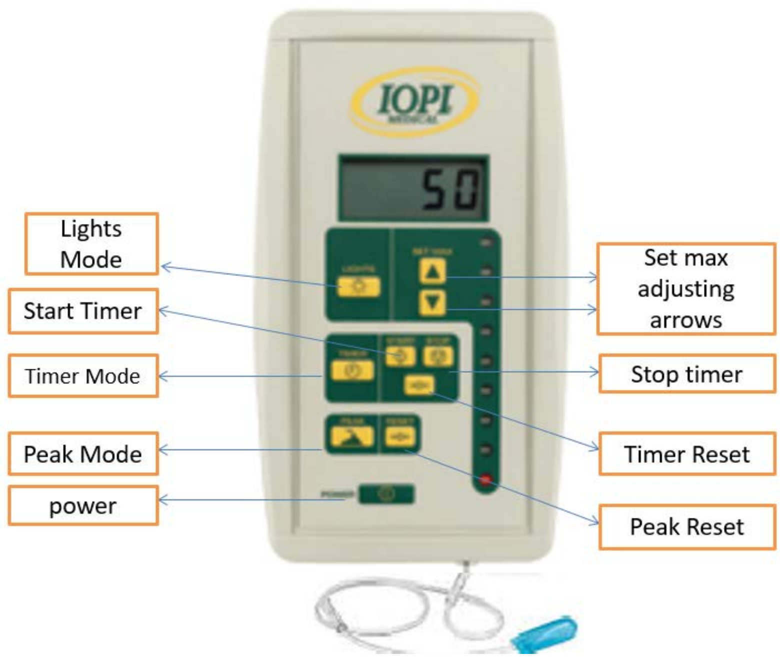

Figure 3.1: Iowa oral performance instrument (Model 2.1)

The device consists of various control buttons which can be manually manipulated depending on the measure of interest i.e. strength or endurance. The power button to turn on/off the device and peak mode enable the strength measures. A peak reset button to reset the value on the device to (0) at the beginning of task performance of the strength during each trial and set max adjusting arrows to set target strength values for endurance measures. A lights mode button to turn on/off led bulbs on right side of the device which serve as visual feedback through illumination of green light (indicate maintanance of target value of strength) or red light (indicate poor sustainance of target value of strength). The timer mode to set the device to track timing during endurance task, start and stop timer buttons to initiate and stop tracking the duration displayed on the device, timer reset to reset the value on the device to (0) at beginning of the endurance task performance.

Procedure

A rapport was built with each participant. The consent was obtained from the parents/concerned persons for each participant. A detailed demographic data was obtained and the necessary tools as mentioned above were administered. Measures of strength and endurance of lips and the tongue were collected separately for each participant. Instructions and demonstration of task was provided to the participants prior to the actual task performance by the participants. IOPI was set to (0) value by pressing the peak reset button prior to the testing which is seen on LCD display of the instrument. Before using, child the bulb of the IOPI device was sterilized by using Savlon antiseptic liquid. IOPI was calibrated once in a month as recommended by the manufacturer, to ensure accurate measurement by following the procedure provided in the manual.

Lip strength (inter-labial compression) was measured by placing the bulb between the upper and lower lips (at tubercle of upper lip and groove of lower lip) at the middle. This placement has been planned based on the method used by Solomon et al., (2008) which was adopted, so that the pressure exerted gets distributed evenly across the entire surface of the tongue bulb to provide an accurate pressure reading. The participants were instructed in the following manner, “Press the bulb between your lips as hard as you can for about 2-3 seconds”. After the participant has made his or her response, the value displayed was recorded. The instrument was reset again by pressing peak reset button [0]. The participants were asked to rest for 30 – 60 seconds and then the same task was repeated for three trials. Highest of the three recorded values was considered as peak strength values of lips. If the values consistently decrease over the three trials, the rest period was increased. To measure the endurance of the lip, the LCD display was set to 50% of the participant's peak pressure using set max arrows of the instrument and timer mode button was pressed. Later the bulb was placed in participant's mouth in the same position as described above. The participants were instructed as follows, "Press the bulb as hard as possible until the (green) light illuminates on the device and keep on the bulb squeezing as long as possible". The duration (seconds) that device displayed was recorded. Only one trial was conducted for each participant.

The tongue strength was measured by placing the bulb against the participant's hard palate just behind the alveolar ridge. Only anterior tongue strength and endurance was measured. This was planned based on the results from two studies; one by Clark and Solomon (2012) and the other by Potter and Short (2009) who reported that during posterior measurements, a few children in their study refused to place bulb at posterior portion and a few of them exhibited a gag reflex. The participants were instructed in the following manner, "Press the tongue bulb with your front (anterior) part of tongue as hard as you can for about 2-3 seconds". The same procedure used in recording lip strength was followed for measuring tongue strength at three trials. After identifying the peak tongue strength value of the participant, the tongue endurance was measured after 30-60 seconds of rest. Only one trial for each participant was conducted. To measure the endurance of the tongue same procedure as described under lip endurance was followed. Later the bulb was placed in the participant's mouth similar to the placement during strength measurement and the participants were asked to squeeze the bulb until the (green)light illuminates on the device and keep the bulb squeezing as long as possible. The values were measured in terms of duration (seconds). At the end of the data collection, reinforcers were provided. The approximate time taken to perform all four tasks (lip strength, lip endurance, tongue strength and tongue endurance) was 15-25 minutes for each participant.

For children with cerebral palsy (clinical group), demographic details and consent was obtained from parents of each participant by explaining the purpose of the study and the tasks to be performed by their children. Adequate rapport was built with each child prior the evaluations. The assessment of oral motor, oral praxis and verbal praxis skills in persons with Down syndrome (Rupela & Manjula, 2008) protocol was used to evaluate the oromotor abilities of each participant and their scores were recorded manually. Before testing (IOPI) instructions and demonstration of each task was provided to each participant clearly. Measures of strength and endurance of lips and the tongue were collected separately for each participant. As mentioned in the previous section, the sterilization was carried out before each participant's task performance. Later each child was allowed to perform the tasks for 1-2 practice trials and 30-60seconds of rest period was provided for each participant between practice trials and actual task performance. The data was recorded manually based on the above described procedure. The time required for each participant to perform all the tasks (lip strength, lip endurance, tongue strength and tongue endurance) was approximately 20-30minutes.

Test-retest reliability

To assess the test retest reliability, all four tasks i.e. lip and tongue strength and endurance) using IOPI was administered again on 10% of subjects of the total population (11 participants from both the age groups) who were selected randomly after one week of the initial data collection.

Pilot study

A pilot study was carried out in which the data was collected on two typically developing children in each age group to check for the feasibility of measuring lip strength and endurance as well as tongue strength and endurance. During the pilot study tongue strength and endurance was measured at the tongue anterior and posterior parts. Majority of the children had a gag reflex and reported discomfort during the task, especially on the posterior tongue measures. Hence posterior tongue measures were not considered in the present study. The time taken for the data collection from each child was 20-30minutes (approximately) including providing instructions, demonstration of the task to the child by the clinician and actual task performance by the child.

Analysis

The scores obtained from each participant with respect to each task (lip strength, lip endurance, tongue strength and tongue endurance) and trials were totalled. Among three trials for strength measures of lips and tongue each, the maximum value was considered as final output of strength with respect to each participant. However for endurance measures only one trial was performed by each participant for both lip and tongue, therefore the recorded values were considered as final output values. These scores were averaged across all the participants and fed to the computer for statistical analysis.

Statistical analysis

SPSS version 21.0 software was used for the statistical analysis. For assessing the reliability of the data, Cronbach’s Alpha was used. Descriptive statistics was carried out to obtain mean, median and standard deviation for the typical and clinical population across age groups (6-7years and 7-8years) and gender. Shapiro-Wilk test was performed to check for the normality of the obtained data. Mann Whitney (non-parametric) test was performed to find the significant difference for strength and endurance measures of lips and tongue across the age groups, gender as well as between typically developing children and clinical group (cerebral palsy). The results obtained have been presented and discussed in the next chapter.

CHAPTER IV

RESULTS AND DISCUSSION

The main aim of this study was to investigate the lip and tongue strength and endurance in typically developing Indian children across the age range of 6-8 years using Iowa oral performance instrument (IOPI) and thereby develop norms. The specific objectives of the study were to investigate the changes in strength and endurance of lips and tongue, if any, that occurred across different age groups and gender and to assess the clinical validity of the data obtained from typically developing children by comparing this data with that of the age matched children with cerebral palsy.

A total of 110 typically developing Kannada speaking children in the age group of 6-8 years were selected for the study. These participants were further divided into 6-7 years (mean age: 6.10 years) and 7-8 years (mean age: 7.5 years). Each group consisted of 55 children, with 28 males and 27 females in the 6-7years age group and 27 males and 28 females in 7-8 years age group. Age matched 10 children with cerebral palsy were included, which constituted the clinical group. The strength and endurance measures of lips and tongue were obtained from all the participants using IOPI, which were averaged and subjected to statistical analysis using SPSS version 20 software. Descriptive statistics was done to obtain mean, median and standard deviation. Appropriate statistical measures were used as listed below:

- For checking the test-retest reliability, Cronbach's alpha was used.
- Normality was checked using Shapiro-Wilk test for the obtained data. Since the data was not following the normal distribution, Mann Whitney (non-parametric) test was performed to check for significant difference, if any, in the following:
    i. Strength and endurance measures of lips and tongue across gender
    ii. Strength and endurance measures of lips and tongue across age groups
    iii. Strength and endurance measures of lips and tongue for typically developing children and children with cerebral palsy.

The results obtained from all the above statistical analyses have been presented and discussed under different sections below:

I. Test-retest reliability

Test-retest reliability was computed for 10% (11 children from both the age groups) of the total sample of typically developing children. The Cronbach's alpha for the lip strength, lip endurance, tongue strength and tongue endurance was 0.94, 0.92, 0.98 and 0.97 respectively. The 'α' varied between 0.92 and 0.98, which indicated high test-retest reliability for the obtained data.

II. Comparison of strength and endurance of lip across gender

Descriptive statistics wereobtained to find the mean, median and standard deviationvalues of lip strength and lip endurance for females and males in both the age groups.The mean lip strength values for females were higher than age matched male participants in both the age groups (6-7 years & 7-8 years). Similarly the mean lip endurance values for females were higher than males for the 6-7year age group, however, for the 7-8year age group, the scores were higher for the male participants in comparison to the female participants. Mann-whitney test was performed to check whether any significant differences existed for gender in both the age groups for lip strength and endurance. The results revealed that for lip strength, a significant difference ($p=0.05$) was present between females and males at 6-7years, however there was no significant difference ($p>0.05$) found at 7-8years.For lip endurance, no significant difference ($p>0.05$) was found between gender at 6-7years, significant differences was found ($p=0.05$) at 7-8years. The mean values along with the standard deviation, median and results of Mann-whitney test have been depicted in the Table 4.1.

Table 4.1

Mean, standard deviation (SD), median and results of Mann Whitney test(/z/ and p value) for strength and endurance of lips across gender

Age	**Measure***	**Females**			**Males**			**/z/ value**	**p value**
		Mean	**SD**	**Median**	**Mean**	**SD**	**Median**		
6-7 years	LS	28.18	1.46	28.00	27.39	1.49	27.00	1.94	0.05**
	LE	17.74	1.91	18.00	16.96	1.89	16.00	1.42	0.15
7-8 years	LS	36.00	1.85	36.00	35.82	2.68	37.00	0.12	0.89
	LE	23.26	1.56	23.00	24.10	1.91	24.00	1.94	0.05**

**Note: LS –Lip strength; LE – Lip endurance; **p=0.05indicates significant difference*

The findings of the current study indicated that sexual dimorphism existed at prepubertal stages of child, especially for lip strength at 6-7 years and for lip endurance at 7-8 years.Studies comparing the gender for lip strength and endurance using IOPI device in typically developing children are scarce. The results of the present study are in consonance with the studies which investigated the developmental aspects of lip and tongue. Vorperian et al. (2011) documented that there were statistically significant gender differences that existed in the anatomy of the prepubertal vocal tract at approximately 3 and 7 years of age. This was done using 605 MRI and CT images in a horizontal region ranging from a line tangential to lips to the posterior pharyngeal wall. Another study conducted by the same authors in 2004 also indicated differences between the growth speeds in males and females showing ongoing growth with no sexual dimorphism at early life period i.e. between birth and age 6 years, whereas later, a period of accelerated growth spurt takes place for most vocal tract structures with sexual differences. Therefore the results of the current study add on to the literature that gender differences are evident atleast less significantly, at 6-8years with respect to strength and endurance measures of lips.

A few studies have been conducted in adults as well, which included gender comparison as one of the variable using the IOPI device. The study by Jeong et al. (2017) is in partial agreement with the findings of the present study who considered healthy adult population and found no significant differences in maximal lip strength between genders, however for lip endurance, significant differences were found between females and males with the males exhibiting higher mean values than females.In contrast Clark et al. (2012) found significant differences between adult females and males w.r.t. lip strength, where males showed greater lip strength than females. These variations in the findings could be due to differences in certain variables/factors among the studies such as number of participants, their ages, regional differences, and measurements tools/techniques, biological factors etc. which should be taken into consideration when comparing and concluding the results.

III. Comparison of strength and endurance of tongue across gender

Descriptive statistics were obtained to find the mean, median and standard deviation values of strength and endurance measures of tongue for females and males in both the age groups.The mean tongue strength and endurance values were higher in males than females in both the age groups. The values of mean, standard deviation and median have been depicted in the Table 4.2.

Table 4.2

Age	Measure*	Females			Males			/z/ value	p value
		M ean	S D	M edian	M ean	S D	M edian		
(-7 years	S	1.48	2 .11 5	1.00	2 1.57 6	1 .87 8	1.50	2 8	.27	.78

	E	.96	.53	.00	.00	.86	.00		.84	.00**
'			2		2	:		2		
-8 years	S	7.38	.44	7.00	7.62	.22	6.00		.90	.36
			7		7	8		9		
	E	.61	.38	.00	.44	.59	.00		.51	.13

Mean, standard deviation (SD), median and results of Mann-whitney test (/z/ and p value) for strength and endurance of tongue across gender

**Note: TS – Tongue strength; TE – Tongue endurance; **p<0.01 indicate highly significant difference*

To investigate whether any significant difference existed on tongue strength and endurance measures between gender in both age groups, Mann-whitney test was performed. The results revealed that at 6-7years, there was no significant difference ($p>0.05$) across gender for tongue strength, however a highly significant difference ($p<0.01$) was seen for tongue endurance measure. In the 7-8year age group, no significant differences were found between females and males for both tongue strength and endurance measures. The results (/z/ and p values) of Mann Whitney test have been depicted in the Table 4.2.

The results of the present study is in consonance with the evidences provided by Potter et al. (2009) who measured maximal tongue strength in typically developing children and adolescents in the age range 3–16 years with IOPI device. There was no significant difference in tongue strength across gender for children in the age range of 3–14 years. However, a trend was seen with females showing greater tongue strength slightly but not significantly than males at age 10 years, followed by males surpassing females and showing greater tongue strength slightly, but not significantly at ages 14 and 16 years. Hence the authors concluded that sexual dimorphism in children begins at childhood before 10years of age, though it is not significant. Limited studies are available that have assessed the influence of gender on tongue endurance in children, which allows no clear comparison with the findings of the current study.

A few studies that have compared tongue strength and endurance measures in adults across gender using the IOPI device, have shown contradictory findings. Crow et al., (1996) examined tongue strength and endurance in typical individuals of age range 19-96 years (52 male and 47 female participants). The gender analysis revealed significantly lower tongue pressures in females (64.7 ±19.6 kPa) compared to males (74.8 ± 18.9 kPa) and there was no significant difference in tongue endurance between males and females. But results found by Youmans et al. (2009) in 96 participants with normal swallowing from age range of 20–79 years, indicated no significant differences between men and women for tongue strength measure. Vanderwegen et al. (2013) collected data on the maximum anterior and posterior tongue strength and endurance in 420healthy Belgians across the adult life span (20–30, 31–40, 41–50, 51–60, 61–70, 70–80, and above 81 years old) using IOPI. The effect of gender by combined age on anterior tongue strength and endurance in this study remained significant but minor. In agreement with the findings of the current study, this study also shown higher tongue strength (47.31kPa) and endurance (25.18seconds) in males than in females (41.22kPa and 19.89seconds).

Various factors such as age groups, tasks and instructions, instrumental (version) differences, methodological differences, performance variations, participant's inclusion criteria for evaluation, life style aspects, body mass index, regional differences, nutritional status and individual developmental differences etc. could have contributed to these differences among the studies.

IV. Comparison of strength and endurance of lip across age groups

Descriptive statistics wasobtained to find the mean, median and standard deviation values of strength and endurance measures of lip for both the age groups. Irrespective of gender, the mean values for lip strength and endurance were higher in the 7-8 years old children than the 6-7years old children. These mean values along with the standard deviation and median for each age group with respect to gender have been depicted in the Table 4.3.

Table 4.3

Gender	Measure*	6-7 Years			7-8 Years			/z/ value	p Value
				M			M		
		ean	D	edian	ean	D	edian		
F					2		3		0
emales	S	8.18	.46	8.00	6.00	.85	6.00	.27	.00**
					1		2		0
	E	7.74	.91	8.00	3.26	.56	3.00	.22	.00**
M					2		3		0
ales	S	7.39	.49	7.00	5.82	.68	7.00	.50	.00**
					1		2		0

	E	6.96	.89	6.00	4.10	.91	4.00	.45	.00**

Mean, standard deviation, median and results of Mann Whitney test (/z/ and p value) for comparison of *strength and endurance of lips across age groups*

**Note: LS – Lip strength; LE – Lip endurance; **p<0.01 indicates highly significant difference*

The mean values were subjected to Mann-whitney test to check whether there was a significant difference between the two age groups within each gender for lip strength and endurance measures. The results of the test revealed highly significant difference between both the age groups (p<0.01) within each gender for both lip strength and endurance measures. The results of Mann Whitney test have been depicted in the Table 4.3.

The results of the present study is in agreement with the study by Song(2015) who found significance differences on maximal different age groups on lip strength and concluded that lips strength increased with age.

In the current study the mean value for lip strength and endurance was higher for the older age group (7-8 years>6-7years) in both females and males. This indicated that the structure and functional aspects of the lips undergo development during childhood. These results can be further supported by the studies conducted on orofacial development using physiological and other methods, which concluded that the basic development in oromotor movements especially in jaw and lower lip takes place up to 4 years and in the later stages, the oromotor system will undergo a process of fine refinement (Sharkey & Folkins, 1982). Murdoch, Cheng, and Goozee (2011) suggested that gradual development of lip progresses from 6 years and continue till adulthood. Fitch and Giedd (1999) found growth rate of lips size increased by an average of 12% between childhood and puberty, and by 5% between puberty and adulthood. Watkins and Fromm

(1980) found that precision of lip motor control in speech, markedly increased between 7-10 years.

Similarly Ferrario et al. (2000) investigated dimensions of lips (linear distances and ratios, vermilion area, volume) using 3-dimensional computerized system in 1348 healthy subjects between 6 years of age and young adulthood and also the relevant growth changes and gender differences in growth patterns in them. Similar findings were found as in the present study i.e. significant differences were found between 6-7years and 7-8years in certain measures such as total lip volume and height, lower lip volume, total, upper and lower lip vermilion area and height in both girls and boys. Hence they concluded that the developmental trends were evident between 6-7years and 7-8years for lip growth in terms of its total volume and height, lower lip volume and total upper and lower lip vermilion area, indicating that prepubertal changes/ development takes place.

In support to the above studies, findings of the current study add on to the literature that developmental trends are evident in lips even at prepubertal stages of children, especially at 6-8years of age in terms of lip strength and endurance, which is in parallel to the anatomical/physiological changes such as its length, thickness, muscle fiber density and other aspects.

IV. Comparison of strength and endurance of tongue across age groups

Descriptive statistics was extracted to find the mean, median and standard deviation values of strength and endurance measures of tongue. The mean values for tongue strength and endurance measures were higher for the children (both females and males) in the 7-8 years age group thanfor children in the age group of 6-7 years.These mean values along with the standard deviation and median for each age group with respect to gender have been depicted in the Table 4.4.

Table 4.4

Mean, standard deviation, median and results of Mann Whitney test (/z/ and p value) for comparison of strength and endurance of tongue across age groups

Gender	Measure*	6-7 years				7-8 years		/z/ value	p value
					M		M		
		ean	D	edian	ean	D	edian		
F					2		2		
emales	S	1.48	.11	1.00	7.38	.44	7.00	.25	.00**
					6		7		
	E	.96	.53	.00	.61	.38	.00	.69	.00**
M					2		2		
ales	S	1.57	.87	1.50	7.62	.22	6.00	.42	.00**
					8		9		
	E	.00	.86	.00	.44	.59	.00	.46	.14

Note: TS – Tongue strength; TE – Tongue endurance; P<0.01 indicate highly significant difference*

To compare the strength and endurance measures of tongue across two age groups within each gender, Mann-whitney test was performed. The results revealed highly significant difference ($p<0.01$) between both age groups (6-7 years and 7-8years) in females for tongue strength and endurance. However, in males highly significant differences were found for tongue strength only, and not for tongue endurance between both the age groups. The results of Mann Whitney test i.e. /z/ and p values have been depicted in Table 4.4.

These findings are in consonance with the studies conducted in the past (Potter & Short, 2009; Song, 2015). These studies also showed significant difference in children across the age groups on maximum tongue strength scores using IOPI device. They concluded that children showed developmental changes in terms of tongue strength with increase in the age.

Physiological evidences were provided by Harris, Jackson, Paterson and Scammon, (1930). They reported that the tongue reaches nearly adult size by 8 to 10 years, which could be due to the classic neural growth pattern. Green et al., (2000) suggested that coordinative organization of the articulatory gestures shift dramatically during the first several years of life and continue to be refined past age 6 and tongue movement patterns exhibited by 6-year-olds were similar to those of adults, but were found to be more variable, indicating that it was still under process of refinement. These findings support the fact that articulatory structures and functions undergo a process of refinement and maturation which could be observed evidently during the period of 6 to 8 years reflecting neuronal, muscular, anatomical as well as physiological maturation of tongue taking place before prepubertal stages of an individual.

The tongue endurance measures in males did not show any significant difference across age groups, which could be due to the sexual differences in craniofacial growth patterns between males and female i.e., growth in males complete later than females (Enlow, 1990; Bugaighis, Mattick, Tiddeman, & Hobson, 2014).Fitch and Giedd (1999) in their study suggested that lip mature earlier than tongue in children irrespective of gender. Hence based on evidences, it could be hypothesized that, variations in the craniofacial growth pattern between gender and the sequential maturation of lip and tongue in children, would have influenced the results of tongue endurance measure in males.

Although there were no significant difference found for tongue endurance measure in males, the mean endurance scores of older age group (7-8 years)were higher than younger age group (6-7 years), indicating that minor developmental changes are taking place. However in general, various performance factors such as following instructions, comfort level, motivation and interest towards the task performance, and differences in tongue anatomical dimensions such as length, thickness, weight, fibre density etc., could have had an influence on the findings of the present study.

Thus to summarize, a developmental trend was seen with regard to both lip and tongue strength and endurance across the age groups. Based on the research evidences, these changes could also be hypothesized due to transformation of associated fiber type and adaptation of mechanoreceptors of lips and tongue with the increase of age (Saigusa, Niimi, Yamashita, Gotoh, & Kumada, 2001; Kraemer, Ratamess, & French, 2002; Stal, 2003; Karavirta, Hakkinen, Sillanpaa, Garcia-Lopez, Kauhanen & Haapasaari, 2011). The authors suggested that, the facial muscles including lips and tongue generally consist of fatigue resistant type IIa or highly fatigue resistant type I muscle fibers. During childhood muscles such as orbicularis oris, buccinators, and muscles of tongue undergoes period of refinement/ muscle fiber adaptations (muscle fibre hypertrophy, increased number of muscle fibers& utilization of available oxygen). These adaptations directly aids to build fatigue resistant muscle fibers of lip and tongue, reflecting the development of their mobility, strength and endurance.

In comparison with the present study, the mean values of strength and endurance measures of lips and tongue in Indian children were higher than the mean values obtained from Korean children but lower than the American age matched population, who used similar method and device (IOPI). A study conducted by Mallavarpu, Reddy, Jayade, Revathi, Sudheer kumar and Naveen (2010) concluded that lip thickness, length, posture and development in Indian children differed from that of age matched children of Mamandras, Thai and African-American population. Therefore, the present study also supports thefact that ethinocultural variations, linguistic backgrounds, races, regional variations, life style changes can have an effect on the developmental and functional aspects of individuals across the life span. These evidences support the fact that region specific norms are essential.

VI. Normative data for lip-tongue strength and endurance across age and gender

To provide comparative data for clinical applications, predicted means with 95% confidence intervals (CI) have been depicted in the Table 4.5 in addition to observed median, standard deviations, and ranges for both females and males across both the age groups (6-7 years & 7-8 years). The data from the present study could be used for comparing strength and endurance measures of lips and tongue in children with impaired oromotor deficits with typically developing peers based on gender.

Table 4.5

Mean, median, standard deviation and confidence intervals of lip-tongue strength and endurance in females and males at 6-7 years and 7-8 years

Age	Gender	Measure*	Mean	95% CI For Mean		SD	Median
				Lower Boundary	Upper Boundary		
6-7years	Female	LS	28.18	27.60	28.76	1.46	28.00
7-8yerars			36.00	35.25	36.74	1.85	36.00
6-7years		LE	17.74	16.98	18.49	1.91	18.00
7-8yerars			23.26	22.63	23.90	1.56	23.00
6-7years	Male	LS	27.39	26.81	27.97	1.49	27.00
7-8yerars			35.82	34.80	36.84	2.68	37.00
6-7years		LE	16.96	16.22	17.69	1.89	16.00
7-8yerars			24.10	23.37	24.83	1.91	24.00
6-7years	Female	TS	21.48	20.64	22.31	2.11	21.00
7-8yerars			27.38	26.80	27.96	1.44	27.00
6-7years		TE	5.96	5.35	6.56	1.53	6.00
7-8yerars			7.61	6.65	8.57	2.38	7.00
6-7years	Male	TS	21.57	20.84	22.29	1.87	21.50
7-8yerars			27.62	26.39	28.84	3.22	26.00
6-7years		TE	8.00	7.27	8.72	1.86	8.00
7-8years			8.44	7.84	9.05	1.59	9.00

**Note: LS-Lip strength; LE – lip endurance; TS – tongue strength; TE – tongue endurance; CI- Confident intervals for mean*

VI. Comparison of strength and endurance of lip and tongue between typically developing children and cerebral palsy

The mean, median and standard deviation values for all four measures (lip strength, lip endurance, tongue strength and tongue endurance) were obtained for age matched children with cerebral palsy using Descriptive statistics. Mann Whitney test was performed to check whether any significant differences were present between typically developing children and children with cerebral palsy on all four measures. The results revealed highly significant differences ($p<0.01$) on all four measures in comparison to the typically developing children. However, gender comparison could not be done due to limited sample size of clinical group (cerebral palsy). The results of Mann Whitney test (/z/ and p values) along with mean, median and standard deviation values have been depicted in the Table 4.6.

Table 4.6

Mean, standard deviation (SD), median and results of Mann Whitney test (/z/ and p value) for the control and clinical group on strength and endurance measures of lips and tongue

Age	**Measure***	**Clinical group**			**Control group**			**/z/ value**	**P value**
		Mean	**SD**	**Median**	**Mean**	**SD**	**Median**		
6-8	LS	10.40	1.71	10.50	31.84	4.52	30.50	5.23	0.00**
	LE	4.90	1.44	4.50	20.52	3.69	20.00	5.24	0.00**

years	TS	2.70	1.25	3.00	24.51	3.75	24.50	5.24	0.00**
	TE	1.00	0.94	1.00	7.52	2.06	8.00	5.27	0.00**

Note: LS – Lip strength; LE – Lip endurance; TS – Tongue strength; TE – Tongue endurance; p<0.01 indicates highly significant difference*

The findings indicated that children with cerebral palsy had lower strength and endurance of lips and tongue in comparison to age matched typically developing children. Many studies in the past have indicated that children with cerebral palsy frequently have oral-motor involvement, which may include oral, pharyngeal, or esophageal dysphagia (Reilly, Skuse, & Poblete, 1996; Benfer, Weir, & Boyd, 2012) and /or speech impairment. Although prevalence figures for oral-motor involvement in children with CP varied among studies, research suggests that oral-motor dysfunction with subsequent feeding problems may be observed in up to 90% of preschool as well as school age children with CP (Reilly et al., 1996). Further even children with very mild CP may show evidence of oral-motor involvement, which could in turn affect the nutritional intake, functional feeding skills and participation (Gisel, Alphonce, & Ramsay, 2000).

Many studies provided evidences that children with cerebral palsy irrespective of age, gender and type, exhibited abnormal oral muscle tone and strength with respect to lip and tongue, resulting in lack of tongue lateralization, hyper tonicity of tongue, limited tongue movement, lip retraction/reduced lip closure, discoordinated tongue movement patterns, tongue thrust, drooling along with exaggerated bite reflex, poor chewing, poor/absent bolus formation, poor/absent manipulation of bolus, oral pocketing of food, slow oral transit time (slow transportation of bolus) at the level of oral phase of swallowing and also premature spill into the pharynx, delayed swallow initiation, slow pharyngeal transit time, residue in the pharynx after a swallow (incomplete clearance), pooling of food in the valleculae or pyriform sinus, aspiration/penetration before, during or after swallow, nasal regurgitation, gagging, increased frequency of choking and coughing, respiratory distress during meals, reduced pharyngeal motility and poorly coordinated ventilatory cycle and swallowing (Arvedson, Buck, Smart, & Msall, 1994; Gangil, Patwari, Aneja, Ahuja, & Anand, 2001; Rogers, Redstone, & West, 2004; Arvedson, 2013; Aggarwal, Chadha, & Pathak, 2015).

Other physiological evidences also suggest poor muscle tone and strength of the orbicularis oris muscle and its coordination with other muscles of face such as masseter, infrahyoid muscles in children with CP, which often result in certain issues like drooling in association with speech and feeding difficulties especially at oral phase, which further hampers the initiation and control of swallowing (Sochaniwskyj, Koheil, & Bablich, 1986).

The lower strength and endurance measures of lip and tongue also might be due to the differences between the physical activity of the typically developing children and children with cerebral palsy who are lesser physically active due to their topographic distribution. This indirect effects of physical activity of children may also be observable in the muscles of the tongue. Support for this notion is provided by findings of a recent study on rats showing improved tongue strength and endurance after an 8-week exercise programme consisting of treadmill running (Kletzien, Russell, Leverson & Connor, 2013). The authors speculated that an increased respiratory rate during physical activity could place greater demands on tongue muscle fibers to support upper airway patency in rats (Shi, Seto-Poon, & Wheatley, 1998).

Jayanti Ray (2016) investigated the efficacy of IOPI device in enhancing swallowing functions in a 24-yearold female with mixed developmental dysarthria who was born with cerebral palsy at birth. The client underwent for 33 treatment sessions. Each session lasted for about 60 minutes with a frequency of 2 sessions per week. To improve overall swallowing functions, the client was engaged in strength and endurance training of tongue and lip using the IOPI, allowing repeated measures. The results of the study revealed that the rate of swallows increased by 38% due to the exercises and was satisfactory due to the increased number of swallows and reduced drooling. Hence author conclude that the IOPI was successful in facilitating desirable swallowing behaviours by improving strength and endurance aspects of tongue and lip.

In sum, significant gender differences was seen only for lip strength and tongue endurance at 6-7years and for lip endurance at 7-8years. Highly significant difference was found for strength and endurance measures of lips and tongue in females, whereas in males highly significant differences were found only for lip strength, lip endurance and tongue strength. The mean values of strength and endurance measures of lip and tongue of older age group (7-8years) were higher than mean values of younger age group (6-7years). Therefore it can be concluded that developmental trends and prepubertal sexual dimorphism occurs w.r.t strength and endurance measures of lip and tongue in children at 6-8years. The results of the study indicated that, the test-retest reliability was high for strength and endurance measures of lip and tongue.Further, there was a high significant difference between the control group (healthy participants) and the clinical group (cerebral palsy) for strength and endurance measures of lips and tongue indicating good clinical validity of the data obtained from typically developing children. The mean strength and endurance values of clinical group were lower in comparison with typically developing healthy children. Therefore the developed normative data of strength and endurance measures of lip and tongue, can be used as a reference during evaluation and treatment of children with oromotor deficits associated with various speech and swallowing disorders.

CHAPTER V

SUMMARY AND CONCLUSIONS

Lips and tongue are important structures of articulatory system. Their strength, mobility and sustenance are crucial for speech production and swallowing acts. Many disorders and conditions have been reported in the literature, which are associated with oromotor deficits including the lips and tongue, such as orofacial myo-functional disorders, cerebral palsy, developmental delays, intellectual disabilities, cleft lip and palate, autism spectrum disorders and other syndromic and metabolic disorders irrespective of age. Therefore evaluating lip and tongue function is important in the assessment and treatment of impairment in chewing, swallowing and other speech disorders. During the oromotor assessment, the integrity of the lips and tongue musculature can be examined through visual assessment of the concerned articulator at rest, during sustained posture and movement, which are usually done subjectively during routine clinical practice. However, this method raises concerns regarding the reliability of the assessment performed due to an inability to eliminate the assessor bias and the variability among multiple assessors in most of the clinical environments. To eliminate such issues, there is an increasing emphasis on the usage of objective tools during clinical examination.

Lushei in early 1990’s developed a device called Iowa oral performance instrument (IOPI) which is a portable hand-held device that uses an air-filled pliable PVC bulb to evaluate strength and endurance measures of lip, tongue and cheek. A few studies have been conducted in the past and recent years using IOPI to assess the lip and tongue strength and endurance in individuals of different age groups. Further studies have been carried out to assess its efficacy in treating the clinical population. The results of most of these studies revealed lower values of strength and endurance of the lip and tongue among clinical population in comparison to the typical population.

A review of the existing literature revealed that studies to measure the lip - tongue strength and endurance in the paediatric population are scanty. Most of the studies have been carried out in the healthy adults and elderly. Evidence was strongest for strength measurements and was best established for measurements of tongue strength. However, very few studies have measured lip strength and endurance. Some of these studies conducted on adults, have developed norms using IOPI so that the same can be used for rehabilitation purposes. However, these norms cannot be used with children, since they differ from adults w.r.t. anatomical dimensions and maturation of speech motor system, muscle size and physiology, shape of individual structures and their positional relationships. Further, the development of articulators continues throughout the childhood. Most of the studies on children that have been conducted are in the western population. The norms provided as a part of these studies cannot be used with children from other ethnic/linguistic backgrounds as the developmental patterns and physiology could vary.

There is a great need for objective quantitative measures of strength and fatigability of tongue and lips to aid in the assessment and management of feeding, swallowing as well as speech disorders in children across the age and gender. Keeping this in view, the present study was planned with the aim of developing normative data of lip-tongue strength and endurance in typically developing Indian children in the age range of 6-8 years using IOPI. The specific objectives of the study were to determine whether strength and endurance of the tongue and lips varied with gender, to investigate the changes in strength and endurance of the lips and tongue across different age groups, and to assess the clinical validity of the data obtained from the typically developing children by comparing the same with the strength and endurance of the lips and the tongue, in age matched children with cerebral palsy (CP).

The participants included two groups in the study; one group consisted of typically developing children and the other group consisted of children with CP. A total of 110 typically developing Kannada speaking children in the age group of 6-8 years were selected for the study. These typically developing participants were further divided into two different age groups; 6-7 years (mean age 6.10 years) and 7-8 years (mean age 7.5 years). Each group consisted of 55 children with, 28 males and 27 females in 6-7years age group and 27 males and 28 females in 7-8 years.All ethical standards were met for participant selection and their participation. Prior to testing, a written consent was obtained from the teachers of the participants after explaining the purpose of the study. Socioeconomic status and other demographic details was noted regarding the participants included in the study. The WHO Ten-question disability screening checklist (Singhi, Kumar, Malhi, & Kumar, 2007) was used to screen the typically developing children to rule out the presence of speech and language disorders, neurological, oromotor, psychological, physical and sensorimotor disorders. Only those participants without any of these problems were included. Children with a history of structural or neurologic impairments, presence of fever, cold, seizures, oral infections, dentures, pain in jaw and lips, oromotor sensory deficits, malocclusion (misaligned teeth), high arched palate, poor oral hygiene, respiratory disease, cognitive and language deficits, major head or neck surgery or any kind of health issues at the time of data collection were excluded from the control group.

A group of 10 children (5 females and 5 males) with CP in the age range of 6-8 years were considered as clinical group for the study. All children of CP were of spastic type with topographic distribution of hemiplegia in 6 children and diplegia in 4 children. Only those who were diagnosed as ‘Delayed speech and language or developmental dysarthria secondary to cerebral palsy’ by a qualified team of professionals including speech-language pathologist, paediatrician, physiotherapist and a clinical psychologist were included for the study. Those children with associated problems such as sensory impairment, seizures, malocclusion (misaligned teeth), high arched palate, etc. were excluded from the clinical group, however children with mild intellectual disability were included. Their oromotor abilities were assessed by administering the Assessment of Oral Motor, Oral Praxis and Verbal Praxis Skills in Persons with Down syndrome (Rupela & Manjula, 2008). Only children with oromotor deficits were included for the validity testing.

Later the participants were examined for their strength and endurance measures of lip and tongue using IOPI with appropriate instructions and demonstrations provided by the clinician for each child. Lip strength (inter-labial compression) was measured by placing the bulb between the upper and lower lip (at tubercle of upper lip and groove of lower lip) at the middle and the participants were asked to press the bulb as hard as possible for 2-3seconds; 3 trials were performed with 30-60 seconds rest period between the trials and the values (pressure) displayed on the device were noted by clinician manually. Similar placement was used to measure the endurance of the lip and the LCD display was set to 50% of the participant's peak pressure and the participants were instructed to press the bulb as hard as possible until the (green) light illuminates on the device and keep on the bulb squeezing as long as possible. The duration (seconds) displayed on the device was recorded and only one trial was conducted for each participant. Following this, the anterior tongue strength was measured by placing the bulb against the participant's hard palate just behind the alveolar ridge with similar instructions and number of trials provided to measure lip strength and the values (pressure) displayed on the device were noted. To measure tongue endurance, a similar placement was used as placed for tongue strength measurement with single trial and duration was noted. Later to assess the test-retest reliability, all four tasks i.e. lip and tongue strength and endurance) were administered again on 10% of subjects of the total population (11 participants from both the age groups) who were selected randomly after one week of the initial data collection.

The data thus collected from both the groups were subjected to appropriate statistical measures using SPSS version 21. For checking the test-retest reliability, Cronbach's Alpha was used. Descriptive statistics was done to obtain mean, median and standard deviation. Mann-Whitney (non-parametric) test was performed to compare the differences of strength and endurance measures of lip and tongue between the gender (females vs. males), age groups (6-7years vs. 7-8years), as well as between typically developing children vs. children with CP.

The results of the study indicated that, the test-retest reliability was high for strength and endurance measures of lip and tongue.The results of comparison of strength and endurance measures of lip across gender revealed that for lip strength, a significant difference existed between females and males at 6-7years; whereas, a significant gender difference was found for lip endurance only at 7-8years.Further,the results of comparison of tongue strength and endurance across gender revealed no significant difference in both the age groups for tongue strength, whereas, for tongue endurance, a highly significant gender difference was found only in the 6-7years age group.

Further, the results of age group comparison, revealed highly significant differences for lip strength and endurance between both the age groups (6-7 years and 7-8years) within each gender. For tongue strength and endurance, highly significant differences were found between both age groups (6-7 years and 7-8years) in females. However, in males, highly significant differences were found only for tongue strength between both the age groups. The overall mean values of strength and endurance measures of lip and tongue, were higher for older age group (7-8years) than younger age group (6-7years) in both females and males. Therefore it can be concluded that developmental changes and prepubertal sexual dimorphism occurs w.r.t strength and endurance measures of lip and tongue in children between 6-8years.

Further, comparison of strength and endurance measures of lip and tongue between typically developing group and clinical group (CP) revealed highly significantly difference between the groups. The clinical group exhibited lower mean values of strength and endurance measures of lip and tongue than the age matched typically developing group. The lack of age adequate strength and endurance measures of lip and tongue reflected the presence of oromotor deficits in the children with CP.

Implications of study

The present study could be considered as a first of its kind, in the Indian context that attempted to develop norms using IOPI in typically developing Kannada speaking children in the age group of 6-8years.The study would add on to the body of literature on the use of IOPIspecifically, since the studies to quantify lip - tongue strength and endurance in paediatric population are scanty. The norms developed as a part of the study can be used as a reference to compare the lip and tongue measures obtained using IOPI in the clinical population during the oromotor assessment. The normative data also facilitates the selection on precise target values for strength and endurance measures of lip and tongue, with respect to age and gender, during treatment of oromotor deficits in children.

Limitations of study

There are certain short comings in the study which needs to be taken into account. Factors of lips and tongue such as lip-jaw relations, dentition, facial asymmetry, diameter-thickness of lips and tongue and muscle length could not be delineated during the study. Additional factors such as order of testing, nutrition status, respiratory capacity, body mass index, and level of physical activity were not controlled, which could have influenced the performance of children in both the groups.

Future directions for research

Future research can focus on developing norms for strength and endurance measures of their lips and tongue in other age groups in different regions of India by considering other factors such as body mass index, physical activity, food habits etc. Further, additional studies can be conducted to assess the relationship between lip-tongue measures and speech intelligibility, feeding and swallowing abilities in the clinical population.

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Appendix I

Assessment of Oral Motor, Oral Praxis and Verbal Praxis Skills in Persons with Down syndrome (Rupela, 2008)

ORAL MOTOR ASSESSMENT

A. POSTURE

1. Scoring: ‘1’ if answer is ‘yes’, and ‘0’ if answer is ‘No’

a) Does your child sit up straight? Yes/No

b) Are his/her shoulders symmetrical Yes/No

c) Is the child’s neck in a normal alignment with shoulders Yes/No

2. Scoring: ‘1’ if answer is ‘yes’, and ‘0’ if answer is ‘N

a) Are there any involuntary movements present in the child’s head, shoulders and /or trunk Yes/No

b) Does the child’s mouth position improve when placed in 90 Yes/No

Degree hip, knee and ankle flexion?

3. Instruct the child to imitate the following movements.

Circle the choice found appropriate for each

Score 1 for ‘adequate’ and 0 for ‘inadequate’

a) Forward and backward movement of the head — Inadequate/Adequate

b) Rotation of the head — Inadequate /Adequate

c) Left - right movement of the head — Inadequate /Adequate

d) Left - right movement of the shoulders — Inadequate /Adequate

e) Left - right movement of the trunk — Inadequate /Adequate

f) Forward and backward (bending front and back) Movement of the trunk — Inadequate /Adequate

B. ORAL STRUCTURES AT REST

Score 2 for ‘a’, 1 for ‘b’ and ‘0’ for ‘c’

1. The child’s jaw is :
   a) In normal alignment
   b) Slightly protracted or retracted
   c) Noticeably protracted or retracted
2. The child’s jaw at rest is:
   a) Closed
   b) Slightly open
   c) Noticeably open
3. The child’s lips are :
   a) In a normal position
   b) Slightly protruded or retracted
   c) Obviously protruded or retracted

4. The child
    a) Does not drool
    b) Drools, but tries to swallow it
    c) Drools and does not use any strategy to clear it
5. The child's tongue is :
    a) Placed appropriately inside the mouth
    b) On the bottom of the lower lip
    c) Outside the mouth
6. Based on the interpretation from the five items above, the oral structures seems to show
    a) Normal tone
    b) Mildly abnormal tone
    c) Moderately abnormal tone
7. Involuntary movements are :
    a) Absent
    b) Present but rarely noticeable
    c) Apparently present
8. When the child moves his/her oral structures :
    a) Other parts of the body do not move
    b) Other parts of the body move minimally
    c) Other parts of the body move noticeably and hinder in speech production

C. FUNCTION OF THE ORAL MECHANISM FOR SPEECH

Score 1 for 'adequate' and 0 for 'inadequate'

1. The intra-oral build-up for stops is Adequate/Inadequate
2. Air build up and precision of fricatives is Adequate/Inadequate
3. Oral - nasal distinction is Adequate/Inadequate

The following activities have to be observed without asking the client to imitate or do these activities:

4. When the child spreads his lips, the range of Movements of lips is Adequate/Inadequate

5. When the child opens and closes his/her mouth ,range of movement of jaw is Adequate/Inadequate
6. When the child moves the tongue form side to side, The range of movement is Adequate/Inadequate

D. ORAL SENSORY BEHAVIOUR

The following questions regarding the child are explained to the parent(s) or caregiver and asked how frequently the behaviours are exhibited based on the key given below.

0 - (N) Never

1 - (O) Occasionally

2 - (F) Frequent

3 - (A) Always

0 - (NA) Not applicable

	Questionnaire	N	O	F	A	NA
1.	Reacts aversively to new foods , tastes , or textures – limited repertoire					
2.	Avoids certain texture of food					
3.	Has poor lip closure (due to discomfort of closing lips)					
4.	Is uncomfortable when touched on face /cheeks /lips					
5.	Likes only highly textured or crunchy foods					
6.	Has trouble handling liquids					
7.	Chews or swallows ineffectively due to lack of awareness of food in the mouth					
8.	Constantly puts things in the mouth					
9.	Bites himself or others					
10.	May not notice if food offered is hot or cold					
11.	Demonstrates poor oral motor skill development (biting , chewing , swallowing)					
12.	Is unaware of the food stuck in the teeth or on side of the lips/face					
13.	Is unaware of the pooled saliva and drooling					
14.	Chews hard on things					

15.	Explores food by tasting					
16.	Chews constantly on non –food items –wants to taste everything					
17.	Acts as though all foods taste same –disinterested or bored with eating –poor appetite –fussy while eating					
18.	Only seems to taste foods that are highly spiced					
19.	Messy eater –frequently spills					