ABSTRACT

VALIDATION OF NASALITY SEVERITY INDEX

Aim and Objectives: The aim of the present study is to validate the nasality severity index developed by Navya & Pushpavathi (2015). The objectives of the present study were to evaluate all the four nasality severity index equations in children with RCLP and typically developing children (TDC). To verify the group membership based on the NSI cut-off scores and to evaluate the agreement in group membership derived from estimated NSI with the perceived nasality in Kannada speaking children with RCLP and TDC.

Design and Methods: The current study used standard group comparison design. In the present study**,** both subjective and objective assessments for 40 Kannada speaking children with RCLP and 20 typically developing children (TDC) were carried out. The speech samples containing spontaneous speech, five oral and oro-nasal sentences were collected from all 40 participants with RCLP for the purpose of perceptual evaluation. Five experienced judges analyzed the speech samples based on a standardized rating scale proposed by Henningsson et al. (2008) and assigned ratings accordingly. Other acoustic measurements such as nasalance measurement and one third octave analysis were carried out for all the participants for the estimation of NSI. Nasalance measures are evaluated for various oral, oronasal and nasal sentences along with vowels using Nasometer II 6450. One third octave spectral analysis was evaluated using MATLAB software for vowel /i/ in isolation and /i/ in the context of /pit/ and /tip/.

Results: The results of perceptual evaluation of nasality grouped 17participants with RCLP to mild hypernasality and other 20 participants with RCLP to moderate-severe hypernasal group. The intra and inter rater reliability were obtained using Kappa coefficient measures and results revealed a moderate-good agreement between and across judges. The level of agreement in group membership assigned based on NSI (3 & 4) and perceptual evaluation indicated a good agreement in group membership (0.644; $p<0.01$) based on Kappa statistics. Based on the nasalance and one third octave spectral measures the NSI equations were estimated. The NSI (1 & 2) showed 100% sensitivity and 0% specificity. It is considered to be very poor in identifying the control group. However, NSI (3 & 4) demonstrated 94% sensitivity and 100% specificity. Thus, NSI (3 & 4) indicated a good discrimination of control from clinical group and is appropriate for its clinical application.

Conclusions: The results of the current study indicated that NSI (1 & 2) has shown poor validity in differentiating the groups. Subsequently, NSI (3 & 4) indicated a good validity and can be considered for its clinical application to quantify nasality accurately. NSI is non-invasive, easy to interpret tool and helps in quantitatively evaluating the effect of therapeutic and surgical intervention on hypernasality.

Keywords: Repaired cleft lip and palate (RCLP), hypernasality, nasality severity index

“VALIDATION OF NASALITY SEVERITY INDEX”

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INTRODUCTION

Cleft lip and/or palate (CLP) is a congenital disorder which occurs as a result of incomplete fusion of tissues responsible for the development of upper lip and palate in the early phase of gestation. During gestational period, significant changes in the development of face occur between five to nine weeks and the following two weeks completes the palatal formation (Watson, 2001a). This is the period which entails the development of majority of speech articulators such as lips and palate and at this same time it would also lead to CLP and other craniofacial anomalies. The etiology includes genetic and environmental factors for CLP associated with syndromes; however the exact cause for a non-syndromic cleft is unidentified (Dixon, Marazita, Beaty, & Murray, 2011).

The incidence of CLP is estimated to be around 1 in 700 live births universally (Mossey, Little, Munger, Dixon, & Shaw 2009). However, the prevalence rate differs with respect to cultural background, gender, type of cleft and socio-economic condition of an individual (Bender, 2000). The individuals with CLP face various difficulties as a result of the structural anomalies such as feeding issues, dental difficulties, hearing loss, communication disorders, and psychological problems. Even after surgical repair of cleft palate, certain speech difficulties often persist among children with repaired CLP. The speech of these individuals with RCLP is characterized by hypernasality, audible nasal air emission, weak pressure consonants and compensatory articulatory errors which affects overall intelligibility of speech. These speech abnormalities persisting after surgical correction of cleft are seen as a direct consequence of velopharyngeal dysfunction. The velopharyngeal dysfunction is a condition manifested by abnormal velopharyngeal port function. This results in escape of air inappropriately through nasal cavity affecting speech production at articulatory, resonatory and phonatory levels. Thus, in order to elicit the etiology of VPD and to understand its nature for further management, a comprehensive speech evaluation is necessary. The detailed assessment of speech of children with VPD can be carried out using subjective and objective methods or a combination of both.

The perceptual evaluation is considered as the gold standard to assess the speech abnormalities related to VPD and cleft palate. This includes listener's judgments about overall rating of speech skills, describing certain speech parameters qualitatively (e.g., atypical consonant realizations, hypernasality, creaky voice, etc.) and rating overall speech intelligibility. In the assessment of speech of individuals with RCLP, perceptual ratings help to describe the nature and degree of speech abnormalities. It also helps professionals to decide on surgical intervention, study the effectiveness of speech therapy and to plan, implement and compare across various therapeutic techniques.

During the speech evaluation, it is essential to describe resonance characteristics (Henningsson, Kuehn, Sell, Sweeney, Trost-Cardamone, & Whitehill, 2008) because disturbed nasality is one of the core speech characteristics seen in individuals with repaired cleft palate. In general, nasal resonance is evaluated based on the type (hypernasality, hyponasality, mixed nasality and cul-de-sac resonance), degree (mild, moderate and severe) and consistency (frequent or variable). The most favored approach in this assessment of hypernasality and abnormal airflow is usage of rating scales. The SLPs often utilize binary scales (abnormal vs normal) or scales with equal intervals such as the 4 point scale where 1 = normal, 2 = mild, 3 = moderate and 4 = severe hypernasality to identify the presence and degree of hypernasality. Direct magnitude estimation and paired comparisons (with or without reference samples) have also been used to identify presence of hypernasality(6). Literature reports that descriptive categories and scale of equal intervals are the tools most often used. These perceptual rating scales were considered to study the surgical outcomes of participants with repaired cleft lip and palate (Dalston & Warren, 1986; Sell & Grunwell, 1990).

Also other methodological differences in the assessment of speech in individuals with CLP have been documented across various studies. Different stimuli like isolated vowel, words, sentences (oral, nasal & oronasal), paragraphs and discourse were employed in various studies that were aimed at differentiating individuals with hypernasality from control participants (Spriestersbach & Powers, 1959; Dalston & Seaver, 1992; Watterson, Lewis, & Deutsch, 1998; Searl & Carpenter, 1999). In literature, reliability of judge's rating of hypernasality and distribution of ratings across judges using various speech stimuli had been the focus of investigation in many other studies (Counihan & Cullinan, 1970). There was also a documentation of various speech assessment protocols that were developed in the same scenario.

The perceptual assessment is considered as the best approach in the analysis of speech of individuals with CLP. However, it is influenced by several variables which would affect the quality of assessment. Among them, the stimulus related variables such as type of stimuli (Chen, 2005), co-existing articulation errors in the stimuli (McWilliams, 1954; Starr, Moller, Dawson, Graham, & Skaar, 1984) and the scale used in speech rating (Zraick & Liss, 2000; Whitehill, Lee, & Chun, 2002) affect the reliability of perceptual speech assessment. In addition, other variables like experience of the listeners in judging speech quality perceptually (Kreiman, Gerratt, & Precoda, 1990), effect of listener's training (Huynh, 2007; Lee, Whitehill, & Ciocca, 2009; Stoeckel, 1980), the influence of individual voice quality (Kreiman, Gerratt, Precoda, & Berke, 1992) and effect of different listening conditions (Moller & Starr, 1984) are also reported to be influencing the intra and inter rater reliability in the literature. Hence, it is considerable to evaluate inter and intra judge reliability in order to have good validity in perceptual method.

These reliability measures and also few methodological procedures across different tests and rating scales have been discussed by many studies. This has paved the way to the development of standardized perceptual evaluation protocol by Henningsson, *et al.*, (2008). This protocol has used perceptual parameters which describe speech production of individuals with CLP devoid of any languages. The procedure for speech sampling content and scoring methods with respect to parameters are depicted in detail. The utilization of universal standardized system helps in clinical trials by teaming up with the experts of other geographic areas.

Despite its drawbacks mentioned earlier, the perceptual evaluation is still considered as the favorable approach in the assessment of speech abnormalities of individuals with cleft palate (Peterson- Falzone, Trost-Cardamone, Karnell, & Hardin-Jones, 2006; Henningsson, *et al.*, 2008; Howard, 2011). However, there are several studies which have emphasized the role of objective methods in assessing speech production errors related to CLP (Whitehill, Stokes, & Yonnie 1996; Sell and Grunwell, 2001; Kuehn and Henne, 2003; Gibbon, Lee, Yuen, & Crampin, 2008; Sweeney, Howard, & Lohmander, 2011). It has become customary to combine both subjective and objective assessment methods to analyze resonance and airflow. As a result, using objective techniques such as nasometer and other aerodynamic measures along with perceptual method, obviously yields a better understanding of resonance and airflow analysis. The subsequent section discusses the use of instrumentation in the assessment of speech of individuals with cleft palate.

The objective evaluation of resonance includes both direct and indirect methods. Direct methods directly assist in visualizing the structure and function of velopharyngeal port through the techniques like cineradiography, nasoendoscopy, magnetic resonance imaging (MRI), lateral cephalometric radiography and ultrasound. The indirect methods enable to make conclusions regarding the structure and function of the velopharyngeal mechanism indirectly through acoustic and airflow measures. One among the instrumental measures widely used in clinical assessment for measuring hypernasality is nasometry. It measures nasal and oral acoustic energy which is recorded using two microphones, oral microphone records acoustic energy from oral cavity and another collects energy emitted from nasal cavity. Later, it calculates nasalance scores for a given stimulus. The nasometer has been employed in several studies to evaluate the presence and degree of hypernasality in the speech of individuals with cleft palate. This measure assists in complimenting listener's perceived nasality identified in individuals with velopharyngeal dysfunction (Dalston, Warren, & Dalston, 1991; Watterson, Hinton, & McFarlane, 1996). The studies have also reported variations in nasalance scores with respect to age (Sweeney & Sell, 2008), gender (Anderson, 1996; Nichols, 1999), language, stimuli (Searl & Carpenter, 1999; Watterson, Lewis, Allord, Sulprizio, & O'Neill, 2007) and dialect (Kavanagh, Fee, Kalinowski, Doyle, & Leeper, 1994) and due to such differences, it is intricate to have comparison across speakers, dialects and different languages.

The normative nasalance scores are developed in various Indian languages such as Kannada (Jayakumar & Pushpavathi, 2005), Hindi (Arya & Pushpavathi, 2009) and in Malayalam (Devi & Pushpavathi, 2009). However, despite the availability of standardized nasalance scores across languages, it is always appropriate to use this nasometric data to supplement and not as a substitute for perceptual judgment. Indeed, Sweeney, Howard and Lohmander (2011) emphasize that 'perceptual information must be the basis of all assessment results regardless of the perceived issues related with perceptual evaluation'.

Few studies have also investigated correlation between perceptual and objective methods. The studies have compared nasalance scores with perceptual evaluation to examine the correlation between the two methods (Hardin, Demark, Morris, & Payne, 1992; Watterson, McFarlane, & Wright, 1993; Keuning, Wieneke, Van Wijngaarden, & Dejonckere, 2002). A study carried out by Watterson, et al., (1993) revealed a significant modest correlation between perceived nasality and nasalance values for the non nasal passage (r = 0.49). However, correlations were not significant for both the standard passage (r=0.24), and the nasal passage (r = 0.20). Kuening, et al., (2002) obtained findings of lower correlation coefficients that ranged from 0.34 to 0.71 between subjective and objective measures of nasality. Another study by Sweeney and Sell (2008) which included controlled speech stimuli showed good correlation coefficients (0.69 to 0.74) and these findings were contradictory to the study done by Kuening et al., (2002) study.

The spectrographic analysis can also be carried out to assess resonance and airflow. The acoustic correlates of hypernasal speech include weakening of formants, introduction of additional formants, reduced intensity of F1 and F2 and broadening formant bandwidths (Hawkins and Stevens, 1985; Kataoka, Zajac, Mayo, Lutz, & Warren, 2001). Lately, majority of the acoustic studies related to resonance and airflow in individuals with cleft palate carried out qualitative analysis of speech owing to the reason that quantifying the degree of atypical resonance and airflow is tedious in spectrographic analysis. However, there have been many attempts made at quantification. Few studies (Kataoka, *et al.*, 2001; Rah, Ko, Lee, & Kim, 2001; Lee, et al., 2009) have utilized diverse procedures such as Linear Predictive Coding (LPC) analysis, formant analysis, and spectral analysis to assess hypernasality in individuals with cleft palate and different etiologies.

Several studies have evaluated amplitude of the speech spectrum of individuals with CLP. Kataoka, Michi, Okabe, Miura, and Yoshida (1996) carried out a preliminary study on one third octave spectra analysis including 16 children with CLP. The results indicated increased amplitudes for F1 and F2, and reduced amplitudes between F2 and F3 in the speech spectrum of children with CLP.

To summarize, various protocols are used in subjective assessment to describe and quantify hypernasality. In objective measurement, among other acoustic measures, nasometer has high sensitivity and specificity which is widely used as an objective tool in clinical practice. In addition, one third octave measures provide additional information acoustically related to hypernasality. However, so far in the assessment of resonance, the consensus between subjective and objective methods has not met. As a result, clinician is always confronted with contradictory results regarding evaluation of hypernasality. Thus, there is a need for a multi-parametric approach that integrates subjective and objective methods and helps to unambiguously quantify nasality. To fulfill this need, Van Lierde, Wuyts, Bonte, and Cauwenberge (2007) focused on constructing an equation by considering various measures such as Glatzel test, maximum duration time, and nasalance measures derived from children with CLP in the age range of 4-12 years. They developed an index which derived as "Nasality Severity Index = - 60.69 - (3.24x percent of oral text) – (13.39 x Glatzel value /a/) + (0.244 x maximum duration time (seconds) - (0.558 x % /a/) + (3.38 x percent oronasal text)". The sensitivity and specificity of nasality severity index (NSI) was found to be 88% and 95% respectively which the study concluded efficient for its application in the assessment process of speech in children with CLP.

However, some of the limitations of NSI were also reported. This index was first developed in Dutch language and hence generalizing this to other languages is not relevant. In addition, the index was constructed based on only five variables (nasalance percent of oral text, Glatzel value of /a/, maximum duration time (seconds), nasalance % of /a/, nasalance percent of oronasal text). There were other acoustic parameters (nasalance distance, nasalance ratio, voice low tone to high tone ratio, 1/3rd octave analysis, jitter, and shimmer) and aerodynamic variables (subglottal pressure, mean airflow rate, & laryngeal airway resistance) documented in the literature which were accomplished to differentiate hypernasal and control group. Another limitation is that the study did not include equal number of participants in each severity level of nasality. Due to the limited number of CLP subjects, the study failed to obtain any cutoff scores based on severity of hypernasality.

Therefore, an effort was made by Navya (2015) to construct a nasality severity index in Indian context for evaluating overall severity of perceived nasality based on amalgamation of aerodynamic and acoustic measurements in Kannada speaking children with repaired cleft lip and palate. The speech samples from 67 RCLP subjects and 35 typically developing children (TDC) were collected to construct NSI. Two NSI equations were derived using discriminant function analysis for differentiating three groups exhibiting various nasality in speech based on cut off scores. These equations consists of 27 variables based on one third octave spectral analysis and nasalance measures. To concise the equation, a step wise discriminant function analysis was used and two more equations were derived. These equations are comprised of only five parameters based on one third octave spectral and nasalance measures. The validity of the index was verified by considering only 5 children in each group exhibiting normal, mild, and moderate to severe perceived nasality. Since only few samples were taken to check the validity of NSI, it does not hold good to generalize this to larger population. Hence, verifying the validity using large number of samples is considered necessary. Thus, the present study aimed at validating the nasality severity index (NSI).

AIM: The present study was aimed to validate the nasality severity index developed by Navya and Pushpavathi (2015).

Objectives of the Study: The following objectives were considered in the study.

- Grouping of children with RCLP based on perceived nasality by using standardized perceptual rating scale.

- To estimate nasality severity index for all the four equations in children with RCLP and typically developing children (TDC) and verifying the group membership.

- To evaluate the agreement in group membership derived from estimated nasality severity index with the perceived nasality in children with RCLP and TDC.

REVIEW OF LITERATURE

Speech is witnessed as a key to human existence that involves a complex process. This complex process of speech can be disturbed by various disorders, one among them is the cleft lip and palate condition. It is considered as the most common congenital condition which occurs due to incomplete fusion of various tissues during early pregnancy. According to a study by Ankola, Nagesh, Hegde, & Karibasappa (2005) the incidence of cleft lip and palate is (CLP) approximately one in 500 live births. The prevalence rate varies with respect to different reports (Raju, 2000; Ankola et al., 2005; Murthy & Raman, 2005). The children with CLP exhibit a range of associated issues that include feeding problems, dental issues, hearing loss, abnormal speech, language delays and psychological crisis. These defects will have a long term adverse effect on overall development of the child. Therefore a team approach is necessary to address these various issues and to enable effective management. The multidisciplinary team usually includes Plastic surgeon, Orthodontist, Speech-language pathologist, Audiologist, ENT specialist, Prosthodontist, Paediatrician and psychologist. Of which, the prime role is held by a speech language pathologist, on who's report the other professionals rely when making recommendations regarding the surgical management of structural defects affecting a child's speech.

The individuals with CLP form a heterogeneous group which ranges from isolated clefts to syndromic clefts and communication disorders associated with each of these cleft types can vary. Scherer, D'antonio, & McGahey (2008) reported several factors such as type of cleft, severity of cleft, age and time of palatal repair, unrepaired cleft, efficacy of palatal repair, status of velopharyngeal function, hearing status, and socioeconomic and linguistic status that could impact communication in this population. The following section emphasizes the communication disorders that are most frequently seen in children with CLP.

Communication Disorders Seen in CLP Population

It is notable that the presence of CLP may adversely affect a child's ability to communicate effectively and this will cause huge social, emotional, and educational hardship. Thus, the assessment and management of communication difficulties related to CLP is an important aspect of comprehensive cleft care. In this manner, studying the nature of communication skills exhibited by children with RCLP becomes critical.

Chapman, Hardin-Jones, Schulte & Halter, (2001) and Raman, Jacob, Jacob & Nagarajan, (2004) have reported delay in the expressive language skills which is signified by slower pace in acquiring vocabulary and reduced phonetic inventory during the early stage of child's development. The recent evidences elucidate that they may also present delays in both receptive and expressive language skills (Scherer, D'Antonio, Kalbfleisch, & 1999). Few other reports shed light on these early language difficulties persisting into childhood in some children. (O'Gara & Logemann 1990; Lohmander-Agerskov, Soderpalm, Friede, & Lilja, 1998). Thus, it remains as a crucial factor to screen issues related to language delays while assessing the infants and children born with CLP who has undergone a surgical correction.

Although language difficulties are noticed in these children, the most important area of concern both to parents and professionals is the child's speech skills. The presence of speech deviances in CLP population has been identified long years ago. However, it is from the past 20 to 30 years that the speech abnormalities have been described in detail. It is well known that following palatal repair, speech abnormalities in children with CLP often persist and generally almost all children present with delay in speech sound development. Also, they exhibit typical cleft palate speech characteristics (Jones, Chapman, & Hardin-Jones, 2003). The speech deviances featuring unusual consonant productions, disturbed voice quality, abnormal nasal resonance, nasal air emission and nasal or facial grimaces constitute the cleft palate speech. (Sell, Harding, & Grunwell, 1999).

A study by Nagarajan, Subramaniyan, Sendhilnathan, and George (2008) investigated communication disorders in 129 South Indian individuals with RCLP who were above three years of age. It was revealed that among 129 individuals, 38% of them demonstrated normal and age appropriate communication skills. The majority of those with normal communication skills had isolated cleft of the lip. Other 43% of the total 129 individuals exhibited articulation and resonance difficulties, 12% showed only articulation abnormalities and 3% only abnormalities in resonance. Another 3% of these individuals exhibited delays in language development. The following section discusses speech deviances observed in CLP in detail.

Articulation. It is generally agreed that among other speech impairments, the speech of children with CLP is majorly characterized by difficulty in articulating speech sounds (Van Riper & Irwin, 1958) The causes for speech sound disorder in children with cleft lip and palate are structural deformity in oronasal cavity, inadequate functioning of velopharyngeal port, learned neuromotor patterns during early infancy and psychosocial development. Among the broad range of speech sound errors, the major sound classes that are being affected in cleft lip/palate children are stops, fricatives and affricates (known as pressure consonants). Fricatives and affricates are the highly misarticulated sounds followed by stops, glides and nasals. In general, the manner of articulation is preserved in children with cleft palate while they sacrifice the place of articulation. Trost-Cardamone (1997) classified speech production errors as obligatory and compensatory errors. Obligatory errors are the production errors which are due to the presence of structural defects like improper alignment of the tooth, fistula in the oronasal region, residual clefts etc. These errors usually cause the change in manner of articulation and are primarily corrected through surgery, followed by a superficial speech therapy. On the other hand, compensatory errors are the maladaptive learned articulatory placements which are developed by children with CLP during their developmental period. These errors retain their manner of articulation and are only corrected by intensive speech therapy.

Resonance and voice. The children with CLP often encounter resonance disorder because of inadequate functioning of the velopharyngeal valve that fails to stop the involvement of nasal cavity from adding its nasal resonance during the production of pressure consonants. As a result, hypernasality is observed in the speech of individuals with CLP due to velopharyngeal dysfunction (VPD) and rarely because of velopharyngeal mislearning. Thus hypernasality affects the overall quality of speech. It is usually appreciable on vowels as they are voiced and relatively longer in duration. The VPD also results in audible nasal air emission during the production of consonants especially on high pressure sounds such as plosives, fricatives, and affricates. In the presence of VP dysfunction, the air leaks through the VP valve and is escaped through nasal cavity. Another variety of nasal air emission is nasal rustle also called as nasal turbulence. This nasal rustle produces a very disturbing shrill sound and is said to occur when the huge amount of air is rushed through a relatively smaller opening in the VP port resulting in a friction noise (Kummer & Neale, 1989; Kummer, Curtis, Wiggs, Lee, & Strife, 1992). There can be phoneme specific nasal air emission where only the production of specific sounds are associated with nasal air emission and it is mainly substituted for sibilants. However, change in the articulatory placement of those sounds might eliminate the accompanied nasal air emission. The air leakage through velopharyngeal valve lead to inadequate oral air pressure resulting in weak articulatory speech production (McWilliams, Morris, & Shelton, 1990).

The children with RCLP are also likely to show high occurrence of voice symptoms such as abnormal pitch, hoarseness, breathiness and low intensity (McWilliams, Lavorato & Bluestone, 1973; D'antonio, Muntz, Province, & Marsh, 1988). To compensate for the inadequate VP closure, they forcefully hyper adduct the vocal folds and increased respiratory and muscular effort is exerted to achieve the closure, thus resulting in dysphonia. The presence of dysphonia often masks nasality which makes the perceptual evaluation a hard task for clinicians.

These speech deviances that were discussed earlier are often complex and multifactorial. They collectively affect speech intelligibility of children with CLP and hence a detailed assessment targeting these speech errors is often necessary. Peterson-Falzone, Hardin-Jones, and Karnell (2001) stated that among children with CLP, atleast 50% of them necessitates services of a speech language pathologist. They need to undergo systematic evaluation and effective management to acquire better articulation skills or adequate phonological development and expressive language skills. Few CLP children may show articulation and resonance difficulties secondary to velopharyngeal dysfunction (Peterson-Falzone et al., 2006). These speech deviances that they present hinder the child's overall career growth including his/her education and employment and would have a long term social and psychological implications on children and their families.

The child with CLP who exhibits disturbed speech characteristics needs to undergo comprehensive assessment in order to seek information about the anatomy and physiology underlying these abnormal speech patterns. The speech evaluation should be done rigorously for better understanding of the nature of speech abnormalities and to plan for an appropriate intervention. The primary goal of the assessment of children with CLP is finding out the speech production errors associated with VPD and treating them appropriately. Thus the assessment should involve ideal procedures. Primarily assessment of hypernasality involves subjective and objective evaluations. The following section concerns the review of perceptual and objective evaluation procedures in the assessment of children with CLP.

Perceptual assessment

The perceptual evaluation stands as a basic foundation of speech assessment especially in the case of cleft lip and palate. Kuehn (1982) states that 'in a sense, a speech disorder does not exist until it is perceived by a listener' supporting the need and prime importance of perceptual measures in the assessment of speech. When making an ultimate decision regarding the presence of hypernasality or other speech difficulties in any individual, subjective assessment plays a major role (Moll, 1964). Even though there has been various objective measurement procedures (e.g., acoustic, aerodynamic) which were developed by researchers for speech evaluation, at all times ''ear of the listener'' is considered to be the ''gold standard'' for speech evaluation (e.g., McWilliams et al., 1990; Kreiman et al., 1993; Kent, 1996; Kuehn and Moller, 2000; Oates, 2009; Sweeney, 2011). The perceptual evaluation is looked as the final judge in clinical decision making and it acts as a benchmark for objective results. Perceptual assessment is necessary because treatment should only be indicated when a problem is perceived (Conley et al., 1997).

Several instrumental measures such as nasalance, velopharyngeal valve size even though has shown fair to moderate correlation with perceptual ratings are still considered unfavourable when perceptual evaluation is deemed. The multiple listeners' judgement of speech is favoured over objective technique results when speech outcomes are concerned and while making surgical recommendations.

During 1940’s-50’s, the perceptual evaluation was solely focused on identifying articulation errors and then sometime during 1950-60‟s, focus was shifted towards identifying other speech parameters that were affected in children with CLP such as resonance, compensatory articulation errors, nasal grimaces etc (McWilliams, 1958; Morris & Smith, 1962; Morris, 1968; Olson, 1965; Bzoch, 1965). Later different protocols were developed across the globe with the stipulation of assessing the speech errors and other difficulties associated with cleft palate in one concise format. Hence, in 1990s, the usage of protocols in everyday assessment of speech characteristics seen in children with CLP was initiated and the research also aimed at developing standardized protocols for the same. It is always suitable to use a protocol that throws light on all the aspects with which a cleft palate individual has difficulties.

Some of the protocols has been reviewed and used in various research studies (Shaw, Semb, Nelston, Brattstrom, Molsted, Prahl-Andersen, & Gundlach 2001; Grunwell & Sell, 2001). One among them is Great Ormond Street Speech Assessment (GOS.SP.ASS) which is a multi parameter assessment protocol that assesses speech parameters like articulatory characteristics, phonation, resonance, nasal emission, nasal turbulence and grimace. It also involves mirror test and oral examination. Sell, Harding, and Grunwell (1994) conducted a survey to evaluate its reliability of usage for inter center comparisons and it revealed few ambiguities. Therefore, in order to overcome these loopholes, Harland, Harland and Razzell (1996) developed Clinical Audit Protocol for Speech (CAPS). The revised version of which was proposed by John, Sell, Sweeney, Harding-Bell, and Williams (2006). This assessment protocol used a color coding rating system to evaluate cleft speech characteristics and these protocols also gave various assessment schedules provided with scoring system.

However these protocols demonstrated lack of agreement regarding evaluation procedure and reporting of speech outcomes. Hence, this was revised and proposed as universal parameters for reporting speech outcomes in children with CLP by Henningson et al., (2008). They considered different parameters such as hypernasality, hyponasality, nasal air emission and consonant production errors to study and report the speech outcomes in persons with cleft palate. They aimed at achieving more consistency when measuring speech outcomes worldwide devoid of any language.

It is also well documented that several variables such as individual specific and task variables can impact reliability and validity of perceptual judgements. The individual differences like listener's experience, perceptual habits and personal biasing affect the perceptual ratings. The definition of the rating scale, familiarity of the listener towards rating scale and perceptual context are some of the task factors which may have a potential influence. The listener's decision confronts biases when there is a lack of information about the terminology used in rating system to describe nasality appropriately (Kent, Weismer, Kent, Vorperian, & Duffy, 1999; Whitehill, 2002). In addition to it, type of rating scale used, inclusion of reference samples and training prior to actual analysis also play the role (Kreiman, Gerratt, Kempster, Erman, & Berke, 1993).

Despite its drawbacks, the perceptual evaluation is still considered gold standard method of assessment. It is defined as the core of speech and language evaluations against which the instrumental measures are validated (Dalston & Warren, 1986; Hirschberg & Van Demark 1997). The perceptual task of accurately measuring the degree of nasality is reported to be easier

(Philips, 1980; Pannbacker, Lass, Middleton, Crutchfield, Trapp & Scherbick, 1984). For an appropriate diagnosis and intervention, the perceptual rating of resonance should be collaborated with objective methods. Several studies have been incorporated with combined assessment of both perceptual and objective evaluations for rating the degree of nasality and have been proved as an immaculate assessment method (Hardin et al., 1992; Watterson et al., 1993; Keuning et al., 2002; Sweeney et al., 2008). Therefore, perceptual evaluation was considered as one of the parameters to derive Nasality severity index (Van Lierde et al., 2007).

The perceptual evaluation has gained prime importance in the area of CLP for studying the speech characteristics of adults with CLP and there is a dearth of studies which have focused on children with CLP. The studies have focused on perceptual evaluation as a part of other assessment protocols (Karling, Larson, Leanderson, Galyas, & Serpa-Leitao, 1993; Laczi, Sussman, Stathopoulos, & Huber, 2005) to evaluate speech production. Few studies focused on correlation of perceptual and instrumental evaluation of speech (Dalston, Warren, & Dalston 1991; Nellis, Neiman, & Lehman, 1992; Bressmann, Sader, Whitehill, Awan, Zeilhofer, & Horch, 2000) by using various rating scales and stimuli (Whitehill et al., 2002; Watterson et al., 1996). The following studies emphasized perceptual evaluation of speech in children with CLP.

Bradford, Brooks, and Shelton (1964) conducted a study on perceptual evaluation of hypernasality in children with CLP (n=17) in the age range of 6 to 14 years with the mean age of 9 years. There were two groups of judges for perceptual judgement of nasality, one group consisted of two experienced listeners who were post graduate SLP's expertise in the area of CLP for more than three years. The second group consisted of two post graduate SLP's who had less than three years of experience but not skilled in the assessment of speech of cleft palate and they were considered as inexperienced. These judges were instructed to carryout perceptual ratings of nasality using a 7-point rating scale, where 0 indicated no hypernasality and 6 showed extreme hypernasality. The study included the stimuli of spontaneous speech sample and /a-i/ test (Jonson, Darley & Spriestersbach, 1963). The results revealed a poor reliability for both experienced (0.14 and 0.25) and inexperienced judges (0.25 to 0.33) for the stimuli of spontaneous speech and /a-i/ test. Among the judge group, inexperienced SLP's showed relatively higher reliability. The poor reliability was related to the factor of scale values which were used to rate the reliability as it is a 7 point scale. All subjects had the typical voice quality which showed no contrast among them and this fact affected the reliability. Among the stimuli used, /a-i/ test yielded more reliable scores to that of spontaneous speech sample. This outcome was correlated with the fact that /a-i/ test was devoid of articulatory variables which had chances of biasing nasality judgement. Hence, the authors concluded that caution should be taken while taking clinical decisions in the management based on perceptual evaluation of hypernasality.

Another study in the similar line was conducted by Counihan et al., (1970) to investigate the reliability of hypernasality judgement that was carried out in clinical settings without any special pre training. Their aim was to study the reliability of experienced and inexperienced listeners both as a group and as an individual, in doing perceptual judgement with the given sample of spontaneous speech and during the production of /a-i/ vowel combination. 17 children of the age six years and older with cleft lip and palate participated in their study. A spontaneous speech sample and /a-i/ test were used for the assessment of nasality. These were given to both experienced and inexperienced clinicians for the judgment of hypernasality on a seven point rating scale and they indicated a yes or no judgment. Then judge's reliability of nasality ratings were analyzed and it was indicated that neither inexperienced nor experienced listeners made reliable judgments regarding the perceived nasality in the speech of cleft palate children. They conclude by opining that a much cautious decision should be taken when speech therapy and physical management based on hypernasality ratings made in a clinical setting are concerned This study indicates necessity of the supplement assessment measure along with the perceptual test for the proper judgment of nasality.

The perception of hypernasality varies as a function of articulation disorder. Sherman (1970) studied the correlation between degree of hypernasality and extent of articulation disorder in speech of children with cleft palate. The samples taken were 154 which consisted of set of 13 sentences. These samples were randomly recorded and played to listeners for perceptual analysis which was done on the first five second duration of each sample using 7 point rating scale. Initially the samples were rated for articulation disorder, later it was rated for nasality by 37 speech language pathologists. In order to avoid the influence of articulation errors on nasality rating, samples were played backward while rating the nasality. In the results, moderate correlation (0.34) was found between articulation rating and nasality and this findings was said to be reported since only limited number of speech samples were taken for perceptual ratings. The authors concluded that function correlation exists between defective articulation and nasality.

A retrospective study was conducted by Warren, Dalston and Mayo (1993) for studying the nature of resonance judgements. The study included 293 nonsyndromic children who had secondary cleft palate. In 293 children, there were two age range groups. One group consisted of 219 children whose age range varied between one to two years. Among these children, 83 had undergone primary palatoplasty and rest 136 had unrepaired cleft palate. The second group had 74 children between 4 to 5 years old who had repaired cleft palate. All the participants underwent the routine assessment protocol of articulation, resonance and language. For assessing the severity of hypernasality and hyponasality, perceptual evaluation was carried out. The severity rating of hypernasality was based on a six point rating scale. The clinicians retrospectively analysed the results of hypernasality. The rating system on a six point equal appearing interval scale appeared as 1 to represent normal resonance and 6 to indicate severe oronasal imbalance. From 2 to 5 on a scale mild, mild to moderate, moderate and moderate to severe hypernasality were denoted respectively. The speech samples obtained through the interaction method from the child were the phonological samples of 30 minute duration in a clinical setting. When clinicians rate 0 on scale, it indicated that either the clinician is unable or he is being unwilling to assess hypernasality. In the results, zero rating was obtained for 31% and 12% of children with unoperated and operated 18 palatal cleft respectively in the age range of 1 to 2 year old. However, in older children (4-5 years), only about 1.4% was rated with zero for hypernasality. The conclusion was that acoustic features of voice and vocal tract resonances affect the resonance evaluation in young children regardless of surgical status. The study also concludes that its often very hard to gain phonological samples to assess hypernasality in young children (1-2 years).

The speech outcomes are also measured to document the efficacy of surgery. An attempt was made by Khosla, Mabry, and Castiglione (2008) who evaluated the efficacy of a surgical technique and its speech outcomes. Furlow Z-plasty was used for primary palatal repair in 140 children of the age range 2 to 12 year 4 months. The speech outcomes were evaluated using perceptual evaluation. The speech stimulus used was a standardized set of syllables selected according to the developmental age of the child. After surgical correction, evaluated for hypernasality, nasal escape, and articulation errors in children and these errors were scored on a pattern of 0 to 3 suggesting none, mild, moderate, and severe respectively by assessing these primary symptoms on each postoperative visit. The total score for each child was verified. The score of zero depicted absence of VPD, mild rating was given for a score of 1 to 3, 4 to 6 showed moderate rating, 7-9 illustrated severe VPD. Later a rank based on a scale from 0 to 3 indicating none, mild, moderate, and severe was assigned to VPD based on many factors of speech assessment. The results reported that about 83% of the children did not show the confirmation of hypernasality, 91% of them had no nasal escape and no articulation errors were reported in 69%. In general, velopharyngeal insufficiency was not noted in 85% of the children, 2.1 % necessitated secondary posterior pharyngeal flap, whereas 3.6% children had oronasal fistulas. They concluded that good speech outcome was reported in Furlow Z-plasty in children with CLP with least fistula formation, velopharyngeal insufficiency and with no need of additional repairs.

The correlation between velopharyngeal gap and perceptual ratings of nasality was investigated by Paniagua, Signorini, De Costa, Collares, and Dornelles (2013). The comparison of velopharyngeal gap with the perceptual evaluation was made for 49 children with CLP. For speech assessment, perceptual rating of hypernasality and hyponasality was carried out using a three point rating scale of mild, moderate and severe. During analysis, they checked for compensatory and obligatory articulatory errors. The videonasoendoscopic procedure was carried out to examine the velopharyngeal gap during the production of a sibilant sound /s/. After evaluating velopharyngeal gap, it was classified as having no gap, small gap, moderate gap, large gap and very large gap. The results revealed that children having a hypernasality rating of moderate to severe exhibited severe VPD than those having a mild hypernasality rating. The presence of hypernasality along with articulatory errors had good correlation with moderate to large VP gap. Thus they concluded the existence of good correlation between perceptual evaluation and velopharyngeal gap.

One more study by Padilha, Dutka, Marino, Lauris, Silva, and Pegoraro-Krook (2015) focused on finding out the differences in auditory perceptual judgements of nasality between the live ratings and speech ratings from a recorded sample. They compared the perceptual rating of hypernasality performed by a speech language pathologist live, with the recorded speech samples containing uttered high and low pressure consonants of 100 children with repaired cleft lip and palate in the age range of 5 to 12 years. In the results, it was found that 69% of children showed no presence of hypernasality during live speech assessment. Among the left over participants, about 23% was being rated as mild and 8% of them exhibited moderate hypernasality. For recorded speech sample ratings, around 50% of children were identified as having hypernasality while producing high pressure consonants and 62% in low pressure consonants. There was a statistically significant difference between live ratings and judgements for recorded samples of high pressure consonants. 79% agreement was present for high pressure consonants and within the moderate range 80% was found for low pressure consonants. The conclusion of the study was that while performing live judgements, most of the samples were given ratings of normal nasality or mild hypernasality, as compared to the judgements using recorded speech samples. Even then, practical difficulties such as reproducing, quantifying and sharing the data with team members come up with the live judgements.

From the above review of literature, perceptual evaluation is inevitably proven to be an important aspect of evaluation procedures. Although few studies have acknowledged the puzzling problems accompanied with this approach (Sell et al., 1999; John, Sell, Sweeney, Harding-Bell, & Williams, 2006), still its role in the analysis of speech of CLP is crucial. However, to compensate the limitations of perceptual assessment, amalgamation of auditory perceptual assessment with at least one instrumental or objective assessment of velopharyngeal function is recommended for refining the understanding of cleft speech (Paniagua et al., 2013).

Objective Evaluation

The evaluation of speech in CLP was performed by subjective and objective methods. In the subjective evaluation, perceptual judgments are considered as gold standard (Folkins & Moon, 1990; Sell & Grunwell, 2001). Hence, the surgical or speech therapy outcomes are also evaluated using perceptual rating scales across many multidisciplinary cleft centres. Even though, perceptual judgement is considered as the benchmark in assessment, it is influenced by several variables for instance, experience (Lewis, Watterson, & Houghton, 2003), type of rating scale (Whitehill et al., 2002), vocal quality (Kataoka et al., 2001), compensatory articulation (Bzoch, 1997), inter-intra rater variability and vowel content (Watterson et al., 2007). As the perceptual assessment method is susceptible to errors due to its nature of subjectivity, there has been an increasing desire to seek objective methods that could improve the quality of this evaluation. The speech language pathologists often combine subjective assessment with objective technique to support their findings. The objective assessment procedures give us details regarding anatomy and physiology of the structures involved in underlying deficit and quantifying resonance. It allows us to make an easy comparison with the already obtained information and improves the overall accuracy and quality of assessment (Vogel et al., 2009).

The instrumental methods in the assessment of hypernasality mainly focus on measuring the velopharyngeal closure by direct and indirect assessment procedures (Shprintzen, & Bardach, 1995). Some of the direct imaging methods such as that of Multiview Videofluoroscopy, Cineradiography, Videonasoendoscopy, Nasopharyngoscopy, Nasopharyngeal Fibroscope, and Magnetic Resonance Imaging provide the real dynamic images of the structures of larynx, pharynx, and nasal cavity. Hence, in the recent past the imaging techniques gained popularity to diagnose VPD. Some of these imaging pictures provide clear picture of velopharyngeal closure pattern, presence, and extent of VP gap. They also document frequent changes in the degree of soft palate movement and pharyngeal wall (Kuehn & Henne, 2003; Shprintzen, 2004; Williams, Heningsson, & Pegoraro-Krook, 2004). In addition to the imaging techniques, the indirect techniques such as mirror fogging test, Nasometry, aerodynamic, and acoustic investigations (Paniagua et al., 2013) are also most commonly used by clinicians for evaluation of speech and VPD in children with RCLP. The following section focused on studies related to acoustic speech measures that are used by many researchers for evaluating speech of individuals with cleft lip and palate.

Acoustic Measures of Speech. The current study investigated two acoustic measures such as nasalance and one third octave spectral analysis of speech in children with repaired cleft lip and palate. The following studies emphasize the supporting literature on acoustic analysis reported in children with CLP.

Nasalance Measures of Speech. The nasometer (Kay Elemetrics, Pine Brook, NJ) is a widely used objective measure in the clinical set up. This instrument is a computer based consisting of PC compatible hardware and a software system. Nasalance is an instrumental measure given by nasometer that quantifies nasal resonance. It is derived by computing the proportion of nasal energy in speech from separate estimations of nasal and oral sound pressure level (Fletcher, 1970, 1976). These nasalance values should be compared with normative scores available across different languages for different stimuli to assess the level of hypernasality. However, the examiner must interpret the scores based on knowledge regarding resonance and articulation. It has been exhibited that nasalance measurements correlate well with perceptual judgments of nasality, as demonstrated by the sensitivity and specificity of nasalance measurements. Investigating the reliability and compatibility aspects of nasometer with the perceptual assessment of speech were also been the focus of the study by many researchers (Watterson, Lewis, & Brancamp, 2005; Bae, Kuehn, & Ha, 2007; Lewis, Watterson, & Blanton, 2008).

The normative data of nasalance values has been developed in various languages, on different speech stimuli (Vowels, high pressure consonants, words, sentences, paragraphs) and for different age groups (children and adults) which will be used in everyday clinical practices (Gnanavel, Gopisankar & Pushpavathi, 2013; Mahesh & Pushpavathi, 2008). The normative data helps to differentiate normal population who has a normal resonance from the clinical group having abnormally high nasality and assists in routine diagnosis. It also acts as a reference against which the post therapy outcomes can be checked. In Indian scenario, normative data have been developed in various languages such as, Tamil (Sunitha, Roopa, & Prakash, 1994), Kannada (Jayakumar & Pushpavathi, 2005), Malayalam (Devi & Pushpavathi, 2009), and Hindi (Arya & Pushpavathi, 2009).

A study by Jayakumar and Pushpavathi (2005) derived normative nasalance scores for Kannada speaking children and adults across syllables and sentences. They also evaluated the gender effect for both the groups. Fifty children in the age range of 5-10 years and fifty adults who were between the age range of 20-35 years had been included for the study. All the participants who met the selection criteria were chosen. The children were instructed to repeat meaningful set of 8 oral and nasal sentences each. In addition, they were given a task of syllable repetition which consisted of both oral and nasal syllables. The perceptual ratings were carried out prior to the nasalance measurement and ratings were based on five point rating scale. There was no significant gender differences noticed in children, thus the single mean value was considered.

The nasalance value for nasal sentences was 51.03% (SD= 7.02) and the score for oral sentences was 9.08% (3.49). For syllable repetition task, nasalance value for nasal syllables was found to be 66.44% (6.63) and for oral syllables it was 10.66% (4.07).

The mean nasalance scores have shown variations with respect to gender. This gender related differences in nasalance value can be attributed to basic structural and functional differences across gender. However, the influence of gender and age on nasalance values has shown contradictory results in many studies (Jayakumar & Pushpavathi, 2005; Van Doorn, & Purcell, 1998; Van Lierde, Wuyts, Bodt, & Van Cauwenberge, 2003). In contrast, few studies have quoted higher nasalance scores in girls as compared to boys and supported the gender differences in nasalance scores (Sunitha et al., 1994; Fletcher, 1978; Seaver, Dalston, Leeper, & Adams, 1991, Van Lierde, Wuyts, Bodt, & Van Cauwenberge 2003).

The clinical implications of normative nasalance scores include differentiating children with RCLP from typically developing children and quantification of hypernasality in children with RCLP. A related study was conducted by Navya (2014) who computed mean nasalance values and other two derived measures for children with RCLP. The study considered 60 children with RCLP in the age range of 4-12 years who were grouped into mild and moderate-severe hypernasal categories based on perceptual judgment. For control group, 30 participants with normal resonance were selected. The stimuli used for perceptual analysis was spontaneous speech. For nasalance measurement, oral and sentences were considered. The speech samples were collected and subjected to perceptual assessment by three judges using standardized four point rating scale. During nasalanace measurement, all participants were instructed to repeat standardized Kannada oral and nasal sentences (Jayakumar & Pushpavathi, 2005). Later, the mean nasalance values were calculated for all the stimuli and using the mean nasalance values, nasalance distance and ratio were derived. MANOVA was applied to find the differences in mean nasalance and nasalance distance and ratio between the groups. The results reported highly significant difference ($P<0.01$) between the groups for oral sentences, nasalance distance and nasalance ratio. In addition, hypernasal group (mild and moderate) exhibited higher nasalance scores in comparison with control group. The nasalance values increased as the severity of hypernasality increased. Thus, the study concluded the importance of newly derived measures (ND & NR) in differentiating the children with RCLP based on severity and from the typically developing children.

Nasalance has also shown sensitivity to phonetic composition of speech stimuli, which varies across vowels, syllables, words and sentences. A study related to it was carried out by Lewis, Watterson and Quint (2000) who studied the effect of vowels on nasalance scores. They selected thirty eight English speaking children in the age range of 4-18 years with a mean age of 8.1 years. Among them, 19 had VPD and 19 were typically developing children. The stimuli used for their study included five oral sentences (each sentence had different vowels: a high front vowel /i, I/, a high back vowel /u, U/, mixed vowel, low front vowel /ɛ, æ/ and low back vowel /a, o/) and four sustained vowels (/i/, /u/, /æ/, /a/). The Nasometer II was used to record the stimuli and the nasalance score was computed. The results of their study revealed that the nasalance scores on all the vowels were relatively high when compared to typically developing children. The nasalance scores in high front vowels were significantly more than low back vowels in both sentences and sustained vowel stimuli. They concluded that vowel /i/ can serve as a sensitive stimulus in identifying nasality, and hence high vowels can be included in formulating the syllables, words, and sentences to evaluate the nasalance values. Few other studies (Watterson et al., 1996; Lewis et al., 2000) also indicated the influence of the phonetic content of speech stimuli on nasometer scores such as the inclusion of nasal consonants (m, n, ŋ) and high vowels.

Apart from the type of stimuli, nasalance values measured using nasometer are influenced by various factors such as type of cleft, age (Haapanen, 1991; Van Lierde et al., 2003; Hirschberg, Bok, Juhasz, Trenovszki, Votisky, & Hirschberg, 2006), dialect (MacKay & Kummer, 1994), increased loudness(Watterson, York, & McFarlane, 1994) and within-speaker variability between the recordings (Watterson et al., 2005). All these variables affect the clinical decision making. In the similar lines, even though the perceptual evaluation is considered as gold standard (Henningsson et al., 2008), literature indicates controversial findings of the inter and intra rater reliability measures (Keuning, Wieneke, & Dejonckere, 1999, Kuehn et al., 2003). Therefore, combination of perceptual and instrumental measures is logical to enhance precision of outcomes in the evaluations. The following studies include a review on the correlation of nasalance findings based on nasometry with perceptual evaluation of nasality. The association between perceptual ratings and nasalance scores has been scrutinized in various studies. While few studies have demonstrated a good correlation between these two measures (Dalston et al., 1991; Watterson et al., 1996; Hirschberg et al., 2006; Sweeney & Sell, 2008), few others have shown a moderate association (Dalston, Neiman, & Gonzalez-Landa, 1993; Watterson et al., 1993; Keuning et al., 2002) and even a low correlation have been documented by researchers (Nellis et al., 1992; Lewis et al., 2003). The following studies have documented a good correlation between perceived nasality and nasalance scores.

Hardin et al., (1992) investigated the correspondence between the perceptual judgements of hypernasality, hyponasality and nasalance scores obtained from nasometer which they used it as a screening tool. Seventy four participants took part in the study, among which 51 were cleft palate subjects and 23 were the participants for the control group. Out of 51 subjects with cleft palate, twenty nine of them in the age range of seven to fifteen years had undergone pharyngeal flap surgery. The predictive analysis was used to measure the sensitivity, specificity and efficiency of nasometer. A good correlation was obtained between the perceived nasality judgements and the nasalance scores for non flap subjects. However, the efficiency was found to be poor for flap subjects. For normal participants, sensitivity coefficient was obtained as 0.87 and 0.93 of specificity coefficient was found. They also found that the correspondence between perceived hyponasality and the nasalance values was for control participants without cleft when the nasalance cut off score of 50 was considered. The classifications based on nasometry were in good correspondence with the perceptual judgments.

Sweeney and Sell (2008) studied the relationship between perceived nasality and nasalance measures. The study included 50 children with hypernasality in the age range of 4 to 15 years who were assessed based on Temple Street scale. The mean nasalance scores were calculated for the specified samples for all children using the Nasometer (Kay Elemetrics 6200.3). The correlation analysis was applied to evaluate the relationship between perceptual ratings and the nasometry results. In addition, nasometer was assessed for its test specificity, sensitivity and overall efficiency. The correlation coefficients ranged from 0.69 to 0.74 for perceptual ratings and nasalance measures. The nasometer test sensitivity ranged from 0.83 to 0.88 and its specificity ranged from 0.78 to 0.95. The results reported a strong relationship between perceived nasality and acoustic measurement. The study also emphasized the need to supplement nasometer findings along with perceptual assessment.

Brancamp, Lewis, and Watterson (2010) carried out a study on the association between nasalance scores and judgments of nasality using equal appearing interval scale and direct magnitude estimation measures. The study included 39 participants with the age range of 3.8 years to 17.2 years for the study. Among 39 speakers, twenty five subjects belonged to the hypernasal group and other 14 speakers were control participants. For the judgment of nasality, a judge having 30 years of clinical experience in the assessment of resonance disorders was selected. They used a stimulus of turtle passage which contained 29 syllables with no nasal phonemes to obtain the speech samples of the participants. The nasalance scores were acquired by Nasometer II(Model 6400) and speech samples were collected simultaneously with nasalance scores. Inter rater reliability was taken for equal appearing interval scale (EAI scale) and the scale ranges from 1 which represents normal resonance to 5 representing severe hypernasality. They randomly selected 10 samples from 39 samples. To establish inter rater reliability, a clinician with more than 15 years of experience was selected. Later, judge and a clinician separately were instructed to rate these samples. Inter rater reliability for direct magnitude estimation (DME) scale was also established by the judge and the clinician by rating the same 10 samples using DME procedures. To assess the strength of the relationship between nasalance scores and nasality ratings which were made using EAI and DME scaling procedures, separate bivariate correlations were applied. The nasometer test sensitivity and specificity were also calculated for nasalance scores and equal appearing interval (EAI) and direct magnitude estimation (DME) scaling procedures. The results showed that the significant difference was not obtained for correlation between nasalance values and EAI nasality ratings (r= .63) and between nasalance and DME ratings of nasality (r = .59). The nasometer test sensitivity and specificity calculated for EAI-rated nasality were 0.71 and 0.73, respectively. The test sensitivity and specificity which used a DME-rated nasality showed scores of 0.62 and 0.70, respectively. They convened that regression of EAI nasality ratings on DME nasality ratings did not depart significantly from linearity. The study finally concluded by considering the findings obtained that there was no difference found in the association between nasalance and perceived nasality when used EAI versus DME procedures to rate the nasality. Both EAI and DME-rated nasality attained similar scores on nasometer test sensitivity and specificity. Therefore, the study recommended using either of the procedures in order to obtain valid and reliable estimates of nasality. The studies discussed so far have shown a good agreement between perceptual judgments of hypernasality and nasalance measures.

There are studies which showed moderate correlation among subjective and objective evaluation. Watterson, McFarlane and Wright (1993) conducted a study regarding the correspondence of nasalance values with nasality judgments of 25 children with repaired cleft lip and palate in the age range of 3-14 years. The stimuli used in the study contained non nasal passage without the presence of nasal phonemes, the standard passage wherein nasal phoneme occurrence was 10% and the nasal passage with 35% occurrence of nasal phonemes. To perform perceptual judgments, ten judges who had a good experience in the assessment and treatment of speech disorders related to CLP were selected. All judges were asked to rate the speech stimuli based on a five point rating scale. The judges were given practice sessions before performing perceptual assessment. The reliability measures were carried out using Cronbach's alpha test and there was a good reliability (0.96) of ratings among judges. Later, the mean nasalance values were computed for all the subjects across stimuli using nasometer. The results showed a significant moderate correlation between nasalance and nasality for a non nasal passage (r=0.49). However, non significant correlation between judgments of hypernasality and nasalance measures was obtained for nasal (r=0.20) and standard passages (r=0.24). They concluded that significant correlation was found between the perceived nasality and nasalance values for the stimuli which included oral consonants only. The study stated that the lack of agreement may be because of the limitation of nasometer in measuring all spectral information related to hypernasality in comparison with listener's judgments.

A retrospective study by Prado-Oliveira, Marques, Souza, Souza-Brosco, and Dutka, (2015) verified the relationship between different modalities of assessment of hypernasality in children with PRS syndrome with the operated cleft palate. They assessed the percentage of hypernasality in each of the four different modalities of assessment in 69 children. Live ratings of speech nasality by an experienced SLP, listener's ratings of recorded phrase and nasometric assessment were carried out for all 69 participants. For live ratings of nasality, connected speech sample was collected from each participant and ratings of hypernasality were made using a four point rating scale, with 1 showing absence of hypernasality and 4 being severe hypernasality. At the same time, they established an index of consistency of hypernasality using cul-de sac test during the production of ten oral words. For ratings of recorded sample, participants production of an oral phrase were recorded during nasometric assessment using an AKG C420 microphone (condensed, unidirectional) and the recorded audio samples were given to three listeners who are SLPs with more than five years of clinical experience for the perceptual rating of hypernasality where they have to simply record just the presence and absence of hypernasality in those audio samples. Nasalance scores from nasometer assessment were obtained for the same oral phrase which was previously been recorded. They also compared the degree of hypernasality between two surgical techniques Furlow and von Langenbeck. A statistical procedure of Kappa statistic was used to verify the relationship between four assessment modalities. In results, Kappa statistics scores varied from 0.87 (almost perfect agreement) to 0.32 (reasonable agreement), with a mean score of 0.47 indicating moderate agreement between all modalities. These differences between four assessment modalities were attributed to various factors like usage of different stimuli for live and recorded ratings, the length and phonetic context aspects of the stimulus used for nasometric assessment, the presence of covert contrast unidentified by listeners, and also vocal tract characteristics specific to speakers with RS which were not controlled in this study.

There are few studies which have reported that agreement between nasalance score and perceptional rating of nasality is not consistently strong. Nellis et al., (1992) studied the relationship of listener's judgment of hypernasality and nasalance scores obtained from nasometer in 16 children who have undergone pharyngeal flap surgery. For perceptual rating, they used a speech sample consisting of seven sentences for which the nasalance scores were also obtained. Ten judges rated the audio recordings of speech samples of subjects for assessing the degree of hypernasality and hyponasality. The judgment of degree of nasality was based on a two six point rating scale. The study found that the judge's ratings of nasality did not show any systematic increase with the increase in nasalance scores, indicating a low correlation between the two assessments.

Lewis et al., (2003) investigated the ratings made by three general teachers (no academic or clinical training in cleft palate 21 speech), three graduate SLP students (academic training in cleft palate speech, but no clinical training), three craniofacial surgeons (clinical experience with cleft palate speech but no academic training), and three SLPs with both academic training in cleft palate speech as well as extensive clinical experience. These four groups of listeners made ratings on five-point EAIs with anchor stimuli for 'normal' (1) and 'severely hypernasal' (5). The listeners heard a single utterance with a variety of vowels from 20 subjects representing normal to severely hypernasal resonance. They found that the most experienced rating groups were more reliable and also provided less severe ratings. For example, the mean rating was 2.55 (S.D., 1.0) for the SLP group and the mean rating was 2.82 for the teacher group, a statistically significant difference (p=.019). Finally, the relationship between listener ratings from any group and nasalance scores obtained from the Nasometer was low to modest. The r values ranged from .29-.57 resulting in a low to moderate correlation. Although less severe and more reliable perceptual ratings were provided by the most experienced listeners, no pattern was seen in the relationship of nasalance values and listener experience. The low correlation was attributed to other factors affecting nasalance scores (Lewis et al., 2003).

Unfortunately, the literature is not unequivocal. Other teams of researchers doubt the usefulness of nasalance mean values. Nellis, Nieman and Lehman (1992) carried out a comparison study on ratings of hypernasality and hyponasality against nasalance scores. They obtained the listener's judgments of nasality using a two six-point EAI scales where in 1 indicated absence of hypernasality or hyponasality and 6 had a rating of severe hypernasality or hyponasality. The findings of the study indicated a poor correlation between subjective ratings of hypernasality and nasalance scores and the correlation coefficients varied from 0.02 to 0.43. Also, the sensitivity and specificity of nasometer was questioned by Watterson et al. (1993) who reported a correlation coefficient of only r =5 .49, and the subsequent prediction analysis revealed low values for sensitivity (71%) and specificity (55%).

The studies discussed so far related to nasometry, have used mean values while carrying out nasalance measurement. The mean nasalance value obtained from single words, sentences, paragraphs is the most direct measure provided by instruments such as the nasometer or the nasalview. However, one of the factors such as interspeaker variability in the mean nasalance scores across subjects can influence the accuracy of the measurement. In a study conducted by

Bressmann et al., (1998), for 45 subjects with clinically normal resonance, the nasalance ranged from 19.5% to 35% for an oral sentence, whereas for the same sentence, the obtained mean nasalance values for 27 subjects who exhibited severe hypernasality had a range from 23% to 64.6%. It can be explained that the variability in the normal nasalance scores is due to reasons like individual variations and dialect specific differences related to speech (Seaver et al., 1991). Thus, the variability affects the precise interpretation of nasalance mean values. For instance, participants having normal resonance may be given abnormal mean nasalance scores and the nasalance values obtained for those who presented with obvious hypernasality might be falling within the normal cut-off range.

With the known limitations of mean values, Bressmann et al., (2000) developed two measures with the purpose of providing supplementary information. They aimed at quantifying the individual range of variation in nasal resonance in each speaker so as to better control the individual variability. To develop this range, they derived two measures from post hoc mean nasalance values. These two measures are nasalance distance and nasalance ratio. In the preliminary study, 133 subjects with cleft palate were included and their age range was 10 years to 66 years with the mean age being 17 years. There were 87 males and 46 female subjects among the total 133 subjects. The Nasal view system was used to measure nasalance scores. The children who were perceived with prominent hypernasality and minimal nasality uttered the stimuli of nasal sentences and non nasal sentences from which nasalance distance and nasalance ratio were calculated. A speech language pathologist classified the subjects based on the perceived nasality level using their conversational samples. The study obtained the sensitivity and specificity ranging from 64.4% to 89.6% and from 91.2% to 94.1% respectively, in association with perceived classification. The study emphasized the relevance of the two newly derived measures in routine clinical assessments. Conversely, the effect of gender on these measures was not investigated in this study. Thus, the study concluded that nasalance distance and ratio are two valuable and easily applicable measures which can be used to supplement the mean nasalance values. The above review highlights the use of nasometer and also the studies related to correlation. However, all the measures can be correlated with acoustic measures derived from spectrographic analysis.

One third octave analysis. The acoustic investigation of speech signals provides the graphical representation in terms of spectrograms. The spectrographic analysis is one of the objective measures in the assessment of speech. It provides valuable information related to temporal and spectral parameters of speech of individuals with CLP (Beddor & Hawkins, 1990; Kataoka et al., 1996; 2001; Gopi Sankar & Pushpavathi, 2014). The spectrum shows information associated with the energy distribution over frequencies in a given interval of time. The horizontal axis displays time related information in a given spectrogram and vertical axis provides frequency information of a speech signal being studied. The extent of darkness on a spectrogram indicates energy concentration in speech signals.

Spectrographically, nasal speech is characterized by energy concentration predominantly at low frequency region, spectral prominence around 1000Hz, broadened formant bandwidth, and presence of antiformants. Various spectral and temporal characteristics such as formants, burst duration, voice onset time, closure duration and other features were analyzed in the speech of children with CLP (Vasanthi, 2001; Gamiz, Calle, Amador, & Mendoza, 2006). The acoustic analysis of speech of children with RCLP exhibited increased peak amplitudes around the first formant region. Kataoka (1988) explored the variations in amplitudes across various one third octave frequency bands. They considered this specific bandwidth owing to the fact that one third octave spectral bands are the basic band of frequencies utilized by human ear in analyzing speech (Pols, Vander Kamp, & Plomp, 1969). However, the studies focusing on other acoustic measures such as one third octave spectral analysis and voice low tone to high tone ratio in measuring speech parameters on children with CLP/VPD are sparse. The following section highlights the available review on these parameters.

Kataoka, Michi, Okabe, Miura, and Yoshida (1996) carried out a preliminary study on one third octave spectral analysis of speech samples of 17 typically developing children and 16 children diagnosed with hypernasality between 5-15 years of age. The speech sample of children's productions of Japanese vowel /i/ was collected and the spectral amplitudes at every one third interval were measured. The perceptual analysis of spontaneous speech sample of each subject was also carried out by 20 judges (8 Maxillofacial surgeons and 12 Engineering students). For perceptual judgment, a 5 point interval rating scale was used which had a rating of 0 for normal resonance and 4 for severe hypernasality. The results reported enhanced power level between first and second formant and a drop in the power level was observed in the region of second and third formant for the utterances judged to have hypernasality. The intra judge reliability ranged from 0.80 to 0.94 for perceptual analysis task. There was a high correlation between 1/3rd octave spectral analysis and perceptual ratings. The study assured the usage of this non invasive procedure in routine clinical assessment as there was a good correlation between perceptual ratings and one third octave analysis methods.

A related study was carried out by Kataoka,Warren, Zajac, Mayo and Lutz (2001) who studied the relationship between spectral features of hypernasality and its perceptual ratings. They included 32 children in the age range of 5 to 12 years who had a diagnosis of cleft palate, velopharyngeal dysfunction of varying severity or both. For the control group, 32 children with normal speech characteristics whose age ranged between 6 to 13 years were taken. All 37 speech samples were collected using an omnidirectional electret condenser microphone (Sony ECM 44S) kept at a distance of 15 cm away from each child. All were instructed to sustain vowel /i/ with normal pitch and loudness and given a model before the actual recording. For perceptual judgment, three speech language pathologists and one dentist who had more than 15 years of experience in the assessment of speech of cleft palate individuals were enrolled. The six point equal appearing interval scale was given for the judges to rate the degree of hypernasality on a scale ranging from 1 which represented normal resonance to 6 corresponding to severe hypernasality. The average one third octave spectra were compared between control group and hypernasality group. The findings such as a rise in amplitudes between F1 and F2 and decreased amplitudes in F2 region were noticed. The correlation (*R*50.84) was high between amplitudes of one third octave bands (1 k, 1.6 k, and 2.5 kHz) and perceptual ratings. The higher amplitudes of bands 1k and 1.6 kHz between F1 and F2 and decreased amplitude of the band of F2 at 2.5 kHz were related to increased perception of hypernasality. These results suggest that the amplitudes of the three 1/3-octave bands are appropriate acoustic parameters to quantify hypernasality in the isolated vowel.

One more study used vowel /a/ as a stimulus and carried out a one third octave analysis. Weerasinghe, Sato, and Kawaguchi, (2006) studied the spectral nature of hypernasality with respect to formant amplitudes of the vowel /a/ in 53 children with repaired cleft lip and palate and the relationship of hypernasality with other acoustic parameters. Among those 53 children with RCLP, two groups were made based on the level of hypernasality as moderate to severe hypernasality (n = 33) and mild hypernasality (n = 20) which were obtained from perceptual ratings. In the control group, there were 20 children with no history of cleft palate. The speech sample comprising of vowel /a/ in a segment /ka/ were collected and was subjected to further analysis to extract information such as formant pattern, breathiness values, and amplitudes to do one third octave spectral analysis. The results showed that differences in frequency values found between control group and experimental group were not statistically significant for the fundamental frequency (F0) and formants F1 and F2. The differences were significant for breathiness values in moderate-severe hypernasality group compared to other two groups of mild and normal groups. The spectral analysis exhibited increased amplitudes in the frequency region between F1 and F2 and spectral dips were noted at frequencies ranging from 630 to 800 Hz band and at F2 with an additional Fn peak at 800 to 1000Hz band in moderate to severe hypernasality subjects. The study concluded that the characteristic features of hypernasal vowel /a/ like increased amplitudes in some frequency bands and the presence of extra spectral peaks Fn between F1 and F2 can be revealed by measuring formant amplitude using one third octave spectral analysis.

An Indian study in the same line of thought, was conducted by Navya and Pushpavathi (2013) where they measured one third octave band spectrum in vowels /a/ and /i/ and looked for its sensitivity and specificity in differentiating hypernasality group from the control group. For the study, eight children with RCLP whose age ranged from six to ten years and 16 age and gender matched typically developing children were included in the study as control group. The spectral amplitudes at $1/3^{rd}$ octave spectrum for vowels /a/ and /i/ was obtained using MATLAB software for each child. The nasalance measurement was also carried out for all the subjects along with spectral analysis. The results revealed significant differences (increased amplitudes) in spectral peaks for vowel /i/ observed in mid-frequencies between 997 Hz to 1997 Hz. The increase in amplitudes was observed for frequencies below 1000 Hz which demonstrated a significant difference between the two groups. Another major finding of the study was that the high sensitivity and specificity was found for the frequency region between 998Hz and 2663 Hz (At frequencies above 1KHz, spectral amplitudes were more for CLP group) which shown to be better differentiating the two groups using 1/3rd octave spectra analysis.

The studies discussed earlier demonstrated the strong correspondance between one third octave measure and perceptual assessment. Thus, one third octave measure was considered as an appropriate diagnostic tool to quantify hypernasality. Although spectral evaluation is judged to be objective, non invasive and cost effective (Baken and Orlikoff, 2000; Vijayalakshmi, Reddy, & O'Shaughnessy, 2007), it can be influenced by the factors such as presence of noise, the loudness of the speech sample, interspeaker variation, and the quality of the equipment (Kataoka et al., 1996; Vijayalakshmi et al., 2007). In addition to this, only vowels are considered to study the acoustic correlates which may not reflect the presence of overall hypernasality in running speech. Hence, to overcome the limitations of these currently supported single evaluation methods, combination of various assessment methods may offer a solution.

Thus, perceptual measurement can be supplemented by various instrumental measurements such as acoustic and aerodynamic analysis. Nonetheless, multifaceted nature of resonance disorders makes it difficult to arrive at the solitary conclusion regarding the severity of nasality by comparing both perceptual and objective analysis outcomes which often leads to contradictory results. To sidestep these potential problems, there is obviously a need for a refined objective assessment technique from which the consensus between perceptual and instrumental measurement about quantifying resonance can be achieved, thereby improving the quality of assessment. Hence to fulfill this purpose, nasality severity index was developed by researchers. Van Lierde, Wuyts, Bonte, and Van Cauwenberge (2007) made an attempt to construct nasality severity index by forming an equation derived from five parameters; the nasalance value of the vowel /a/, an oral and oronasal text derived by the Nasometer (model 6200), the maximum duration time (MDT) of /s/, and the mirror-fogging test by Glätzel of /a/. The NSI is considered to reveal the multidimensional nature of the resonance which is derived from noninvasive as well as non disruptive assessment techniques of the articulatory, phonatory, or resonatory processes for the overall evaluation of nasality. In order to determine nasalance and nasality various objective and subjective techniques were employed. The study included 21 children with cleft palate (15 boys and 6 girls) with the age range of 5.4 to 16.3 years (mean age of 11 years) and a control group of 25 typically developing children without cleft palate. A statistical method of stepwise logistic regression was applied to establish the optimal index. The NSI is made up of linear combination of four variables, each of which holds different weight. The NSI equation is NSI = - 60.69 - (3.24x percent of oral text) – (13.39 x Glatzel value /a/) + (0.244 x maximum duration time (seconds) - (0.558 x % /a/) + (3.38 x percent oronasal text). The researchers have found the sensitivity and specificity of NSI to be 88% and 95%. It also has shown good clinical relevance and proved to be an efficient tool to determine the presence of hypernasality. The NSI implementation assists clinicians in quantification of hypernasality. The variables of NSI were the Glatzel mirror test, nasalance measures of oronasal text, oral text and phonation of /a:/, aerodynamic measure of maximum duration time in seconds for /s/ phonation.

Subsequently, Bettens, Wuyts, Graef, Verhegge, and Van Lierde (2013) worked on assessing the effect of age and gender on NSI. There were 74 typically developing children with the age ranging from 4-12 years. Nasalance values were obtained, maximum duration time of vowel /a/ was estimated, mirror fogging test using Glatzel mirror was carried out in order to estimate nasality in the form of condensation. The NSI was calculated using all the acquired measures.

The results demonstrated that with the increase in age, NSI also showed an increase with age indicating major effect of age and statistically no difference was obtained for gender factor. They concluded that NSI varies with respect to age but gender differences were not found in NSI.

There were limitations of NSI apart from its advantages. The limitations included considering only few variables (Percent of nasalance in oronasal text, nasalance % of /a/, percentage of nasalance in oral text, maximum duration time in seconds, Glatzel value of /a/) for evaluation and to construct the index. However in the literature, there were other acoustic and aerodynamic parameters which proved to be efficient in differentiating the two groups. The second limitation of the study was that the NSI was developed basically in Dutch language and thus it cannot be generalized to other Indian languages due to the variations in phonetic structure of that language. Another limitation is that the study did not involve equal number of CLP subjects based on the severity level and details regarding number of CLP subjects included in their study were not specified appropriately. Due to the inclusion of limited number of participants in each severity level of hypernasality, they could not derive cut-off values based on the degree of nasality to differentiate the two groups. Therefore, the study only correlated the NSI values with the perceived nasality and commented on trend observed across the groups.

To overcome all the limitations, an attempt was made to construct nasality severity index in Kannada language which was based on the amalgamation of different acoustic and aerodynamic parameters assessed in children with repaired cleft lip and palate. This index incorporated perceptual ratings of nasality. Navya and Pushpavathi (2015) worked on constructing nasality severity index (NSI) considering different parameters related to acoustic and aerodynamic measures of speech. The study included Kannada speaking children between 5-12 years. The analysis was carried out for 33 CLP subjects with mild hypernasality, 34 subjects with moderate hypernasality, and 35 typically developing children. The grouping was made based on the perceived nasality. Initially by evaluating various subjective and objective measures for all the participants in three groups two equations (NSI 1 & NSI 2) were derived using discriminant function analysis method. The equations included 27 variables based on one third octave analysis and nasalance measures. The cutoff scores were obtained for NSI equations to make a distinction between control group and hypernasal group. Based on NSI(1), if a cutoff score comes below -1.21, then that particular data belongs to the control group and any score below it indicates hypernasal group. The percentage of predicted group membership was 100% for normal group, mild hypernasal group showed 95.7% of prediction and it was 91.7% for moderate to severe hypernasal group. The derived NSI equations are as mentioned.

NSI (1) = -3.10 - 0.01(a)+0.01(b)+0.07(c)-0.01(d)-0.04(e) 0.01(f) + 0.06(g) +0.02(h) +0.02(i) -0.03(j) - 0.12(k) + 0.52(l) + 0.04(m) - 0.02(n) - 0.04(o) + 0.03(p)- 0.01(q) + 0.02(r) - 0.01(s) + 0.02(t) - 0.01(u) + 0.03(v) + 0.02(w) + 0.09(x) - 0.07(y) - 0.01(z) + 2.95(z1).

NSI (2) = 1.46 - 0.02(a) + 0.02(b) + 0.01(c) + 0.15(d) -0.11(e)-0.10(f)-0.02(g)- 0.01(h)-0.30(i)+0.03(j)+0.07(k)-0.17(l)+0.11(m)+0.02(n) 0.01(o) + 0.04(p) + 0.05(q) + 0.01(r) - 0.007(s) + 0.04(t) - 0.03(u) - 0.001(v) - 0.05(w) + 0.14(x) -.18(y) + 0.16(z) - 6.93(z1).

*Note: a=/a/1000Hz, b = /a/1587Hz, c = /i/1000Hz, d = /i/1259, e = /i/1587, f = /i/3174, g = /p/396, h = /p/500, i = /p/793, j = /p/1000, k = /p/1259, l = /p/1587, m = /p/2000, n = /p/2519, o = /p/3174, p = /p/4000, q = /t/396, r = /t/500, s = /t/793, t = /t/100, u = /t/2519, v = M_nasla, w = M_nasli, x = M_O, y = M_N, z = M_ON, z1 = M_NR.

The validity of the index was verified by selecting five subjects from each group of control, mild and moderate-severe hypernasality and calculating NSI equations for selected subjects. The group membership was predicted and it was found that 100%, 60% and 80% correct identification of group membership was obtained for control, mild and moderate to severe hypernasal groups.

A statistical method called step wise discriminant analysis was applied with the goal of formulating an index which has less number of variables so that it can be used with an ease in clinical practice. The equation incorporated 5 parameters based on nasalance values and one third octave spectra analysis.

NSI (3) = -2.39+0.02(M_Nasli)- 0.02(M_ON) - 0.04(M_NDS) + 4.75(M_NRS) + 0.01 (T396).

NSI (4) = 3.63 + 0.03(M_Nasli) - 0.12(M_ON) + 0.09(M_NDS) + 3.64(M_NRS)- 0.05 (T396).

*Note: M_Nasla = Mean nasalance of vowel /a/, M_Nasli = Mean nasalance of vowel /i/, M_ON = Mean nasalance of oronasal sentences, M_NDS = Mean of nasalance distance, M_NRS = Mean of nasalance ratio, M_N = Mean of nasal sentences, T396 = One third octave spectral amplitudes for /i/ in /tip/.

Based on functions derived using this method, if the value of NSI (3) shows more than -0.85 then participants are considered to belong to a hypernasal group and those who exhibit a value of less than -0.85 are considered as TDC. Using NSI (4), when the value is less than 1.29 it indicates moderate to severe hypernasal group and exceeding this indicates mild hypernasal group. It was observed that the two groups showed significant differentiation of 86.9% on NSI (3) and 13.1 % based on NSI (4). The validity of the index was obtained as 100%, 40% and 60% correct identification of the predicted group on TDC, mild hypernasal and moderate to severe hypernasal groups.

The NSI was intended to provide an easy to interpret severity score of hypernasality which would assist in measuring the therapy outcomes. It would also facilitate the communication to the clients and other clinicians, and decisions for treatment planning, based on a multiparametric approach (Bettens, De Bodt, Maryn, Luyten, Wuyts & Van Lierde, 2016). The previous study by Navya and Pushpavathi (2015) checked the validity of NSI by considering only five subjects. Thus, the present study aimed at validating the nasality severity index by including larger number of subjects and also verifying its sensitivity and specificity.

METHOD

Participants

In the study, both subjective and objective assessment of hypernasality was carried out for children with repaired cleft lip and palate and typically developing children (TDC). For the purpose of data collection, more than 60 parents of children with CLP were reached through telephone calls and by posting follow-up letters. However, only 48 children with RCLP reported for follow-up. According to inclusionary and exclusionary criteria of the present study, only 40 children with CLP in the age range of 4-12 years were finally considered. The age and gender matched, 20 typically developing children were selected for the study from a nearby Gangotri School Mysuru through informed consent process.

The speech samples from all 60 children were recorded for the purpose of perceptual evaluation and other acoustic measurements. Among which, group I had 40 children with RCLP and 20 typically developing children were considered in group II. The judges analyzed the speech samples based on a standardized rating scale and assigned ratings. Based on the perceptual analysis, three children with RCLP exhibited normal nasality, thus they were exempted from the study. All children were selected based on the exclusionary and inclusionary criteria. The following criteria were considered for selecting the participants in the present study.

Inclusion criteria for Group I (Children with RCLP)

- Children with RCLP/ repaired cleft palate/ repaired soft palate.
- Children whose age range was between four to twelve years.

- Children who were native speakers of Kannada language and nonsyndromic cleft were considered
- Children identified to be having normal mental and cognitive abilities by a psychologist.
- Children with hearing thresholds of less than 20 dB in the poorer ear based on screening report were taken for the current study.

Inclusion Criteria for Group II (TDC)

- Children passed in informal screening for speech and hearing disorders by a qualified SLPs.
- Children between the age range of 4-12 years.
- Children having hearing sensitivity within normal limits with no history of middle ear infections
- Children who were native speakers of Kannada language.
- Children with normal oromotor structure and functions.
- Children ruled out for different types of disability by administering World Health Organization (WHO) checklist (Singhi, Kumar, Malhi, & Kumar, 2007).

Exclusion Criteria for Group I (children with RCLP).

- Children with the presence of any associated syndromes or other conditions such as heart defects based on the reports of pediatrician or physician.
- Children with submucous palate, unrepaired cleft palate/cleft lip and palate, and, facial clefts.

- Children who underwent secondary pharyngeal surgeries.
- Children who had a history of frequent ear infections, upper respiratory tract infection, other disorders related to ear, nose and throat diagnosed by otorhinolaryngologist.
- Children associated with neurological conditions such as dysarthria and apraxia were not considered.
- Children of pubertal age were not considered (based on the appearance of secondary sexual characteristics and voice characteristics among males).

Exclusion criteria for group II

- Children with the history of frequent cold/ cough/ upper respiratory tract infection
- Children with cold/ cough/ upper respiratory tract infection,
- Children with deviated nasal septum/ enlarged tonsils
- Children with frequent history of otitis media/ adenoidectomy were not considered

Perceptual Analysis

In the perceptual evaluation for group I, children with RCLP were classified into three different groups based on the perceived severity of nasality. The procedure is explained in detail in the next section.

Stimuli. For perceptual analysis, a spontaneous speech sample of 5-10 min and repetition of 5 oral and five oronasal sentences in the Kannada language (Jayakumar & Pushpavathi, 2005) were collected. To elicit spontaneous speech, the child was made to speak on self-introduction, picture description, leisure activities, and school for about five to ten minutes. The oral and oronasal sentences were modeled by the investigator and the child was asked to repeat after the investigator.

Recording. The participants were made to sit comfortably in an upright position on a chair in a sound-treated room. All the speech samples were recorded using SLM microphone which was placed at a distance of 2 feet from each participant (*figure 1*) and the samples were simultaneously video recorded using Sony video recorder. The stimulus of spontaneous speech, oral and oronasal sentences were obtained by instructing all the participants to speak at a comfortable pitch and loudness levels. After the recording of each stimulus, an interstimulus duration of about 5 seconds was given for the next recording. When all the recordings were made, the samples were rechecked by the investigator and were saved in a hard disk of HP computer with Windows 7 operating system.

Figure 1: A child seated in front of SLM for speech sample recording

Material. All the recorded samples of spontaneous speech, oral sentences, and oronasal sentences were subjected to perceptual analysis which was carried out by five experienced SLP's based on their perception of the severity level of hypernasality. The ratings were assigned on a basis of standardized four point rating scale (Henningsson et al, 2007) on which the severity ranged from 0 through 3 where 0 = within normal limits (WNL), 1 = mild, 2 = moderate, 3 = severe hypernasality.

Procedure. The perceptual analysis was carried out by five experienced SLPs separately. The judges performed the ratings by listening to the samples through JB headphones. Before the actual perceptual task, the judges were given an explanation regarding the rating points and corresponding severity level on a scale ranging from 0 to 3. The speech samples were played thrice at a comfortable listening level to the judges. They were made to listen, analyze and rate the samples based on the degree of perceived nasality (Table 1). The participants were classified into the respective groups based on the agreement obtained in the ratings from any three out of five judges for perceived nasality. The participants whose speech samples rated as mild hypernasality by judges were assigned to Group Ia and the speech samples of participants being rated as moderate and severe together were categorized into Group Ib. Based on the perceptual ratings, there were more number of mild hypernasal participants and only fewer participants were assigned with the ratings of moderate and severe hypernasality. In addition, the availability of subjects exhibiting moderate and severe hypernasality was less frequent when compared to mild hypernasal participants. Thus, both moderate and severe hypernasality levels were included together in a single category. Among 40 subjects with CLP, 17 participants were categorized to mild hypernasality group and other 20 participants were classified as moderate-severe group.

Table 3.1

Demographic details of participants

Participants	No. of participants	Age range (Years)	Mean (Years)	Gender M	Gender F
RCLP group	37	4-12 years	7.2	21	17
TDC group	20	5-12 years	8.3	12	8

Note. M = males, F = females.

Reliability Measures. Inter and intra judge reliability was performed using kappa coefficient measure. The perceptual rating of all 40 samples obtained from five judges were considered to perform inter judge reliability. Whereas to evaluate the intra judge reliability, 40 samples were reanalyzed by the same five raters and perceptual ratings were obtained.

Instrumental Evaluation

In the present study, acoustic measurements such as estimation of nasalance and one third octave spectral analysis were carried out. The evaluations were performed for both group I and group II participants. The procedures of these objective measures are explained in detail in the following section.

Nasalance measures for vowel /a/, /i/, oral, nasal and oronasal sentences. Nasalance is the objective measure of nasality derived from the proportion of nasal to the sum of nasal and oral acoustic energy of speech using Nasometer. Nasalance is obtained by measuring the ratio of nasal energy (SPL) in speech by using oral and nasal microphones of nasometer (Fletcher, 1970, 1976). In the current study, the Nasometer 6450 II model was used to obtain nasalance measures. Nasometer was calibrated before carrying out the actual testing based on the procedure given in the manual.

Material. The vowels /a/ and /i/, standardized Kannada oral, nasal and oronasal sentences (Jayakumar & Pushpavathi, 2005) were used as stimuli for nasalance measurement. The oral sentences were made up of only oral consonants with the combination of vowels. The nasal sentences are embedded majorly with nasal consonants and oronasal sentences are balanced with equal proportions of oral and nasal consonants.

Procedure. All the subjects were made to sit in an upright position. The nasometer was kept calibrated before the data collection. Nasometer headset was mounted comfortably for each participant and was properly adjusted prior to the measurement. All the stimuli were demonstrated to the child and was asked to imitate the production of the investigator. . The children were instructed to phonate the vowels /a/ and /i/ thrice at a comfortable pitch and loudness levels as demonstrated by the investigator. An inter stimulus duration of three seconds was kept between the repetitions of vowels in order to obtain valid nasalance measures. The recording samples were saved separately in a folder.

Analysis. The speech stimuli were retrieved from the folder into the nasometer home screen for the analysis of nasalance. The required part of the stimulus was selected using two blue selection cursors from onset to offset of the stimulus. Nasalance was measured for all three repetitions of vowels and the mean of the three repetitions of each vowel was considered as final measurement. The mean nasalance value for each sentence was calculated separately. To check the test-retest reliability of nasometer, twenty five percent of the participants were chosen randomly. For the selected participants, the nasalance measurement was carried out again after 5 min of the first recording without changing the headset on the same day.

Measuring the nasalance distance and nasalance ratio. The other two acoustic measures included for the construction of NSI were nasalance distance and nasalance ratio. These are derived post hoc measures from the mean values for both sets of sentences. The nasalance distance and nasalance ratio were obtained using the formulas given by Bressmann et al. (2000). Nasalance distance was derived by the difference between maximum nasalance and minimum nasalance. Nasalance ratio was calculated as proportion of minimum to maximum nasalance.

Procedure. To measure nasalance distance and nasalance ratio, mean nasalance values of both oral and nasal sentences were considered. Nasalance distance was derived from the difference of the mean nasalance value of five oral sentences and mean nasalance value of five nasal sentences. Nasalance ratio was derived by calculating the ratio of mean nasalance values of oral sentences to mean nasalance values of nasal sentences.

One-Third Octave Spectra Analysis. One third octave spectra analysis involves exploring spectral band energy at every one third octave interval ranging from 100 Hz to 16000 Hz (Kataoka, Michi, Okabe, Miura, & Yoshida, 1996).

Instrumentation. A LENOVO laptop with windows 8 operating system was used and the *Praat* software was utilized to edit the necessary data for analyzing spectral bands. Later, MATLAB software was employed to carry out the one third spectral analysis.

Materials. The speech stimuli used to acquire spectral bands were phonation of vowels /a/ and /i/ and repetition of non-nasalized CVC words (/pit/ & /tip/). For one third octave spectral analysis, vowels in the CVC context were frequently used in the literature . The stimuli /pit/ & /tip/ were considered to examine the effect of nasality on /i/ within non nasalized phonemic environments.

Instructions. All the participants were made to sit comfortably in front of SLM microphone at a distance of 2 feet. The stimulus production was modeled by the investigator before the actual recording and each participant was given practice trails to ensure the correct production. They were instructed to phonate steady state vowels /a/ and /i/ and repeat /i/ in CVC contexts (/pit/ & /tip/) at comfortable pitch and loudness levels and three repetitions were obtained by giving an inter-stimulus interval of 10-15 seconds.

Procedure. The recording of the stimuli for one third octave spectral analysis was performed using SLM microphone in a sound-treated room. The *Praat* software was used to do the necessary editing of the data required to carry out the further one third spectral analysis.Using *Praat,* the steady state portion of middle 500 milliseconds in the isolated production of vowel (/i/) and 50 milliseconds in the production of vowel /i/ in the context of /pit/ and /tip/ were extracted for analysis. The extracted stimuli were later used for MATLAB analysis using MATLAB 7.0 version software and the spectral amplitudes were obtained at various frequency bands across stimuli.

Overall, amplitudes at 23 one third octave bands between100–16,000 Hz were obtained for all the speech stimuli (/i:/, /pIt/, /tIp/). However, the statistical analysis was applied to those frequency bands which have shown sensitivity to hypernasality (Kataoka, et al (2001); Lee, Yang, & Kuo, 2003). The frequency bands selected for spectral analysis were 396Hz, 500Hz, 630Hz, 793Hz, 1000Hz, 1259Hz, 1587Hz, 2000Hz, 2519Hz, 3174Hz, and 4000Hz. The reliability of one third octave analysis was measured by reanalyzing the 25% of the samples by the investigator and the obtained results were compared with the rest of the data utilized in the study.

Statistical analysis

The appropriate statistical measures were applied to the data using Statistical Package for Social Science (SPSS). The reliability measures were carried out initially to evaluate inter and intra-rater reliability of perceptual ratings using Kappa coefficient measure. The kappa coefficient measure was also used to find out the level of agreement between NSI equations and perceptual ratings.

RESULTS AND DISCUSSION

The present study was aimed to validate the nasality severity index developed by Navya and Pushpavathi (2015). The study was carried out on Kannada speaking children with CLP in the age range of 4-12 years. The main objectives of the study were

- Grouping of children with RCLP based on perceived nasality by using standardized perceptual rating scale.
- To estimate nasality severity index for all the four equations in children with RCLP and typically developing children (TDC) and verifying the group membership.
- To evaluate the agreement in group membership derived from estimated nasality severity index with the perceived nasality in children with RCLP and TDC.

The results are discussed with respect to each objective of the study.

1. Grouping of participants based on perceptual evaluation

The perceptual evaluation of nasality was performed by the SLPs based on a 4-point rating scale given by Henningson (2008). The speech samples considered for perceptual evaluation were oral, oro-nasal sentences and spontaneous speech which were obtained from 40 RCLP subjects with varying degree of hypernasality. All judges were randomly presented with the speech samples of children with RCLP and a single rating was obtained for each participant across the stimuli based on their perceived nasality. Based on the consensus obtained in the ratings given by minimum 3 judges out of five were considered for final grouping of participants. Among 40 children with RCLP, 17 children had been grouped to mild hypernasal group (Group Ia) and 20 were categorized to be the moderate-severe hypernasal group (Group Ib).

Table 4.1

Grouping of participants based on perceptual judgments

Participants	Age range (Years)	Mean	Gender		Severity of nasality
			M	F	
Group Ia	5-12	7.8	11	6	Mild
Group Ib	4.5-12	8.9	10	10	Moderate-severe
Group II	5-12	8.3	12	8	Normal nasality

Reliability measures. Intra and inter rater reliability were obtained using Kappa coefficient measures and the strength of agreement was observed.

Intra-raters reliability. The intra-rater reliability of the perceived nasality of the speech stimuli was obtained for all five raters. The results of kappa statistics indicated that rater 1 and 5 had good agreement of 0.887 and 0.760 respectively between the intra ratings of perceived nasality at $p<0.01$. The raters 2, 3, and 4 achieved significantly good agreement of 0.914, 0.855, and 0.803 correspondingly for intra ratings at $p<0.01$.

Inter-rater reliability. The results of inter-rater reliability of perceived nasality by the first, second, and third rater with the other raters ranged from 0.5 to 0.65, 0.4 to 0.8, and 0.4 to 0.7 respectively indicating moderate to good agreement between the raters. The raters four and five also exhibited moderate to good agreement in rating perceived nasality.

2. Estimating Nasality Severity Index and verifying group membership

The estimation of NSI was another objective of the study which included four equations. The four NSI equations considered for validation were:

NSI (1) = -3.10 - 0.01(a)+0.01(b)+0.07(c)-0.01(d)-0.04(e)- 0.01(f) + 0.06(g) +0.02(h) +0.02(i) - 0.03(j) - 0.12(k) + 0.52(l) + 0.04(m) - 0.02(n) - 0.04(o) + 0.03(p)- 0.01(q) + 0.02(r) - 0.01(s) + 0.02(t) - 0.01(u) + 0.03(v) + 0.02(w) + 0.09(x) - 0.07(y) - 0.01(z) + 2.95(z1).

NSI (2) = 1.46 - 0.02(a) + 0.02(b) + 0.01(c) + 0.15(d) -0.11(e)-0.10(f)-0.02(g)- 0.01(h)- 0.30(i)+0.03(j)+0.07(k)-0.17(l)+0.11(m)+0.02(n)- 0.01(o) + 0.04(p) + 0.05(q) + 0.01(r) - 0.007(s) + 0.04(t) - 0.03(u) - 0.001(v) - 0.05(w) + 0.14(x) -.18(y) + 0.16(z) - 6.93(z1).

NSI (3) = -2.39 + 0.02(M_Nasli) - 0.02(M_ON) - 0.04(M_NDS) +4.75(M_NRS)+ 0.01 (T396)

NSI (4) = 3.63 + 0.03(M_Nasli) - 0.12(M_ON) + 0.09(M_NDS) + 3.64(M_NRS)- 0.05 (T396).

*Note 1: a=/a/1000Hz, b = /a/1587Hz, c = /i/1000Hz, d = /i/1259, e = /i/1587, f = /i/3174, g = /p/396, h = /p/500, i = /p/793, j = /p/1000, k = /p/1259, l = /p/1587, m = /p/2000, n = /p/2519, o = /p/3174, p = /p/4000, q = /t/396, r = /t/500, s = /t/793, t = /t/100, u = /t/2519, v = M_nasla, w = M_nasli, x = M_O, y = M_N, z = M_ON, z1 = M_NR.

*Note 2: M_Nasla = Mean nasalance of vowel /a/, M_Nasli = Mean nasalance of vowel /i/, M_ON = Mean nasalance of oronasal sentences, M_NDS = Mean of nasalance distance, M_NRS = Mean of nasalance ratio, M_N = Mean of nasal sentences, T396 = One third octave spectral amplitudes for /i/ in /tip/.

These equations were based on various measures obtained from one third octave spectral analysis and nasalance values. In one third octave spectral analysis, spectral amplitudes at various frequency bands raging from 365Hz to 4000Hz were obtained for the stimuli /a/, /i/, /pit/, and /tip/. The nasometer was used to obtain mean nasalance values, and nasalance distance and ratio were calculated for all the stimuli. For all the four equations, NSI was obtained across the groups and group membership was verified based on the cutoff scores developed by Navya and Pushpavathi (2015).

The tables 4.2, 4.3 and 4.4 depict the estimated NSI (1 & 2) and (3 & 4) measures of all the participants included in the mild, moderate-severe hypernasal and normal groups based on perceived nasality. As per the cut-off scores given by Navya and Pushpavathi (2015), if NSI (1) was below -1.21, then it indicates TDC group and any score above it indicates hypernasal group. Among hypernasal group, if cutoff scores of NSI (2) are below -0.18 then it indicates a mild hypernasal group and any score above -0.18 indicates moderate to severe hypernasal group. Using NSI (3 & 4) equations, if NSI (3) score exceeds -0.85, then it indicates hypernasal group. If subjects are exhibiting a score which is less than -0.85, it is indicating a TDC group. For NSI (4), if the participant's nasality severity index score is less than 1.29, then they belong to moderate-severe hypernasal group and exceeding this indicates mild hypernasal group.

Thus based on the cut-off scores, using NSI (1 & 2) all 17 participants were correctly classified as mild hypernasal group. Whereas using NSI (3 & 4), 11 participants out of 17 were correctly identified as belonging to a mild hypernasal group. However, among other 6 participants who were considered as mild (based on perceptual rating), 3 of them were identified as normal group and 3 participants were grouped to moderate-severe hypernasal category by NSI (3 & 4).

Table 4.2

The estimated NSI equations for mild hypernasality group

Mild hypernasal group	NSI 1	NSI 2	Rating	NSI 3	NSI 4	Rating
1	16.86	-13.17	Mild	0.10	0.13	Moderate
2	10.42	-14.94	Mild	-0.15	3.01	Mild
3	12.89	-16.12	Mild	-1.72	2.62	Mild
4	11.61	-14.08	Mild	0.13	3.18	Mild
5	13.41	-8.29	Mild	-1.48	2.44	Normal
6	10.86	-16.15	Mild	-1.52	2.05	Normal
7	14.76	-11.80	Mild	2.21	2.20	Mild
8	13.84	-12.06	Mild	1.82	2.50	Mild
9	6.90	-7.47	Mild	2.02	2.09	Mild
10	17.80	-16.21	Mild	2.06	3.29	Mild
11	19.25	-16.98	Mild	1.01	2.84	Mild
12	8.37	-13.21	Mild	-1.60	1.50	Normal
13	9.89	-11.75	Mild	-0.67	2.77	Mild
14	15.35	-15.66	Mild	-0.20	1.52	Mild
15	10.18	-11.94	Mild	0.17	1.13	Moderate
16	19.12	-14.35	Mild	0.15	0.79	Moderate
17	14.344	-13.0752	MIld	0.592	0.735	Mild

Note. NSI = nasality severity index

In a moderate-severe hypernasal group of 20 participants, as per the established cut-off scores, none among the 20 subjects were correctly identified as moderate-severe hypernasality on NSI (1 & 2). Using NSI (3 & 4), 16 participants out of 20 were correctly interpreted as having moderate-severe hypernasaity. The remaining four participants were identified as mild instead of moderate-severe hypernasal group by NSI (3 & 4).

Table 4.3

The estimated NSI equations for moderate-severe hypernasality group

Moderate hypernasal group	NSI 1	NSI 2	Rating	NSI 3	NSI 4	Rating
1	13.7	-8.07	mild	1.44	0.42	Moderate
2	15.3	-9.01	mild	2.31	0.32	Moderate
3	19.30	-13.67	mild	2.59	0.75	Moderate
4	14.79	-12.54	mild	1.44	1.37	Moderate
5	19.37	-15.29	mild	1.71	1.52	Moderate
6	15.87	-10.19	mild	1.61	-0.44	Moderate
7	24.45	-11.56	mild	2.33	0.19	Moderate
8	23.19	-14.53	mild	1.48	1.00	Moderate
9	18.64	-14.38	mild	1.50	2.18	Mild
10	20.53	-12.45	mild	1.08	1.64	Mild
11	21.18	-12.05	mild	2.63	0.93	Moderate
12	19.33	-14.24	mild	2.51	3.11	Mild
13	18.58	-16.18	mild	3.01	-1.00	Moderate
14	23.09	-14.16	mild	2.40	-1.07	Moderate
15	20.02	-10.70	mild	2.60	1.00	Moderate
16	15.64	-15.21	mild	0.98	1.19	Moderate
17	15.66	-12.66	mild	2.15	1.27	Moderate
18	18.53	-13.88	mild	2.40	1.11	Moderate
19	12.64	-8.62	mild	1.91	2.30	Mild
20	33.80	-18.01	mild	1.36	0.90	Moderate

Note. NSI = nasality severity index

All the participants in the normal group were interpreted as mild hypernasal group based on NSI (1 & 2) cut-off scores. However, by using NSI (3 & 4), all participants were correctly identified with 100% accuracy.

Table 4.4

The estimated NSI equations for normal group

Normal group	**NSI 1**	**NSI 2**	**Rating**	**NSI 3**	**NSI 4**	**Rating**
1	12.09	-12.43	Mild	-2.19	2.15	Normal
2	8.58	-9.62	Mild	-2.48	3.50	Normal
3	7.62	-8.34	Mild	-1.44	1.85	Normal
4	8.46	-13.10	Mild	-2.11	2.03	Normal
5	10.37	-9.95	Mild	-0.65	-0.19	Normal
6	11.59	-13.62	Mild	-0.89	1.01	Normal
7	9.47	-17.26	Mild	-2.26	2.16	Normal
8	8.14	-12.32	Mild	-1.49	2.23	Normal
9	7.44	-11.45	Mild	-1.69	2.53	Normal
10	5.11	-9.47	Mild	-1.10	0.77	Normal
11	8.16	-11.89	Mild	-1.67	1.58	Normal
12	9.79	-13.81	Mild	-0.88	2.46	Normal
13	8.63	-10.18	Mild	-1.97	1.00	Normal
14	13.63	-4.47	Mild	-1.96	-1.24	Normal
15	11.58	-12.63	Mild	-1.81	2.75	Normal
16	5.44	-12.65	Mild	-1.45	2.60	Normal
17	12.42	-14.68	Mild	-1.70	2.36	Normal
18	14.02	-15.95	Mild	-1.64	1.98	Normal
19	14.25	-16.20	Mild	-1.80	2.34	Normal
20	7.048	-9.87	Mild	-1.70	2.17	Normal

Note. NSI = nasality severity index

3. Group membership based on NSI and perceived nasality

The group membership is derived based on NSI equations and perceptual analysis of nasality. The agreement in group membership assigned based on nasality severity index and perceptual evaluation ratings were examined using Kappa coefficient measure. Based on the NSI scores (1 & 2), all the participants across the groups were categorized into mild hypernasal group. Thus, kappa statistics could not provide any statistic value indicating the level of agreement in group membership based on NSI (1 & 2) and perceived nasality. Whereas the level of agreement in group membership assigned based on NSI (3 & 4) and perceptual evaluation indicated a good agreement in group membership (0.644; $p < 0.01$) based on Kappa statistics

In the present study, NSI (1 & 2) showed 100% sensitivity and 0% specificity. It is considered to be very poor in identifying the control group. However, NSI (3 & 4) demonstrated 94% sensitivity and 100% specificity. Thus, NSI (3 & 4) indicated a good discrimination of control from clinical group and is appropriate for its clinical application. Table 6 depicts the sensitivity and specificity and verification of group membership based on NSI (1 & 2), NSI (3 & 4) and perceptual evaluation of nasality .

Table 4.5

Group membership, sensitivity and specificity of NSI

Group	**Perceived nasality**	**NSI (1 & 2)**	**NSI (3 & 4)**
Mild	17	17	11
Moderate-severe	20	0	16
Normal	20	0	20
Sensitivity	Percentage (%)	100	94
Specificity	Percentage (%)	0	100

Note. NSI indicates nasality severity index

DISCUSSION

The present study aimed at validating the nasality severity index by selecting more number of subjects. Before the validation of NSI, initially perceptual analysis and other acoustic measures were carried out for the estimation of NSI. Perceptual evaluation was considered as gold standard along with the objective measures in clinical investigations of hypernasality (Kuehn & Moller, 2000). The presence of hypernasality will have an impact on perception of speech. Hence, the children with RCLP were evaluated for perceived nasality by five judges who used four point rating scale developed by Henningsson et al. (2008). The results of the present study indicated that the children with RCLP exhibited varying degrees of perceived nasality, thus rejecting the first null hypothesis which stated that there is no difference in perceived nasality across the groups. All the participants were divided into three groups such as participants exhibiting normal nasality (n= 23), mild hypernasality (n=17) and moderate-severe hypernasality (n=20). Out of these, 17 participants exhibited mild hypernasality, 20 participants were exhibiting moderate-severe hypernasality, and 20 participants were having normal resonance characteristics. .

These variations in the degree of perceived nasality exhibited by participants in the current study may be because of inconsistent velopharyngeal closure in RCLP subjects. The perceived nasality varies with the change in the size of the velopharyngeal opening. When there is a large velopharyngeal opening, the hypernasality becomes most noticeable and thus the degree of hypernasality perceived will be severe. In contrast, smaller VP openings are associated with the normal speech and resonance characteristics (Kummer, 2013).

These explanations were supported by the previous studies which were aimed to find out the correlation between degree of nasality and VP gap. A study by Paniagua et al., (2013) evaluated the correlation between perceptual evaluation and velopharyngeal gap. The participants exhibiting moderate to severe hypernasality were associated with severe VPD than mild hypernasality. A similar finding was also obtained by Kummer, Briggs, & Lee (2003) who studied the relationship between perceptual characteristics of hypernasality, nasal air emission, nasal rustle and velopharyngeal gap. They reported that VP gap and perceived nasality are directly proportional to each other.

Another study by Scarmagnani, Barbosa, Fukushiro, Salgado, Trindade and Yamashita (2015) also investigated the correlation among VP closure, hypernasality, audible nasal air emission (NAE) and nasal rustle (NR) in individuals with repaired cleft palate. They found a significant correlation between hypernasality and velopharyngeal gap suggesting that velopharyngeal gap increased when the degree of hypernasality increased.

However, a study by Lipira, Grames, Molter , Govier , Kane and Woo (2011) did not find a significant correlation (moderate correlation, 0.583; $p<.001$) between NAE and the velopharyngeal gap size. They reported that the lack of correlation is because of using the scale with more levels to rate the perceived nasality by the raters which increased the probability of variations. This lack of consensus across the studies in correlating VP closure with perceived nasality could also be due to the influence of various factors that affects reliability of perceptual evaluation. The various factors that could affect reliability of perceptual ratings across various studies include the type of stimuli (Cheung, 2004), co-existing articulation errors in the stimuli (McWilliams, 1954; Starr, Moller, Dawson, Graham, & Skaar, 1984), the experience of the listeners in judging speech quality perceptually (Kreiman et al., 1990), the effects of listeners training (Huynh, 2007; Lee et al., 2009 ; Stoeckel, 1980), the influence of individual voice quality (Kreiman et al., 1992), the effects of different recording systems and different listening conditions (Moller & Starr, 1984), the scale used in rating speech (Cheng, 2006; Whitehill et al., 2002; Zraick & Liss, 2000), etc.

Thus, the present study also evaluated the intra and inter judge reliability of perceived nasality to ensure reliable results. The results of inter rater reliability indicated a moderate to good agreement and intra rater reliability exhibited good agreement. The good reliability can be attributed to several reasons. One among them is the inclusion of more number of experienced judges to perform perceptual ratings. In few studies, evaluations based on experts resulted in good reliability. One such study was conducted by Lewis et al. (2003) who reported high inter rater reliability ranging between 0.71 and 0.73 on weighted Kappa measures for three expert listeners. Another study by Grunwell, Brondsted, & Gunill (2000) also reported that the hypernasality ratings made by expert judges had achieved good agreement.

The findings of good reliability among judges can also be due to the effect of training the judges prior to the actual task. It reduced the chances of personal bias among judges in rating the degree of hypernasality. This was also opined by Sell et al. (2001) who documented high kappa values for hypernasality (κ=0.81) owing to the fact that listeners had undergone extensive training prior to the study.

In addition, the speech samples used in the present study were recorded in a sound treated room using SLM microphone. Thus, the reduction in the background noise during recording could have lead to good reliability of perceptual ratings. The study by Tak, Waknis, Kulkarni (2016) also reported good reliability in ratings by judges using perceptual evaluation. They attributed their findings to the factors such as good quality of recordings, optimal listening condition and experience of the judges in carrying out perceptual assessment.

However, there are few studies which have reported poor to moderate agreement on perceptual ratings. In a study carried out by Watterson et al., (2007) reported that on perceptual judgments of hypernasality, there was poor to moderate reliability for two expert listeners. They analyzed reliability for ratings by the judges to the perceived nasality in low back and high front vowels. The poor reliability could be due to the difficulty in judging hypernasality for isolated vowels as speech is a multidimensional task.

Thus, the poor reliability of the judges reported in few studies might affect the perceptual evaluation. As the perceptual assessment is susceptible to errors due to its subjectivity, it has to be augmented with objective methods to obtain better results. In addition, there is a need for a multiparametric approach to achieve the consensus between subjective and objective methods. Thus the present study worked on validating a multidimensional measure by considering various objective measures such as one third octave and nasalance measures.

The second objective of the study was to estimate NSI by evaluating nasalance measures and one third octave spectal amplitudes. The nasalance measures were found to be significant in the construction of nasality severity index. In the present study, the nasalance scores obtained for children with RCLP were higher across stimuli as compared to TDC group. The increased nasalance values in RCLP can be attributed to the oral – nasal imbalance due to velopharyngeal impairment. These findings supports the findings of Navya and Pushpavathi (2014) who carried out nasalance measurement of vowels /a/ and /i/ in children with RCLP and typically developing children (TDC). The results showed higher nasalance values for children with RCLP than TDC and vowel /i/ exhibited increased scores compared to /a/ in both the groups. They also reported high sensitivity (0.87; 1.00) and specificity (0.93) of the nasalance values for both /a/ and /i/.

In addition to nasalance measures, one third octave spectral measures also provides complimentary information related to hypernasal speech and it is considered to be a potential tool in quantifying nasality (Kataoka et al., 2001, Navya and Pushpavathi, 2013). The results of the study by Navya and Pushpavathi (2013) indicated higher amplitudes over one third octave spectral frequencies in RCLP group for stimuli /i/, /pit/, & /tip/ as compared to control group. The study also found a good correlation between one third octave spectral measures and perceptual ratings. They reasoned that the increased spectral energy in the vowel production of children with RCLP was due to the presence of reinforced harmonics at frequencies where the energy is not normally expected. They concluded that one third octave spectral analysis is an appropriate measure for quantifying hypernasality. Similarly a study by Kataoka et al. (2001)

also reported higher spectral amplitudes between F1 and F2 for RCLP group than normals. Thus, the present study also evaluated one third octave spectral measures for the estimation of NSI.

Another major objective of the current study was to verify the group membership of participants based on nasality severity index. The results revealed poor agreement in group membership based on NSI (1 & 2) and perceptual ratings. Whereas the group membership assigned based on NSI (3 & 4) and perceptual ratings of hypernasality exhibited a good agreement with Kappa Coefficient of 0.644 ($p < 0.01$). These findings were supported by Bettens et al., (2016) who also evaluated the correlation between nasality severity index and perceptual ratings. They reported a moderate significant correlation between NSI 2.0 scores and perceived hypernasality ($r = \_0.64$) and the presence of severe hypernasality was indicated by a more negative NSI score 2.0. They concluded that NSI correlates significantly with the perceptual evaluation.

The NSI was verified for its sensitivity and specificity based on the subjects it correctly identified. The sensitivity (true positive rate) measures the percentage of RCLP subjects who were correctly identified as having hypernasality. The specificity (true negative rate) measures the percentage of typically developing children who were correctly identified as not having hypernasality. The sensitivity and specificity of all four NSI equations were verified. However, NSI (1) and (2) failed in differentiating the two groups (sensitivity: 100%, specificity: 0%). The NSI (3) and (4) equations showed good sensitivity (94%) and specificity (100%) in differentiating RCLP and TDC. In total 11 of the 17 mild hypernasal subjects were correctly classified by the NSI (3) and (4) and among moderate-severe group, 16 out of 20 samples were accurately classified. In normal group, all samples were identified with 100% efficacy. The reason for high sensitivity can be because the index is a multidimensional tool which included various objective measures such as one third octave analysis and nasalance measures. Thus, this index helped to sidestep the limitations imposed by single assessment methods and resulted in an optimal discrimination of clinical group exhibiting hypernasality and TDC group. These findings are in consensus with the study by Bettens et al., (2016) who also constructed NSI 2.0, a weighted linear combination of three variables and was obtained using the equation NSI 2.0 = 13.20 - (0.0824 - nasalance /u/ (%)) - (0.260 -nasalance oral text (%)) - (0.242 -VLHR /i/ 4.47*F0Hz (dB)). The results revealed that the NSI showed high sensitivity of 92% and a specificity of 100% in differentiating hypernasal from normal groups. The variables included in the equation are basically derived from the nasalance and the acoustic measures (VLHR). They concluded that NSI 2.0 has high sensitivity and specificity in the correct identification of RCLP.

The reasons for poor specificity of NSI (1) and (2) can be due to the methodological variations involved in the construction of NSI (1) and (2). The statistical methodology used was different for NSI (1) & (2) and NSI (3) & (4). While formulating the NSI (1) and (2) equation, the variables were manually selected based on the significant Wilk's Lambda values obtained in the discriminant function analysis. Whereas the variables included in NSI (3) and (4) were automatically generated by using the stepwise discriminant analysis. Thus, these variations might affect the validity of NSI (1) and (2) making it inappropriate for clinical application.

SUMMARY AND CONCLUSIONS

The present study aimed to validate the nasality severity index which was earlier constructed by Navya and Pushpavathi (2015). The study included 40 Kannada speaking children with RCLP and 20 typically developing children in the age range of 4-12 years. The participants were evaluated for perceived nasality and for estimating the nasality severity index. The stimuli for perceptual assessment were repetition of oral, oro nasal sentences and spontaneous speech sample. The perceptual evaluation was performed by five experienced judges using a standardized four point rating scale. To estimate NSI, various acoustic and nasalance measures were derived. The stimuli for nasalance measurement included sustained phonation of vowels /a/ and /i/, repetition of five oral, nasal and oro nasal sentences. The mean nasalance measures were obtained for all the stimuli using Nasometer. The one third octave spectral analysis across frequencies ranging from 369Hz to 4000Hz was carried out for the stimuli /a/, /i/, /pit/ and /tip/ using MATLAB software. The extracted measures from different parameters were used to estimate NSI (1 & 2) and NSI (3 & 4).

Based on the results of perceptual evaluation, the participants (Children with RCLP) were divided into three groups. Among them, 17 subjects were grouped into mild hypernasal category, 20 subjects were grouped into moderate-severe category and 20 subjects were classified to normal category. The Kappa coefficient correlation measures were performed to evaluate the inter and intra rater reliability of perceived nasality. The results indicated a good reliability within and across judges owing to the reasons such as experience level of judges, good quality recordings and using the rating scale with fewer points to evaluate perceived nasality.

Another major finding of the study was that NSI (1) and NSI (2) failed to discriminate the hypernasal and TDC groups accurately. However, using NSI (3) and NSI (4) equations, participants were discriminated and categorized into three groups. Out of 17 mild hypernasal participants, 11 were correctly classified and in moderate-severe group out of 20 participants, 16 were accurately classified based on NSI (3) and NSI (4). All subjects from a control group had been identified with 100% accuracy. Overall, NSI (3) and (4) showed the sensitivity of 94% and specificity of 100%. Later, the group membership agreement based on perceptual ratings and NSI (3) and (4) equations was examined using Kappa coefficient. The results revealed a score of 0.644 ($p<0.01$) indicating a good agreement between the two. The NSI (1) and (2) which showed poor validity (Sensitivity: 100%, Specificity: 0%) in differentiating the groups perhaps due to the methodological variations should not be considered further for the estimation of hypernasality. Subsequently, NSI (3) and (4) which has indicated a good validity in differentiating hypernasality and normal group ought to be considered for its clinical application to quantify nasality accurately. The NSI has significant clinical implications as it is a multiparametric approach utilizing different acoustic measures and it is noninvasive, easily repeatable, convenient to establish and easy to interpret. It also helps in quantitatively evaluating the effect of therapeutic and surgical intervention on hypernasality.

Future scope:

- NSI can be implemented in clinical settings for the clinical evaluation of hypernasality
- It can be used to evaluate the efficacy of surgical and therapeutic techniques.
- It can be employed to compare the outcomes of different rehabilitation techniques.

References

Anderson, R. T. (1996). Nasometric values for normal Spanish-speaking females: a preliminary report. *The Cleft Palate-Craniofacial Journal*, *33*(4), 333-336.

Ankola, A., Nagesh, L., Hegde, P., & Karibasappa, G. (2005). Primary dentition status and treatment needs of children with cleft lip and/or palate. *Journal of Indian Society of Pedodontics and Preventive Dentistry*, *23*(2), 80.

Arya, P., & Pushpavathi, M. (2009). Normative nasalance value in Hindi language. *Student research at AIISH (Articles based on dissertation done at AIISH), Vol. VII, Part B,* 187-198.

Bae, Y., Kuehn, D. P., & Ha, S. (2007). Validity of the nasometer measuring the temporal characteristics of nasalization. *The Cleft Palate-Craniofacial Journal*, *44*(5), 506-517.

Baken, R. J., & Orlikoff, R. F. (2000). *Clinical measurement of speech and voice*. Cengage Learning.

Baylis, A., Chapman, K., Whitehill, T. L., & Group, T. A. (2015). Validity and reliability of visual analog scaling for assessment of hypernasality and audible nasal emission in children with repaired cleft palate. *The Cleft Palate-Craniofacial Journal*, *52*(6), 660-670.

Beddor, P. S., & Hawkins, S. (1990). The influence of spectral prominence on perceived vowel quality. *The Journal of the Acoustical Society of America*, *87*(6), 2684-2704.

Bender, P. L. (2000). Genetics of cleft lip and palate. *Journal of Pediatric Nursing*, *15*(4), 242-249.

Bettens, K., De Bodt, M., Maryn, Y., Luyten, A., Wuyts, F. L., & Van Lierde, K. M. (2016). The relationship between the Nasality Severity Index 2.0 and perceptual judgments of hypernasality. *Journal of Communication Disorders*, *62*, 67-81.

Bettens, K., Van Lierde, K. M., Corthals, P., Luyten, A., & Wuyts, F. L. (2016). The nasality severity index 2.0: Revision of an objective multiparametric approach to hypernasality. *The Cleft Palate-Craniofacial Journal*, *53*(3), e60-e70.

Bettens, K., Wuyts, F. L., De Graef, C., Verhegge, L., & Van Lierde, K. M. (2013). Effects of Age and Gender in Normal-Speaking Children on the Nasality Severity Index: An Objective Multiparametric Approach to Hypernasality. *Folia Phoniatrica et Logopaedica*, 65(4), 185-192.

Bettens, K., Wuyts, F. L., D'haeseleer, E., Luyten, A., Meerschman, I., Van Crayelynghe, C., & Van Lierde, K. M. (2016). Short-term and long-term test-retest reliability of the Nasality Severity Index 2.0. *Journal of Communication Disorders*, *62*, 1-11.

Bettens, K., Wuyts, F. L., De Graef, C., Verhegge, L., & Van Lierde, K. M. (2013). Effects of Age and Gender in Normal-Speaking Children on the Nasality Severity Index: An Objective Multiparametric Approach to Hypernasality. *Folia Phoniatrica et Logopaedica*, *65*(4), 185-192.

Bradford, L. J., Brooks, A. R., & Shelton, R. L. (1964). Clinical judgment of hypernasality in cleft palate children. *Cleft Palate Journal*, *1*(329), 1-1.

Brancamp, T. U., Lewis, K. E., & Watterson, T. (2010). The Relationship Between Nasalance Scores and Nasality Ratings Obtained With Equal Appearing Interval and Direct Magnitude Estimation Scaling Methods. *The Cleft Palate-Craniofacial Journal*, *47*(6), 631-637. doi:10.1597/09-106

Bressmann, T., Sader, R. A., Awan, S., Busch, R., Zeilhofer, H. F., Brockmeier, J., & Horch, H. H. (1998). Measurement of nasalance using NasalView in a follow-up examination of patients with cleft palate. *Sprache Stimme Gehor*, *22*(2), 98-106.

Bressmann, T., Sader, R., Whitehill, T. L., Awan, S. N., Zeilhofer, H., & Horch, H. (2000). Nasalance Distance and Ratio: Two New Measures. *The Cleft Palate-Craniofacial Journal*, *37*(3), 248-256.

Brogårdh, C., Persson, A. L., & Sjölund, B. H. (2007). Intra- and inter-rater reliability of the Sollerman hand function test in patients with chronic stroke. *Disability and Rehabilitation*, *29*(2), 145-154.

Brunnegard, K. (2008). *Evaluation of nasal speech: a study of assessments by speech-language pathologists, untrained listeners and nasometry* (Unpublished doctoral dissertation). Umea university, Sweden.

Brunnegård, K., Lohmander, A., & Van Doorn, J. (2012). Comparison between perceptual assessments of nasality and nasalance scores. *International Journal of Language & Communication Disorders*, *47*(5), 556-566.

Bzoch, K. R. (1965). Articulation proficiency and error patterns of preschool cleft palate and normal children. *Cleft Palate Journal*, *2*, 340-349.

Bzoch, K. R. (Ed.). (1997). *Communicative disorders related to cleft lip and palate*. Pro-Ed.

CAGS, P. L., Suphawatjariyakul, R., & Thinnaithorn, R. (2012). Reliability of perceptual assessment for resonance disorders in patients with cleft palate. *Journal of the Medical Association Thailand*, *95*(11), S73-S79.

Chapman, K. L., Hardin-Jones, M., Schulte, J., & Halter, K. A. (2001). Vocal Development of 9-Month-Old Babies With Cleft Palate. *Journal of Speech Language and Hearing Research*, *44*(6), 1268. doi:10.1044/1092-4388(2001/099)

Chen, P. D. (2005). *Spectral correlates of hypernasality in consonants* (Unpublished doctoral dissertation). University of Hong Kong, Pokfulam, Hong Kong.

Cheng, T. H., & 鄭子豪. (2006). Direct magnitude estimation versus visual analogue scaling in the perceptual rating of hypernasality.

Conley, S. F., Gosain, A. K., Marks, S. M., & Larson, D. L. (1997). Identification and assessment of velopharyngeal inadequacy. *American Journal of Otolaryngology*, *18*(1), 38-46.

Cordero, K. N. (2008). *Assessment of cleft palate articulation and resonance in familiar and unfamiliar languages: English, Spanish, and Hmong*. University of Minnesota.

Counihan, D. T., & Cullinan, W. L. (1970). Reliability and dispersion of nasality ratings. *Cleft Palate Journal*, *7*, 261-270.

Dalston, R. M., Warren, D. W., & Dalston, E. T. (1991). Use of nasometry as a diagnostic tool for identifying patients with velopharyngeal impairment. *The Cleft Palate-Craniofacial Journal*, *28*(2), 184-189.

Dalston, R. M., Neiman, G. S., & Gonzalez-Landa, G. (1993). Nasometric Sensitivity and Specificity: A Cross-Dialect and Cross-Culture Study. *The Cleft Palate-Craniofacial Journal*, *30*(3), 285-291.

Dalston, R. M., & Seaver, E. J. (1992). Relative values of various standardized passages in the nasometric assessment of patients with velopharyngeal impairment. *The Cleft Palate-Craniofacial Journal*, *29*(1), 17-21.

Dalston, R. M., & Warren, D. W. (1986). Comparison of Tonar II, pressure-flow, and listener judgments of hypernasality in the assessment of velopharyngeal function. *The Cleft Palate Journal*, *23*(2), 108.

Dalston, R. M., Warren, D. W., & Dalston, E. T. (1991). A preliminary investigation concerning the use of nasometry in identifying patients with hyponasality and/or nasal airway impairment. *Journal of Speech, Language, and Hearing Research*, *34*(1), 11-18.

D'antonio, L. L., Muntz, H. R., Province, M. A., & Marsh, J. L. (1988). Laryngeal/voice findings in patients with velopharyngeal dysfunction. *The Laryngoscope*, *98*(4), 432-438.

Devi, T. R., & Pushpavathi, M. (2009). Normative nasalance value in Malayalam language. *Student research at AIISH, Mysore*, *7*, 67-82.

Dickson, D. R. (1962). An Acoustic Study of Nasality. *Journal of Speech Language and Hearing Research*, *5*(2), 103.

Dixon, M. J., Marazita, M. L., Beaty, T. H., & Murray, J. C. (2011). Cleft lip and palate: synthesizing genetic and environmental influences. *Nature reviews. Genetics*, *12*(3), 167.

Fletcher, S. G. (1976). Nasalance" vs. listener judgements of nasality. *Cleft Palate Journal*, *13*, 31-44.

Galvao, M. J. C. (1998). The nasal vowels of Iberian Portuguese. *The Journal of the Acoustical Society of America*, *103*(5), 3087-3087.

Gamiz, Calle, Amador & Mendoza (2006). VOT analysis in cleft palate patients after surgery. C *Cirugia Pediatrica*. 19(1), 27-32

Gibbon, F., Lee, A., Yuen, I., & Crampin, L. (2008). Clicks produced as compensatory articulations in two adolescents with velocardiofacial syndrome. *The Cleft Palate-Craniofacial Journal*, *45*(4), 381-392.

Gnanavel, K., Gopisankar, R., & Pushpavathi, M. (2013). Normative nasalance values across stimuli and gender in Malayalam speaking individuals. *Otolaryngology online journal*, *3*(4), 85-98.

Gopi Sankar, R., Pushpavathi, M., & VH, S. (2014). Voice Onset Time (VOT) in Kannada Speaking Children with Cleft Palate: A Pre-and Post-Operative Comparison. *Language in India*, *14*(2).

Grunwell, Kirsten Brondsted, Gunill, P. (2000). A six-centre international study of the outcome of treatment in patients with clefts of the lip and palate: the results of a cross-linguistic investigation of cleft palate speech. *Scandinavian Journal of Plastic and Reconstructive Surgery and Hand Surgery*, *34*(3), 219-229.

Grunwell,P., & Sell,D.A.(2001). Speech and cleft palate/velopharyngeal anomalies. *Management of Cleft Lip and Palate. London: Whurr*.

Haapanen, M. (1991). Nasalance Scores in Normal Finnish Speech. *Folia Phoniatrica et Logopaedica*, *43*(4), 197-203.

Hardin, M. A., Demark, D. R., Morris, H. L., & Payne, M. M. (1992). Correspondence between Nasalance Scores and Listener Judgments of Hypernasality and Hyponasality. *The Cleft Palate-Craniofacial Journal*, *29*(4), 346-351.

Harding, A., Harland, K., & Razzell, R. E. (1996). Cleft Audit Protocol for Speech: CAPS. 1996. *Available from St. Andrew's Centre for Plastic Surgery, Broomfield Hospital, Essex, CM1 7ET England*.

Hawkins, S., & Stevens, K. N. (1985). Acoustic and perceptual correlates of the non-nasal–nasal distinction for vowels. *The Journal of the Acoustical Society of America*, *77*(4), 1560-1575.

Henningsson, G., Kuehn, D. P., Sell, D., Sweeney, T., Trost-Cardamone, J. E., & Whitehill, T. L. (2008). Universal Parameters for Reporting Speech Outcomes in Individuals With Cleft Palate. *The Cleft Palate-Craniofacial Journal*, *45*(1), 1-17.

Hirschberg, J., & Van Demark, D. R. (1997). A proposal for standardization of speech and hearing evaluations to assess velopharyngeal function. *Folia phoniatrica et logopaedica*, *49*(3-4), 158-167.

Hirschberg, J., Bók, S., Juhász, M., Trenovszki, Z., Votisky, P., & Hirschberg, A. (2006). Adaptation of nasometry to Hungarian language and experiences with its clinical application. *International journal of pediatric otorhinolaryngology*, *70*(5), 785-798.

Huynh, Y. S. (2007). Training perceptual rating of hypernasality with co-existing speech disorders.

Jayakumar, T., & Pushpavathi, M. (2005). Normative score for nasometer in Kannada. *Student research at AIISH (Articles based on dissertation done at AIISH)*, *7*, 44-53.

John, A., Sell, D., Sweeney, T., Harding-Bell, A., & Williams, A. (2006). The cleft audit protocol for speech—augmented: A validated and reliable measure for auditing cleft speech. *The Cleft Palate-Craniofacial Journal*, *43*(3), 272-288.

Johnson, W., Darley, F. L., & Spriesterbach, D. C. (1963). *Diagnostic methods in speech pathology*, Harper & Row.

Jones, C. E., Chapman, K. L., & Hardin-Jones, M. A. (2003). Speech development of children with cleft palate before and after palatal surgery. *The Cleft Palate-Craniofacial Journal*, *40*(1), 19-31.

Karling, J., Larson, O., Leanderson, R., Galyas, K., & De Serpa-Leitåo, A. (1993). NORAM—an instrument used in the assessment of hypernasality: a clinical investigation. *The Cleft Palate-Craniofacial Journal*, *30*(2), 135-140.

Kataoka, R. (1988). Quantitative evaluation of hypernasality - Relation between spectral characteristics and perception of hypernasality. *Journal of Japanese Cleft Palate Association, 13*, 204-216.

Kataoka, R., Michi, K., Okabe, K., Miura, T., & Yoshida, H. (1996). Spectral Properties and Quantitative Evaluation of Hypernasality in Vowels. *The Cleft Palate-Craniofacial Journal*, *33*(1), 43-50.

Kataoka, R., Zajac, D. J., Mayo, R., Lutz, R. W., & Warren, D. W. (2001). The Influence of Acoustic and Perceptual Factors on Perceived Hypernasality in the Vowel [i]: A Preliminary Study. *Folia Phoniatrica et Logopaedica*, *53*(4), 198-212.

Kataoka, R., Warren, D. W., Zajac, D. J., Mayo, R., & Lutz, R. W. (2001). The relationship between spectral characteristics and perceived hypernasality in children. *The Journal of the Acoustical Society of America*, *109*(5), 2181-2189.

Kavanagh, M. L., Fee, E. J., Kalinowski, J., Doyle, P. C., & Leeper, H. A. (1994). Nasometric values for three dialectal groups within the Atlantic provinces of Canada. *Journal of Speech Language Pathology and Audiology*, *18*, 7-13.

Kendrick, K. R. (2004). Lousisiana State University Nasalance Protocol Standardization.

Kent, R. D., Liss, J. M., & Philips, B. J. (1989). Acoustic analysis of velopharyngeal dysfunction in speech. *Bzoch K. Communicative Disorders: related to cleft lip and palate. Boston: Little Brown*, 258-70.

Kent, R. D., Weismer, G., Kent, J. F., Vorperian, H. K., & Duffy, J. R. (1999). Acoustic studies of dysarthric speech: Methods, progress, and potential. *Journal of Communication Disorders, 32*(3), 141-186.

Keuning, K. H., Wieneke, G. H., & Dejonckere, P. H. (1999). The intrajudge reliability of the perceptual rating of cleft palate speech before and after pharyngeal flap surgery: the effect of judges and speech samples. *The Cleft Palate-Craniofacial Journal*, *36*(4), 328-333.

Keuning, K. H., Wieneke, G. H., Van Wijngaarden, H. A., & Dejonckere, P. H. (2002). The Correlation Between Nasalance and a Differentiated Perceptual Rating of Speech in Dutch Patients With Velopharyngeal Insufficiency. *The Cleft Palate-Craniofacial Journal*, *39*(3), 277-284.

Khosla, R. K., Mabry, K., & Castiglione, C. L. (2008). Clinical outcomes of the Furlow Z-plasty for primary cleft palate repair. *The Cleft Palate-Craniofacial Journal*, *45*(5), 501-510.

Kreiman, J., Gerratt, B. R., & Precoda, K. (1990). Listener Experience and Perception of Voice Quality. *Journal of Speech Language and Hearing Research, 33*(1), 103. doi:10.1044/jshr.3301.103

Kreiman, J., Gerratt, B. R., Precoda, K., & Berke, G. S. (1992). Individual Differences in Voice Quality Perception. *Journal of Speech Language and Hearing Research*, *35*(3), 512.

Kreiman, J., Gerratt, B. R., Kempster, G. B., Erman, A., & Berke, G. S. (1993). Perceptual Evaluation of Voice Quality. *Journal of Speech Language and Hearing Research*, *36*(1), 21.

Kuehn, D. (1982). Assessment of resonance disorders. *Speech language and hearing*, *11*, 499-524.

Kuehn, D. P., & Henne, L. J. (2003). Speech evaluation and treatment for patients with cleft palate. *American Journal of Speech-Language Pathology*, *12*(1), 103-109.

Kuehn, D. P., & Moller, K. T. (2000). Speech and language issues in the cleft palate population: the state of the art. *The Cleft Palate-Craniofacial Journal*, *37*(4), 348-348.

Kummer, A. W., Curtis, C., Wiggs, M., Lee, L., & Strife, J. L. (1992). Comparison of velopharyngeal gap size in patients with hypernasality, hypernasality and nasal emission, or nasal turbulence (rustle) as the primary speech characteristic. *The Cleft Palate-Craniofacial Journal*, *29*(2), 152-156.

Kummer, A. W., & Neale, H. W. (1989). Changes in articulation and resonance after tongue flap closure of palatal fistulas. *Cleft Palate Journal*, *26*, 51-55.

Kummer, A., Briggs, M., & Lee, L. (2003). The Relationship Between the Characteristics of Speech and Velopharyngeal Gap Size. *The Cleft Palate-Craniofacial Journal*, *40*(6), 590-596.

Kummer, A. W., Clark, S. L., Redle, E. E., Thomsen, L. L., & Billmire, D. A. (2012). Current Practice in Assessing and Reporting Speech Outcomes of Cleft Palate and Velopharyngeal Surgery: A Survey of Cleft Palate/Craniofacial Professionals. *The Cleft Palate-Craniofacial Journal*, *49*(2), 146-152.

Kummer, A. W. (2013). *Cleft palate & craniofacial anomalies: Effects on speech and resonance*. Nelson Education.

Laczi, E., Sussman, J. E., Stathopoulos, E. T., & Huber, J. (2005). Perceptual evaluation of hypernasality compared to HONC measures: The role of experience. *The Cleft Palate-Craniofacial Journal*, *42*(2), 202-211.

Lee, A., Whitehill, T. L., & Ciocca, V. (2009). Effect of listener training on perceptual judgement of hypernasality. *Clinical Linguistics & Phonetics, 23*(5), 319-334.

Lewis, K. E., Watterson, T., & Quint, T. (2000). The effect of vowels on nasalance scores. *The Cleft Palate-Craniofacial Journal*, *37*(6), 584-589.

Lewis, K. E., Watterson, T. L., & Houghton, S. M. (2003). The influence of listener experience and academic training on ratings of nasality. *Journal of Communication Disorders, 36*(1), 49-58.

Lewis, K. E., Watterson, T., & Blanton, A. (2008). Comparison of Short-Term and Long-Term Variability in Nasalance Scores. *The Cleft Palate-Craniofacial Journal*, *45*(5), 495-500.

Lierde, K. V., Wuyts, F. L., Bodt, M. D., & Cauwenberge, P. V. (2001). Nasometric values for normal nasal resonance in the speech of young Flemish adults. *The Cleft Palate-Craniofacial Journal*, *38*(2), 112-118.

Lohmander-Agerskov, A., Söderpalm, E., Friede, H., & Lilja, J. (1998). A comparison of babbling and speech at pre-speech level, 3, and 5 years of age in children with cleft lip and palate treated with delayed hard palate closure. *Folia phoniatrica et Logopaedica*, *50*(6), 320-334.

MacKay, I. R., & Kummer, A. W. (1994). Simplified nasometric assessment procedures. *Lincoln Park, NJ: Kay Elemetrics*.

Mahesh, S. M., & Pushpavathi, M. (2008). Nasalance value for Rainbow passage: Normative value for non-native speakers. *Journal of All India Institute of Speech and Hearing*, *27*, 22-28.

McWilliams, B. J. (1954). Some Factors In The Intelligibility Of Cleft-Palate Speech. *Journal of Speech and Hearing Disorders*, *19*(4), 524.

McWilliams, B. J. (1958). Articulation problems of a group of cleft palate adults. *Journal of Speech, Language, and Hearing Research*, *1*(1), 68-74.

McWilliams, B. J., Morris, H. L., & Shelton, R. L. (1990). *Cleft Palate Speech*. Mosby Elsevier Health Science.

McWilliams, B. J., Lavorato, A. S., & Bluestone, C. D. (1973). Vocal cord abnormalities in children with velopharyngeal valving problems. *The Laryngoscope*, *83*(11), 1745-1753.

Medeiros, M. N., Fukushiro, A. P., & Yamashita, R. P. (2016). Influence of speech sample on perceptual rating of hypernasality. *CoDAS*, *28*(3), 289-294.

Moll, K. L. (1964). 'OBJECTIVE'MEASURES OF NASALITY. *The Cleft Palate Journal*, *35*, 371-374.

Moller, K. T., & Starr, C. D. (1984). The effects of listening conditions on speech ratings obtained in a clinical setting. *Cleft Palate Journal*, *21*(2), 65-69.

Morris, H. L., & Smith, J. K. (1962). A multiple approach for evaluating velopharyngeal competency. *Journal of Speech and Hearing Disorders*, *27*(3), 218-226.

Morris, H. L. (1968). Etiological bases for speech problems. *Cleft palate and communication* (pp. 119-168). Academic Press, New York.

Mossey, P. A., Little, J., Munger, R. G., Dixon, M. J., & Shaw, W. C. (2009). Cleft lip and palate. *The Lancet*, *374*(9703), 1773-1785.

Nagarajan, R., Murthy, J., & Raman, S. V. (2005). Providing speech and language services for individuals with cleft lip and palate in India-The Challenge. *Cleft Journal*, *1*, 50-8.

Nagarajan, R., Subramaniyan, B., Sendhilnathan, S., & George, S. A. (2008). Speech services for individuals with cleft lip and palate in a rural community: An assessment of needs. In *Poster presented at* (Vol. 40).

Navya, A., & Pushpavathi, M. (2013). One third octave analysis: a diagnostic tool to measure nasality in conjunction with nasalance in children with repaired cleft lip and palate. *Journal of the All India Institute of Speech & Hearing*, *32*.

Navya, A. (2014). Derived Nasalance Measures of Nasality for Sentences in Children with Repaired Cleft Lip and Palate. *Language in India*, *14*(8).

Navya, A. (2015). *Construction of nasality severity index* (Unpublished master's thesis). University of Mysore, Mysore, India.

Nellis, J. L., Neiman, G. S., & Lehman, J. A. (1992). Comparison of Nasometer and Listener Judgments of Nasality in the Assessment of Velopharyngeal Function after Pharyngeal Flap Surgery. *The Cleft Palate-Craniofacial Journal*, *29*(2), 157-163.

Nichols, A. C. (1999). Nasalance statistics for two Mexican populations. *The Cleft Palate-Craniofacial Journal*, *36*(1), 57-63

O'gara, M. M., & Logemann, J. A. (1990). Early speech development in cleft palate babies. *Multidisciplinary Management of Cleft Lip and Palate. Philadelphia: WB Saunders Company*.

Olson, D. A. (1965). *A descriptive study of the speech development of a group of infants with unoperated cleft palate* (Doctoral dissertation, Northwestern University).

Padilha, E. Z., Dutka, J. D. C. R., Marino, V. C. D. C., Lauris, J. R. P., Silva, M. J. F. D., & Pegoraro-Krook, M. I. (2015). Assessment of speech nasality in individuals with cleft palate. *Audiology-Communication Research*, *20*(1), 48-55.

Paniagua, F. A. (2013). *Assessing and treating culturally diverse clients: A practical guide*. Sage Publications.

Paniagua, L. M., Signorini, A. V., da Costa, S. S., Collares, M. V. M., & Dornelles, S. (2013). Velopharyngeal dysfunction: a systematic review of major instrumental and auditory-perceptual assessments. *International Archives of Otorhinolaryngology*, *17*(03), 251-256.

Pannbacker, M., Lass, N. J., Middleton, G. F., Crutchfield, E., Trapp, D. S., & Scherbick, K. A. (1984). Current clinical practices in the assessment of velopharyngeal closure. *The Cleft Palate Journal*, *21*(1), 33-37.

Peterson-Falzone, S. J., Hardin-Jones, M. A., & Karnell, M. P. (2001). *Cleft Palate Speech* (pp. 266-291). St. Louis: Mosby.

Peterson-Falzone, S. J., Trost-Cardamone, J. E., Karnell, M. P., & Hardin-Jones, M. (2006). Early phonological development in babies and toddlers with cleft palate and non-cleft VPI. *The clinician's guide to treating cleft palate speech. St. Louis: Mosby*, 1-8.

Philips, B. J. (1980). Perceptual evaluation of velopharyngeal competency. *Annals of Otology, Rhinology & Laryngology*, *89*(5_suppl), 153-157.

Pols, L. C., Van der Kamp, L. T., & Plomp, R. (1969). Perceptual and physical space of vowel sounds. *The Journal of the Acoustical Society of America*, *46*(2B), 458-467.

Prado-Oliveira, R., Marques, I. L., Souza, L. D., Souza-Brosco, T. V., & Dutka, J. D. (2015). Assessment of speech nasality in children with Robin Sequence. *CoDAS*, *27*(1), 51-57.

Pulkkinen, J., Haapanen, M., Paaso, M., Laitinen, J., & Ranta, R. (2001). Velopharyngeal Function from the Age of Three to Eight Years in Cleft Palate Patients. *Folia Phoniatrica et Logopaedica*, *53*(2), 93-98.

Rah, D. K., Ko, Y. I., Lee, C., & Kim, D. W. (2001). A Noninvasive Estimation of Hypernasality Using a Linear Predictive Model. *Annals of Biomedical Engineering*, *29*(7), 587-594. doi:10.1114/1.1380422

Raju, S. (2000). In search of a smile: Study of children born with cleft lips and palates in India. *Mumbai, Tata Institute of Social Sciences*.

Raman, S., Jacob, M., Jacob, M. S., & Nagarajan, R. (2004). Providing intervention services for communication deficits associated with cleft lip and/or palate—a retrospective analysis. *Asia Pac Disability Rehabilation Journal*, *15*, 78-85.

Scarmagnani, R. H., Barbosa, D. A., Fukushiro, A. P., Salgado, M. H., Trindade, I. E., & Yamashita, R. P. (2015). Relationship between velopharyngeal closure, hypernasality, nasal air emission and nasal rustle in subjects with repaired cleft palate. *CoDAS*, *27*(3), 267-272.

Scherer, N. J., D'Antonio, L. L., & Kalbfleisch, J. H. (1999). Early speech and language development in children with velocardiofacial syndrome. *American Journal of Medical Genetics*, *88*(6), 714-723.

Scherer, N. J., D'antonio, L. L., & McGahey, H. (2008). Early intervention for speech impairment in children with cleft palate. *The Cleft Palate-Craniofacial Journal*, *45*(1), 18-31.

Searl, J. P., & Carpenter, M. A. (1999). Speech sample effects on pressure and flow measures in children with normal or abnormal velopharyngeal function. *The Cleft Palate-Craniofacial Journal*, *36*(6), 508-514.

Sell, D., Harding, A., & Grunwell, P. (1994). A screening assessment of cleft palate speech (Great Ormond Street Speech Assessment). *International Journal of Language & Communication Disorders*, *29*(1), 1-15.

Sell, D., Harding, A., & Grunwell, P. (1999). GOS. SP. ASS.'98: an assessment for speech disorders associated with cleft palate and/or velopharyngeal dysfunction (revised). *International Journal of Language & Communication Disorders*, *34*(1), 17-33.

Sell, D. A., & Grunwell, P. (1990). Speech results following late palatal surgery in previously unoperated Sri Lankan adolescents with cleft palate. *The Cleft Palate-Craniofacial Journal*, *27*(2), 162-168.

Sell, D., & Grunwell, P. (2001). Speech assessment and therapy. *Management of cleft lip and palate* (pp. 235-250). Whurr, Philadelphia.

Shaw, W. C., Semb, G., Nelson, P., Brattström, V., Mølsted, K., Prahl-Andersen, B., & Gundlach, K. K. (2001). The Eurocleft project 1996–2000: overview. *Journal of Cranio-Maxillofacial Surgery*, *29*(3), 131-140.

Shprintzen, R. J., & Bardach, J. (1995). *Cleft Palate Speech Management: A Multidisciplinary Approach*. Mosby Incorporated.

Shprintzen, R. J. (2004). Nasopharyngoscopy. *Communicative disorders related to cleft lip and palate. 5th ed. Boston: Little & Brown*.

Signorini, A., Costa, S., Collares, M., Dornelles, S., & Paniagua, L. (2014). Velopharyngeal dysfunction: a systematic review of major instrumental and auditory-perceptual assessments. *International Archives of Otorhinolaryngology*, *17*(03), 251-256.

Spriestersbach, D. C., & Powers, G. R. (1959). Articulation skills, velopharyngeal closure, and oral breath pressure of children with cleft palates. *Journal of Speech, Language, and Hearing Research*, *2*(4), 318-325.

Starr, C. D., Moller, K. T., Dawson, W., Graham, J., & Skaar, S. (1984). Speech ratings by speech clinicians, parents and children. *The Cleft Palate Journal*, *21*(4), 286-292.

Stoeckel, R. (1980). Effects of training on nasality ratings. *Unpublished Master of Arts Thesis*, University of Minnesota.

Sunitha, Roopa, N., & Prakash, B. Proceedings of 4th Annual congress of Indian Society of Cleft lip, Palate & Craniofacial Anomalies (Abstract). Hyderabad, India, 1994.

Sweeney, T. & Sell, D. (2008). Relationship between perceptual ratings of nasality and nasometry in children/adolescents with cleft palate and/or velopharyngeal dysfunction. *International Journal of Language & Communication Disorders*, *43*(3), 265-282.

Sweeney, T., Howard, S., & Lohmander, A. (2011). Nasality–assessment and intervention. *Cleft palate speech: assessment and intervention*, 199-220.

Trost-Cardamone, J. E. (1997). Diagnosis of specific cleft palate speech error patterns for planning therapy or physical management needs. *Communicative Disorders related to Cleft lip and Palate*, *5*, 463-91.

Van Doorn, J. & Purcell, A. (1998). Nasalance Levels in the Speech of Normal Australian Children. *The Cleft Palate-Craniofacial Journal*, *35*(4), 287-292.

Van Demark, D. R. & Hardin, M. A. (1986). Effectiveness of intensive articulation therapy for children with cleft palate. *Cleft Palate Journal*, *23*(3), 215-224.

Van Lierde, K. M., Wuyts, F. L., Bodt, M. D., & Van Cauwenberge, P. (2003). Age-related patterns of nasal resonance in normal Flemish children and young adults. *Scandinavian Journal of Plastic and Reconstructive Surgery and Hand Surgery*, *37*(6), 344-350.

Van Lierde, K. M., Wuyts, F. L., Bonte, K., & Van Cauwenberge, P. (2007). The Nasality Severity Index: An Objective Measure of Hypernasality Based on a Multiparameter Approach. *Folia Phoniatrica et Logopaedica*, *59*(1), 31-38.

Van Riper, C. G., & Irwin, J. V. (1958). *Voice and Articulation*. Pitman Medical Publishing Company.

Vasanthi (2001). *Some acoustic aspects in the speech of cleft palate speakers*. Unpublished Masters Dissertation, Submitted to the University of Mysore.

Vijayalakshmi, P., Reddy, M. R., & O'Shaughnessy, D. (2007). Acoustic analysis and detection of hypernasality using a group delay function. *IEEE Transactions on Biomedical Engineering*, *54*(4), 621-629.

Waknis, A., Tak, H. S., & Kulkarni, S. (2016). Perceptual and instrumental analysis of hypernasality in children with repaired cleft palate. *Journal of Cleft Lip Palate and Craniofacial Anomalies*, *3*(2), 67.

Warren, D. W., Dalston, R. M., & Mayo, R. (1993). Hypernasality in the presence of "adequate" velopharyngeal closure. *The Cleft Palate-Craniofacial Journal*, *30*(2), 150-154.

Watterson, T., Lewis, K. E., & Deutsch, C. (1998). Nasalance and nasality in low pressure and high pressure speech. *The Cleft Palate-Craniofacial Journal*, *35*(4), 293-298.

Watterson, T., Lewis, K. E., & Foley-Homan, N. (1999). Effect of stimulus length on nasalance scores. *The Cleft Palate-Craniofacial Journal*, *36*(3), 243-247.r65

Watterson, T., McFarlane, S. C., & Wright, D. S. (1993). The relationship between nasalance and nasality in children with cleft palate. *Journal of Communication Disorders*, *26*(1), 13-28.

Watterson, T., York, S. L., & McFarlane, S. C. (1994). Effects of vocal loudness on nasalance measures. *Journal of Communication Disorders*, *27*(3), 257-262.

Watterson, T., Hinton, J., & McFarlane, S. (1996). Novel stimuli for obtaining nasalance measures from young children. *The Cleft Palate-Craniofacial Journal*, *33*(1), 67-73.

Watterson, T., Lewis, K., & Brancamp, T. (2005). Comparison of Nasalance Scores Obtained With the Nasometer 6200 and the Nasometer II 6400. *The Cleft Palate-Craniofacial Journal*, *42*(5), 574-579.

Watterson, T., Lewis, K., Allord, M., Sulprizio, S., & O'Neill, P. (2007). Effect of vowel type on reliability of nasality ratings. *Journal of Communication Disorders*, *40*(6), 503-512.

Weerasinghe, J., Sato, J., & Kawaguchi, K. (2006). Spectral Evaluation of Hypernasality in Children with Repaired Cleft Palate. *Asian Journal of Oral and Maxillofacial Surgery*, *18*(3), 191-201.

Whitehill, T. L. (2002). Assessing intelligibility in speakers with cleft palate: a critical review of the literature. *The Cleft Palate-Craniofacial Journal*, *39*(1), 50-58.

Whitehill, T. L., Lee, A. S., & Chun, J. C. (2002). Direct Magnitude Estimation and Interval Scaling of Hypernasality. *Journal of Speech Language and Hearing Research*, *45*(1), 80.

Whitehill, T. L., Stokes, S. F., & Yonnie, M. Y. H. (1996). Electropalatography treatment in an adult with late repair of cleft palate. *The Cleft Palate-Craniofacial Journal*, *33*(2), 160-168.

Williams, W. N., Henningsson, G., & Pegoraro-Krook, M. I. (2004). Radiographic assessment of velopharyngeal function for speech. *Communicative Disorders Related to Cleft lip and Palate. 5th ed. Boston: Little & Brown*.

Zraick, R. I., & Liss, J. M. (2000). A Comparison of Equal-Appearing Interval Scaling and Direct Magnitude Estimation of Nasal Voice Quality. *Journal of Speech Language and Hearing Research, 43* (4).979.