# CONSTRUCTION OF NASALITY SEVERITY INDEX

Thesis submitted to the University of Mysuru for the degree of

DOCTOR OF PHILOSOPHY (Ph.D)

IN

SPEECH LANGUAGE PATHOLOGY

***By***

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***Under the Guidance of***

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ALL INDIA INSTITUTE OF SPEECH AND HEARING,

MANASAGANGOTHRI, MYSURU-6, INDIA

AUGUST, 2015

# CERTIFICATE

This is to certify that the thesis entitled **"Construction of Nasality Severity Index"** submitted by Ms. A. Navya for the degree of Doctor of Philosophy (Speech-Language Pathology) to the University of Mysuru was carried out at the All India Institute of Speech and Hearing, Mysuru.

Prof. S. R. Savithri
Director
All India Institute of Speech & Hearing
Mysuru-570006

Place: Mysuru
Date:

# CERTIFICATE

This is to certify that the thesis entitled **"Construction of Nasality Severity Index"** submitted by Ms. A. Navya for the degree of Doctor of Philosophy (Speech-Language Pathology) to the University of Mysuru, is the result of the original work carried out by her at All India Institute of Speech and Hearing, Mysuru, under my guidance.

Place: Mysuru
Date:

Dr. Pushpavathi.M
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# DECLARATION

I declare that this thesis entitled **"Construction of Nasality Severity Index"** which is submitted for the award of the degree of Doctor of Philosophy (Speech-Language Pathology) to the University of Mysuru, is the result of original work carried out by me at the All India Institute of Speech and Hearing, Mysuru, under the supervision of Dr. Pushpavathi.M, Professor of Speech Pathology, All India Institute of Speech and Hearing, Mysuru. I further declare that the result of this work has not been previously submitted for any degree.

Place: Mysuru A. Navya

Date: Candidate

## COMMENTS OF THE EXAMINER AND THE MODIFICATIONS MADE IN THE DOCTORAL THESIS

| Sl. No. | Comments | Modifications done as suggested | Pg. No |
|---|---|---|---|
| **CHAPTER I - INTRODUCTION** | | | |
| 1. | To cut down introduction. | Reduced Introduction | 1-9 |
| 2 | The aim and objectives have to be included at the end of introduction | Incorporated. | 8-9 |
| 3 | To clearly mention about the aim of the study highlighting the development of Nasality severity index for children with RCLP in Kannada language. | Incorporated | 8 |
| 4 | To add significant difference between groups in the objective. | Incorporated | 8-9 |
| 5 | To reframe the hypotheses. | Reframed hypotheses. | 9 |
| 6 | To change hypothesis to hypotheses. | Hypothesis was changed to hypotheses | 9 |
| **CHAPTER III - METHOD** | | | |
| 7 | Add details of the age, gender, degree of nasality and socioeconomic status of the participants. | Included the details of participants | 54 |
| 8 | To define parameter/ task, to type of the procedure for measurement with illustrations/figures. | Incorporated | 55-75 |
| 9 | To provide details about the tasks, material, and stimuli used. | Details are provided | 55-75 |
| 10 | To include the details about the stimuli considered for the training and for the perception task of the judges. | Details of stimuli is mentioned | 56-60 |
| 11 | To include information that vowel /i/ is analysed in the context of CVC syllable /pit/ and /tip/. | Incorporated | 65 |
| 12 | To change the term maximum duration time to | Changed the term | 72 |

| | | | |
|---|---|---|---|
| | maximum phonation duration. | into maximum phonation duration | |
| 13 | To include the details of the judges (number and age). | Details of judges are provided | 59-60 |
| 14 | To remove the author name (Venkatesan, 2009) adjacent to "AIISH Bio behavioural Ethics Committee" and to add a copy of approval letter in the Appendix. | Name is removed and copy is added to Appendix E | 55 |
| 15 | To include the references for Praat and VAGHMI. | References were included | 68 |
| **CHAPTER IV - RESULTS AND DISCUSSION** | | | |
| 16 | To write about mean, SD followed by correlation values, and test - retest reliability. | The order of results is changed as suggested | 82-129 |
| 17 | To rephrase the results in page 75, 79 and 80. | Rephrased | 97-128 |
| 18 | To remove "MANOVA was administered to find the main effect of group on dependent variables" as it is already mentioned in the statistical analyses in the method section | Removed the statement from results section | 82-129 |
| 19 | To type reliability measures as test- retest reliability. | Reliability is mentioned as test retest reliability | 82-129 |
| 20 | To mention whether hypotheses are accepted or rejected. | The information related hypotheses is mentioned. | 80,82, 91, 116,129 152 |
| 21 | Normalization of various quantitative scores may be considered for Discriminant Function analysis as they are in different units. | Information is provided in results and discussion of NSI. | 139 |
| 22 | To rephrase the sentence related to results of MANOVA. | Rephrased | 78 |
| 23 | To provide the data of structure matrix in the results section and to mention the parameters in Function1 and Function 2 of Canonical Discriminant Function. | Incorporated | 139,146 139-149 |
| 24 | To rewrite DF1 and DF 2, as NSI (1) and NSI (2) in page 96 and include both the formulas | DF1 and DF2 were modified as NSI 1 | 142-155 |

| | | | |
|---|---|---|---|
| | which includes 27, and 5 parameters, respectively with cut off scores in the end of the results and discussion section and to include a note specifically mentioning the use for RCLP and the percentage of variance. | and NSI 2.<br>Both the formule were included at end of discussion with percentage of variance. | |
| 25 | To provide the details of how many acoustic, aerodynamic parameters considered in formulation of NSI in each step in page 85-89. | Number of parameters considered for construction of NSI were included | 137,145 |
| 26 | To denote the parameters in NSI (1) and NSI (2) as a, b ,c..etc and to write the name in the footnote for better understanding. | The parameters in NSI (1) and (2) were mentioned in footnote. | 140,141 |
| 27 | To delete the discussion that "tongue is in contact with the palate during the production of vowel /i/". | Removed | 91-93 |
| 28 | To delete the discussion that "/s/ has reduced tactile sensitivity". | Removed | 132-133 |
| 29 | To provide appropriate discussion for the results obtained for the 1/3 octave and VLHR in the discussion section. | Relevant discussion is added and quoted the authors. | 116-121 |
| **OTHER MODIFICATIONS** | | | |
| 30 | To include list of publications at the end of the synopsis. | Included | Appendix F |
| 31 | To append the stimulus. | Stimulus is added in appendix | Appendix B |
| 32 | To mention the same order in procedure, results and discussion. | Incorporated | 52-155 |
| 33 | To correct the syntax and typographical errors in the synopsis. | Syntax and typographical errors were corrected | |
| 34 | To reduce the content of the introduction, | Content is | 1-9, 155- |

| | | | |
|---|---|---|---|
| | summary, and conclusions. | condensed in introduction, summary and conclusions. | 160 |

**ALL INDIA INSTITUTE OF SPEECH & HEARING, MYSORE – 6**

**Proceedings of doctoral committee meeting in respect of Pre-thesis submission colloquium**

| | |
|---|---|
| *Name of the candidate* | : Navya.A |
| *Date of pre-thesis submission colloquium* | : 28.05.2015 |
| *Whether the performance of the candidate was satisfactory* | : Satisfactory |
| *1st or 2nd appearance* | :1st Appearance |

***Recommendations of the Doctoral Committee:***

The candidate presented the synopsis titled "Construction of Nasality Severity Index". The doctoral committee recommended the following modifications.

*Introduction*

- To cut down introduction.
- The aim and objectives have to be included at the end of introduction

*Aim, objectives and hypothesis*

- To clearly mention about the aim of the study highlighting the development of Nasality severity index for children with Repaired cleft palate in Kannada language
- To add significant difference between groups in the objective.
- To reframe the hypotheses.
- To change hypothesis to hypotheses.

*Method:*

- To provide the details of the age, gender, degree of nasality and socioeconomic status of the subjects.
- To define parameter/ task, to type of the procedure for measurement with illustrations/figures.
- To provide details about the tasks, material, and stimuli used.
- To include the details about the stimuli considered for the training and for the perception task of the judges.

- To include information that vowel /i/ is analysed in the context of CVC syllable /pit/ and /tip/.
- To change the term maximum duration time to maximum phonation duration.
- To include the details of the judges (number and age).
- To remove the author name (Venkatesan, 2009) adjacent to "AIISH Bio behavioural Ethics Committee" and to add a copy of approval letter in the Appendix.
- To include the references for Praat and VAGHMI.

*Results and Discussion*

- To write about mean, SD followed by correlation values, and test - retest reliability.
- To rephrase the results in page 75, 79 and 80.
- To remove "MANOVA was administered to find the ~~statistical significant differences between the three groups over the~~ main effect & group on dependent variables" as it is already mentioned in the statistical analyses in the method section.
- To type reliability measures as test- retest reliability.
- To mention whether hypotheses are accepted or rejected.
- Normalization of various quantitative scores may be considered for Discriminant Function analysis as they are in different units.
- To rephrase the sentence related to results of MANOVA.
- To provide the data of structure matrix in the results section and to mention the parameters in Function1 and Function 2 of Canonical Discriminant Function.
- To rewrite DF1 and DF 2, as NSI (1) and NSI (2) in page 96 and include both the formulas which includes 27, and 5 parameters, respectively with cut off scores in the end of the results and discussion section and to include a note specifically mentioning the use for RCLP and the percentage of variance.
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*Others:*

- To include list of publications at the end of the synopsis.
- To append the stimulus.
- To mention the same order in procedure, results and discussion.
- To correct the syntax and typographical errors in the synopsis.
- To reduce the content of the introduction, summary, and conclusions.

**Doctoral committee:**

| Dr.S.R.Savithri<br>Director, AIISH<br>Doctoral Committee Member,<br>AIISH, Mysore | Dr. Y.V. Geetha<br>Professor, Dept of SLS<br>Doctoral Committee Member<br>AIISH, Mysore | Dr. K. Yeshoda<br>Reader , Dept of SLS<br>Doctoral Committee Member<br>AIISH, Mysore |
|---|---|---|

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28.5.15

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# ABSTRACT OF THE THESIS

Cleft lip and palate (CLP) is a congenital abnormality due to incomplete fusion of tissue during the development of face and upper lip in the gestational period. These children undergo surgical intervention for the closure of the cleft. Even after surgical intervention, the children with CLP do exhibit hypernasality, nasal emissions, and compensatory articulatory errors secondary to velopharyngeal dysfunction (VPD). The evaluation of speech in CLP can be performed using subjective and objective methods. Even though the perceptual evaluation is considered as a gold standard, it is influenced by various factors. Hence, the present study aimed to develop nasality severity index by amalgamating the perceptual evaluation with the acoustic and aerodynamic measures of speech. The study included 105 children with repaired cleft lip and palate (RCLP) and typically developing children (TDC). They were grouped based on the perceived nasality using 4 point standardized rating scale. Thirty three children with mild hypernasality (group Ia), 34 children with moderate to severe hypernasality (group Ib) and 35 typically developing children (group II) were considered for further objective analysis. The objective analysis included various acoustic (nasalence, one third octave spectral analysis, voice low tone to high tone ratio (VLHR), jitter, and shimmer measures) and aerodynamic measures (nasal emissions, maximum phonation duration, subglottic pressure, mean airflow rate, laryngeal airway resistance). The stimulus used for various measures is spontaneous speech, oral, nasal, oronasal sentences, vowels /a/, and /i/, in the CVC context /pit/, /tip/, and /s/. The results indicated that increased nasalance measures were found in RCLP than TDC; particularly significant differences were exhibited between group Ib and group II for vowel /i/, oral sentences, vowel /a/, and oronasal sentences. The nasalance distance was increased and nasalance ratio was reduced in TDC than

RCLP. The one third octave spectra analysis indicated significant differences across the groups at mid and high frequency bands indicating increased amplitude at mid and reduced at high frequencies. Among the stimuli, the differences were evident for /pit/, /tip/, /i/ and /a/. The VLHR measures were high in children with RCLP than TDC; however, the differences were not statistically significant. Among the jitter, shimmer measures of vowels /a/ and /i/, only shimmer measures of /a/ was found to be increased in group Ib than group II indicating significant differences across the groups. The nasal emissions were performed using Glatzel mirror, the results indicated significant increase in the amount of condensation on the mirror during the phonation of /a/, /i/ and /s/ by children with RCLP. The maximum phonation duration of /a/ and /s/ indicated significantly reduced production of /s/ by the children in the group Ia, group Ib than group II. The laryngeal aerodynamic parameters (SGP, MAFR, LAR) have not shown significant differences across the groups. However, hypernasal groups exhibited increased SGP, MAFR and LAR than control group. The nasality severity index included all of these parameters except nasal emissions and laryngeal aerodynamic parameters. The index was developed by subjecting all these objective measures for discriminant analysis. The equation included 27 measures, which were based on one-third octave spectral analysis, and nasalence measures exhibiting sensitivity and specificity of 96% and 100% respectively. For clinical use of the index another statistical method was used to reduce the number of measures included in the index. The stepwise discriminant analysis was performed and an index including five measures is developed. The sensitivity and specificity of the equation in differentiating the groups was 75% and 100% respectively. Hence, the index with 27 measures and 5 measures can be used for research and clinical purpose respectively.

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# CHAPTER I

# INTRODUCTION

Cleft lip and palate (CLP) are the congenital defects, which occur very early in pregnancy between the fourth and eighth week of gestation. CLP are malformations of oral and facial structures that occur very early in pregnancy, during gestation period. The incidence of CLP in India is estimated to be approximately one in 500 live births (Ankola, Nagesh, Hegde & Karibasappa, 2005). In India, multicenter survey conducted by the Tata Institute of Social Sciences, Mumbai (Raju, 2000) reported that every year 35,000 children are born with cleft lip and/ or palate. Another survey done by Nagarajan, Murthy, and Raman (2005) reported that cleft lip and/or palate are approximately one in 781 live births. The prevalence rate varies across reports (Ankola et al., 2005; Raju, 2000; Murthy & Raman, 2005).

The associated problems exhibited by individuals with CLP are heterogeneous in nature. The most common associated problems with CLP are feeding difficulties, ear infections, dental anomalies, psychosocial disturbances, delay in speech and language development and at risk for impaired communication (McWilliams, Morris, & Shelton, 1990). CLP can also be associated with various syndromes. The speech of individuals with CLP is primarily characterized by abnormalities in resonance characteristics of vocal tract. This is a direct result of unoperated cleft / fistula and/or velopharyngeal dysfunction. The individual with velopharyngeal dysfunction (VPD) exhibits abnormal closure of velopharyngeal port during the speech production. Therefore, sound energy directed orally escapes through the nasal cavity. The most prominent speech disorders exhibited by individuals with VPD are hypernasality, audible nasal emission, weak pressure consonants, and compensatory articulatory patterns leading to reduction in speech intelligibility.  This calls for the detail assessment of speech in CLP, which can be done either by subjective or objective measures and combinations of both.

The subjective assessment procedures for children with CLP were initiated in early 1930's. The focus was on describing articulatory errors, frequency of errors, type of errors, and comparisons with normative data (Cobb & Lierle, 1936; Aaron, 1942; Masland, 1946; West, Kennedy, & Carr, 1947; Harkins, 1949; McDonald, 1951; Morley, 1954; Van Riper, 1954). The perceptual assessment was used widely by many investigators to describe the resonance characteristics and speech intelligibility. The rating scales were used widely to quantify the speech characteristics and speech intelligibility (Sherman, Spriestersbach, & Noll, 1959; Van Demark, Morris, & Vandehaar, 1979).

The resonance and speech disorders were rated by various listeners (experienced/ inexperienced) across the rating scales ranging from 0 to 2 or 0 to 10 and reliability of these measures were also evaluated (Counihan & Cullinan, 1970). The rating scales were based on equal-appearing intervals or direct magnitude estimation or paired comparison, etc. The perceptual descriptions of resonance in individuals with CLP have included judgments of normal versus abnormal, and severity utilizing descriptive category judgments such as normal, mild, moderate, and severe impairment. (Subtelny, Van Hattum, & Myers, 1972; Moller & Starr, 1984; McWilliams, Morris & Shelton, 1990). The perceptual scales were also used to document the surgical outcomes of individuals with repaired CLP (Dalston & Warren, 1986; Karnell & Van Demark, 1986; Sell & Grunwell, 1990).

The selection of speech stimuli is one of the crucial factor in assessment. Various speech stimuli such as isolated vowels, words, sentences (oral, nasal & oronasal), paragraphs, discourse were used to differentiate the individuals with nasality from other subjects (Spriestersbach & Powers, 1959; Dalston & Seaver, 1992; Watterson, Lewis, & Deutsch, 1998; Searl & Carpenter, 1999). The studies have also investigated the reliability and dispersion of nasality ratings across the judges and in various speech stimuli (Counihan & Cullinan, 1970). Several speech assessment protocols have also been developed in this context.

The perceptual method of assessment is considered as gold standard in speech analysis of CLP. However, there are several variables such as judges, stimuli, scale influencing the perceptual judgment. These factors warrants for the assessment of inter and intra judge reliability to validate the perceptual method. The significant variations in intra and inter judge reliabilities as well as methodological procedures across various tests and rating scales has been put forth by many studies. This has led to the development of the standardized perceptual evaluation protocol by Henningsson, Kuehn, Sell, Sweeney, Trost-Cardamone, and Whitehill (2007). This protocol used perceptual parameters that characterize speech production of individuals with CLP regardless of the language or languages spoken. The guidelines for speech sampling content and scoring procedures in relation to parameters are described in detail. The use of universal standardized system aids in clinical trials by collaborating with the professionals of other geographic regions (Shaw, 2004).

The universal system for reporting speech outcome does have a clear advantage. However, there still exists some practical issues which needs to be addressed. Some of them are reluctance of professionals to accept new evaluation tools, differences in phonetic structure across languages (Hutters & Henningsson, 2004), lack of common understanding or usage of terms (Whitehill, 2002; Lohmander-Agerskov & Olsson, 2004; Sell, 2005). To overcome the limitations of perceptual evaluation, it is strongly recommended to augment the subjective assessment by an objective analysis for resonance disorders.

The objective measures of hypernasality due to VPD are assessed by visualizing VP closure and structures along with measuring the acoustic nasal output of the speech. The acoustic and aerodynamic analysis was widely used along with understanding the physiology of velopharyngeal closure by imaging techniques. Speech pathologists rely on the combination of direct and indirect assessment procedures (Shprintzen, 1995). Direct methods of visualization of the velopharyngeal valve include multiview videofluoroscopy and nasopharyngoscopy, whereas indirect or nonvisualizing procedures are illustrated by the mirror test, aerodynamic and acoustic investigations. The objective measure of nasality led to the evolution of TONAR II developed by Fletcher (1970) to measure the nasality. Later with the technological advancement, Fletcher and Bishop (1973) developed Nasometer and on the similar lines Awan (1997) developed Nasal View

System. Both the systems measure the nasalance by calculating the proportion of the nasal energy in speech from separate measurements of nasal and oral sound pressure level by the formula, Nasalance = nasal/ (nasal +oral) X 100% (Fletcher, 1970, 1976).

Normative nasalance values was been developed across various languages. Haapanen (1991) was the first person to develop the normative data for nasalance value by using Nasometer in normal Finnish speaking adults, followed by in Spanish language (Anderson, 1992), Australian children (Van Doorn & Purcell, 1998), Kannada language (Jayakumar & Pushpavathi, 2005), Hindi language (Arya & Pushpavathi, 2009) and in Malayalam language (Devi & Pushpavathi, 2009). Apart from this, Nasometer is also used widely to understand the physiology of velopharyngeal closure and to measure the nasalance in individuals with unrepaired/repaired cleft lip and palate. The nasalance value is affected by several factors. Nasalance values vary across the age (Sweeney & Sell, 2008), gender (Anderson, 1996; Nichols, 1999), dialects (Kavanagh, Fee, & Kalinowski, 1994) and stimuli (Searl & Carpenter, 1999; Watterson, Lewis, Allord, Sulprizio, & O'Neill, 2007).

Some of the studies have also investigated correlation between subjective and objective methods. These studies have compared the nasalance values with perceptual analysis to find the correlation across these two methods (Hardin, Van Demark, Morris, & Payne, 1992; Watterson, McFarlane, & Wright, 1993; Keuning, Wieneke, Van Wijngaarden, & Dejonckere, 2002). Watterson, McFarlane and Wright (1993) indicated significant but modest correlation between judgments of nasality and measures of nasalance for the non nasal passage ($r = 0.49$), but non-significant correlations for both the standard passage ($r=0.24$), and the nasal passage ($r = 0.20$). A study done by Keuning et al., (2002) indicated lower correlation coefficients, ranging from 0.34 to 0.71 between the perceptual and objective measures of nasality. However, a study by Sweeney and Sell (2008) using controlled speech stimuli revealed good correlation coefficients ranging from 0.69 to 0.74 which contraindicated the outcomes of the study done by Keuning et al (2002).

There were also reports of discrepancies on the correlation of speech based on nasalance scores with perceptual judgments of nasality. The discrepancy can be due to the wide range of nasality exhibited by the normal speakers which renders the task of rating perceived nasality by judges difficult. The literature also indicates few other objective measures of nasality in individuals with hypernasality. Some of these measures are based on speech spectrum. Zajac and Linville (1989) conducted a study to investigate voice perturbations of 10 children with hoarseness and nasality due to VPD. The electroglottograph was used to derive the perturbation measures. The results suggested that jitter was significantly greater in children with VPD than those of the children without VPD and no significant differences were observed across the groups for shimmer measures. Apart from jitter and shimmer measures in the voice spectrum, studies also indicate that the most obvious spectral distortion associated with hypernasality is a reduction in the intensity of the first formant (Smith, 1951; House & Stevens, 1956; Dickson, 1962; Fant, 1970; Kent, Liss, & Philips, 1989). However, there are limited studies done so far addressing this parameter.

Various studies have also focused on evaluating the amplitude across the spectrum in speech of individuals with CLP. Kataoka, Michi, Okabe, Miura, and Yoshida (1996) conducted a preliminary study on 16 children with hypernasality using one-third-octave spectra analysis. Results of their study revealed an increase in power level between the first and second formant, and a reduction in the power level in second and third formant regions among utterances judged to be hypernasal.

Voice low tone to high tone ratio (VLHR) is defined as the division of LFP into HFP and is expressed in decibels. The voice spectrum is divided into low-frequency power (LFP) and high-frequency power (HPF) by a specific cut-off frequency (600 Hz). Lee, Wang, Yang and Kuo (2006) had used voice low tone to high tone ratio (VLHR) to estimate nasalization objectively. There was a significant correlation between VLHR and nasalance scores ($r = 0.76$, $P < 0.01$). The authors concluded that VLHR may become a potential quantitative index of hypernasal speech and can be implemented in either basic or clinical studies.

The salient features of nasality can also be explored using aerodynamic measures. Aerodynamic measures are also used to analyze speech in individuals with CLP/VPD. Aerodynamic parameters are influenced by a number of anatomical features and physiological events, such as the driving pressure arising from respiratory system, constriction, size and timing of movements of the vocal cords, together with the size, shape and biomechanical properties of the vocal tract as a whole (Miller & Daniloff, 1993). On the basis of the relatively direct relationship that exists between laryngeal aerodynamics and laryngeal structure and physiology, it would be expected that aerodynamic parameter values would vary with respect to the different types of cleft and compensatory strategies used by individuals with CLP.

Zajac (1995) studied the laryngeal airway resistance (LAR) during vowel production in children with cleft palate using pneumotachograph and a differential pressure transducer. The findings of his study indicated that children with incomplete VP closure exhibited significantly higher laryngeal resistance. The influence of extent of VPD on laryngeal aerodynamics was reported by Brustello, Fukushiro, and Yamashita (2010). They conducted a study to explore laryngeal resistance in 19 individuals with marginal VP closure. The results indicated that the individuals with marginal VP closure did not modify laryngeal resistance. Individuals with CLP had slightly lower laryngeal resistance values than individuals without cleft. They speculated that the decrease in resistance at some point in the vocal tract can also result in increased airflow required to maintain the stable levels of air pressure.

The low cost appliances have also been used in assessing nasal airflow. One such appliance is Glatzel mirror. The significant difference in nasal emissions across hypernasal and control groups were documented using Glatzel mirror by Van Lierde, Wuyts, Bonte, and Cauwenberge (2007). However, another study by Pochat et al (2012) focused on the use of Glatzel mirror in objective evaluation of nasal airflow before and after rhinoplasty in normal individuals. The results indicated no statistically significant differences in the nasal airflow during pre and post rhinoplasty.

The maximum phonation duration (MPD) is one of the common aerodynamic measures which is employed to comment on the ability to sustain speech continuously by coordinating with respiration in an individual. Maier (2009) evaluated MPD for vowel /a/ in 312 children with CLP and compared them with 726 control participants. The results indicated reduced MPD in participants with CLP than TDC. The findings of the study done by Gnanavel, Sathish, and Pushpavathi (2013) were in accordance with the findings of Maier (2009). They measured MPD in children with VPD in the age range of 7-12 years for vowel /a/. The results indicated significant low scores of MPD by children with VPD than normative values.

The review indicates that the speech of children with CLP is studied using acoustic, aerodynamic and perceptual method. A multidimensional diagnostic measure with high sensitivity and specificity is mandatory to derive consensus across the measure of nasality. To have consensus across the measures of nasality a multidimensional diagnostic measure with high sensitivity and specificity is required. An attempt was made by Van Lierde, Wuyts, Bonte, and Cauwenberge (2007) to construct an equation based on Glatzel test, maximum duration time, and nasalance measures derived from children with CLP in the age range of 4-12 years. The results indicated an index "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)". Their study concluded that nasality severity index with sensitivity and specificity of 88% and 95% respectively can be used in the evaluation process of speech in children with CLP.

However, overcoming the advantages of the NSI equation, some limitations are also reported. This index is based on Dutch language and cannot be generalized universally. Another limitation is that only 5 variables (nasalance percent of oral text, Glatzel value of /a/, maximum duration time (seconds), nasalance % of /a/, nasalance percent of oronasal text) were considered for evaluation and to further formulate the index. The review of literature has also revealed that there are other potential acoustic (nasalance distance, nasalance ratio, voice low tone to high tone ratio, 1/3$^{rd}$ octave analysis, jitter, and shimmer) and aerodynamic variables (subglottal pressure, mean airflow rate, & laryngeal airway resistance) that can be used to differentiate individuals with hypernasality from normals. The study has not included equal number of participants based on severity of hypernasality. Hence they could not derive any cutoff values with respect to the severity of hypernasality exhibited as there were limited numbers of children with CLP under each degree of perceived nasality. Therefore, the study only correlated the NSI values with the perceived nasality and commented on trend observed across the groups. Hence, the present study attempts to construct a nasality severity index that reflects the overall severity of nasality perceived based on an integration of aerodynamic and acoustic measurements in Kannada speaking children with repaired cleft lip and palate.

## 1.1 Aim

The aim of the present study was to construct the Nasality Severity Index (NSI) for Kannada speaking children with repaired cleft lip and palate (RCLP).

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

- Classification of children with RCLP based on perceptual evaluation of nasality using the standardized perceptual rating scale.
- To investigate and compare the following acoustic parameters in mild hypernasal, moderate to severe hypernasal children with RCLP and typically developing children (TDC) for nasalance values of vowels (/a/ & /i/), oral, nasal, oronasal sentences, nasalance distance, nasalance ratio measures, jitter, shimmer measures, voice low tone to high tone ratio (VLHR), and one third octave spectra analysis.
- To investigate and compare the following aerodynamic parameters in mild hypernasal, moderate to severe hypernasal children with RCLP and TDC for nasal emissions of vowels /a/, /i/, & /s/, maximum duration time for /a/

& /s/, subglottal pressure, mean airflow rate, and laryngeal airway resistance.

- Correlating the acoustic and aerodynamic measures with the perceptual measures of nasality in children with RCLP and TDC.
- Constructing and validating the Nasality Severity Index (NSI) for Kannada children with RCLP by integrating the objective measures of acoustic and aerodynamic parameters.

## 1.3 Hypotheses

The null hypotheses were formulated as shown below to verify in the present study.

i) There will be no significant differences in acoustic, aerodynamic and perceptual measures of nasality between the Group Ia, Group Ib, and Group II.

ii) There will be no significant correlation between acoustics, and aerodynamic measures of nasality with the perceived nasality.

iii) There will be no differences in the group centroids of the three groups.

# CHAPTER II

## REVIEW OF LITERATURE

The speech of individuals with cleft lip palate (CLP) is primarily characterized by abnormalities in oral resonance. This is a direct result of unoperated cleft or fistula and/or velopharyngeal dysfunction (VPD). The cleft / fistula may alter the resonance characteristics resulting in the increased nasality in speech. The individuals with VPD cannot either adequately or consistently close the velopharyngeal port during speech. Therefore, sound energy directed orally escapes through the nasal cavity. Compensatory and obligatory articulation errors and reduced voice quality are the speech characteristics observed in these individuals. The final result is a reduction in speech intelligibility (McWilliams et. al., 1990; Kuehn & Moller, 2000; Peterson-Falzone, Hardin-Jones, Karnell, 2001; Bzoch, 2004; Kummer, 2008).

The speech characteristics of individuals with CLP are atypical, complicated, and present significant challenges including delay in speech and language development, articulation errors, abnormal voice and resonance characteristics. John, Sell, Sweeney, Harding-Bell, and Williams (2006) classified the articulation disorders based on cleft type characteristics (CTCs) as anterior oral CTCs (dentalization/ inter-dentalization, lateralization/ lateral, palatalization/ palatal); Posterior oral CTCs (double articulation, back to velar/ uvular); Non oral CTCs (pharyngeal articulation, glottal articulation, active nasal fricatives, double articulation); Passive CTCs (weak and or nasalized consonants, nasal realization of plosives, and/or suspected passive nasal fricative, gliding of fricatives/ affricates) and non-cleft speech immaturity/ errors. It has also been reported that there is a high incidence of voice disorders in individuals with CLP. This can be attributed to the laryngeal hyperfunction in an attempt to compensate for acoustic effects of VPD or compensatory articulation of glottal stops. Deviant resonance and nasal airflow characteristics such as hypernasality, hyponasality, nasal emission, and nasal turbulence are common in these individuals as a result of associated VPD.

Peterson-Falzone, Hardin-Jones, Karnell (2001) reported that at least 50% of children with CLP entails the services of a Speech-language pathologist. These children often require evaluation and intervention to enhance their articulation or phonological development or general expressive language functioning. Some individuals with CLP may have articulation and resonance problems associated with VPD (Peterson-Falzone, Trost-Cardamone, Karnell & Hardin- Jones, 2006). This speech problem can often impede education, employment and becomes a social stigma lasting a lifetime.

The speech characteristics related to articulation and resonance problems in children with CLP requires a detail assessment to comprehend the anatomical and physiological changes contributing to abnormal speech patterns. The evaluation of speech in individuals with CLP is of utmost importance for in depth understanding of speech and to plan effective rehabilitation. Although many tests and procedures are used to assess speech production patterns and nature of the disorders in this population, every child must to be carefully examined because a myriad of factors can contribute to the error patterns. It is often assumed that the primary goal in the assessment of children with CLP is identifying and treating the speech production problems associated with VPD. Therefore, the assessment procedures should be immaculate. The assessment of speech of individuals with CLP can be conferred through subjective and objective evaluations. It is necessary to comprehend the strengths or limitations of each type of evaluation, so that an ultimate amalgamated evaluation procedure can be applied for the assessment of speech in individuals with CLP. The following section deals with the review of perceptual and objective evaluation focused on children with CLP.

## 2.1 Perceptual Evaluation

The perceptual assessment was considered as gold standard (Kuehn & Moller, 2000) in analysis of speech among individuals with CLP. The perceptual assessment procedures started during early 1930-40’s. During the initial stages, the perceptual evaluation was restricted to investigation of articulation skills, which focused predominantly on description of articulation errors, frequency of these errors and type of errors. The comparisons of these errors were usually done with non-cleft children by using traditional SODA (substitution, omission, distortion, addition) analysis (Aaron, 1942; Cobb & Lierle, 1936; Harkins, 1949; Masland, 1946 & Carr, 1947).

Later during 1950-60's the researchers identified many other speech parameters which were affected in individuals with CLP. The parameters such as presence of compensatory articulation, scoring of articulatory errors by using various types of rating scales, etc. were explored. It was during this decade, the focus was shifted on parameters such as resonance, nasal grimaces etc. (McWilliams, 1958; Morris & Smith, 1962; Takagi, Glone, & Millard, 1965; Morris, 1968; Olson, 1965; Bzoch, 1965). This gave rise to development of different perceptual assessment protocols. Some of the protocols has been reviewed and used in various research studies (Shaw, Semb, Nelston, Brattstrom, Molsted, & Prahl-Andersen, 2000; Grunwell & Sell, 2001). Great Ormond Street Speech Assessment (GOS.SP.ASS) is one such protocol which evaluates different parameters such as articulatory characteristics, phonation, resonance, nasal emission, nasal turbulence, grimace, mirror test and oral examination. This test was surveyed for its reliability and its use for inter center comparisons (Sell, Harding, & Grunwell, 1994). The survey revealed ambiguities in the protocol. To overcome the shortcomings of this test Razzell (1996) and Harding, Harland and Razzel (1997) developed Clinical Audit Protocol for Speech (CAPS). A revised version of CAPS-A was proposed by John, Sell, Sweeney, Harding-Bell, and Williams (2006). This included explicit assessment of cleft type characteristics using a colour coding rating system. These protocols proposed many assessment schedule and scoring pattern was also recommended. However, lack of agreement about how to measure and report speech of CLP outcomes still persisted. Hence, this was revised and proposed as universal parameters for reporting speech outcomes in children with CLP (Henningson et al., 2007).

Henningsson et al. (2007) studied various parameters such as hypernasality, hyponasality, nasal air emission and consonant production errors. These parameters were used to report speech outcomes in individuals with cleft palate to achieve greater consistency in reporting speech outcomes globally regardless of the language or languages spoken. A working group of six individuals experienced in the area of speech and cleft palate was formed to develop a system of universal parameters for reporting speech outcomes in individuals born with cleft palate. The system was adopted in conjunction with a workshop held in Washington, D.C. (2002) that was devoted to developing the universal system. The system, which was refined further following the workshop, involves a three-stage plan consisting of 1) evaluation, 2) mapping, and 3) reporting. This report focuses primarily on the third stage, reporting speech outcome. They however opined that perceptual evaluation remains the gold standard for evaluating speech, as well as the most commonly used method.

The reporting stage focuses on the speech parameters as shown in table 1. The guidelines for speech sampling content and scoring procedures in relation to parameters are described in detail in their study. The primary imperative use of such a universal system would be as a tool in clinical trials involving collaborative groups from different geographic regions, including countries or regions that differ not only in how they rate and report perceptual speech data but also in the languages spoken.

Table 1

*Universal parameters for reporting speech outcomes of individuals with CLP.*

| **Parameters (words)** | **Parameters (sentences)** | **Rating** |
|---|---|---|
| Hypernasality | Hypernasality | 0 to 3 = Within normal to Severe |
| Hyponasality | Voice disorder, whole speech sample | 0=Within normal limits, 1= Present |
| Audible Nasal Emission | Audible Nasal Emission | 0 = Within normal limits, 1= Present |
| Consonant production errors | Consonant production errors | 0 = Within normal limits, 1= Present |
| Speech Understandability conversation sample | Speech Acceptability, Whole speech sample | 0=Within normal limits, to 3=severe. |

The perceptual evaluation is influenced by various factors such as type of stimuli, phonetic context, voice quality, pattern of articulation, listener previous experiences and expectations (Carney & Sherman, 1971; Fletcher, 1976; Dalston & Warren, 1986; Fletcher, Adams, & McCutcheon, 1989; McWilliams et al., 1990; Schmelzeisen, Hausamen, Loebell, & Hacki, 1992; Watterson, Hinton, & McFarlane, 1996; Kent, 1996; Zraick & Case, 1999). The perception of hypernasality varies as a function of other aspects of speech. It is more severe on high vowels than on low vowels (Spriestersbach & Powers, 1959; Kuehn & Moon, 1998), and varies according to phonetic context (Lintz & Sherman, 1961). The perceptual judgments by observers are not presented with convincing reliability. This could be due to variable internal standards acquired by different individuals, i.e., all observer experiences are thought to be stored in the memory and are believed to form the internal standards (Gescheider 1970; Kreiman, Gerratt, Kempster, Erman, & Berke, 1993; Keuning, Wieneke, & Dejonckere, 1999).

Today, a variety of psychological scaling procedures are being used (Stevens, 1974). Kuehn and Moller (2000) stated that both descriptive category judgments and rating of severity will continue to be useful in describing changes in resonance after surgical or behavioral intervention. However, there is a great deal of variability among the various systems that are being used to collect and analyze data by using various rating scales and tests to measure the speech and language abilities (Bzoch, 1989; Karling, Larson, Leanderson, & Henningsson, 1993; Kummer, Clark, Redle, Thomsen, & Billmire, 2011). This can lead to differences in inter and intra judge reliabilities. Many studies (Counihan & Cullinan, 1970; Baylis, Munson, & Moller, 2011; Pereira, Sell, & Tuomainen, 2013) have focused on evaluating intra and inter judge reliability measures.

The perceptual evaluations are referred to as customary standard in assessment protocols despite being presented with many drawbacks in evaluation procedures. Garratt, Kreiman, Antonanzas-Barroso, and Berke (1991) defined it as the core of speech and language evaluations against which the instrumental measures are validated (Dalston & Warren, 1986; Hirschberg & Van Demark 1997). It is widely reported that the accurate assessment of the degree of nasality is an exceptionally difficult perceptual task (Philips, 1980; Pannbacker, Lass, Middleton, Crutchfield, Trapp & Scherbick, 1984). The perceptual resonance evaluation should be accompanied with objective measures for accurate diagnostic and timely intervention strategies. Hence many studies (Hardin, Van Demark, Morris, and Payne, 1992; Watterson, et al., 1993; Keuning, et al., 2002; Sweeney et al., 2008) have coupled perceptual evaluation with objective measures and they have proven it to be an impeccable assessment procedure. Hence, perceptual evaluation is considered to derive NSI.

The perceptual evaluation is given considerable importance in investigating the speech in adults with CLP and only few studies have focused in children with CLP. The studies on perceptual evaluation in CLP are focused as a part of other assessment protocols (Karling, Larson, Leanderson, Galyas, & Serpa-Leitao, 1993; Sussman, 1995; Laczi, Sussman, Stathopoulos, & Huber, 2004), perceptual and instrumental correlation studies (Dalston, Warren, & Dalston 1991; Nellis, Neiman, & Lehman, 1992; Bressmann, Sader, Whitehill, Awan, Zeilhofer, & Horch, 2000) by using various rating scales and stimuli (Whitehill, Lee, & Chun, 2002; Watterson, Hinton, & McFarlane, 1996). There are limited studies focusing on the perceptual evaluation in children with CLP. The following studies highlight on the perceptual evaluation of speech in children with CLP.

Bradford, Brooks, and Shelton (1964) evaluated the perception of hypernasality in 17 children (10 boys & 7girls) of 6 to 14 years with the mean age of 9 years. Two groups of four judges consisting of two experienced (post graduate speech language pathologists having more than three years of experience working in the area of CLP and 2 inexperienced (post graduate speech language pathologists who had less than three years of experience and not specifically dealing among children with CLP) were instructed to perceptually rate perceived nasality on seven point rating scale 0 for no hypernasality and 6 representing extreme hypernasality. The stimulus includes spontaneous speech sample and /a-i/ test (Jonson, Darley & Spriestersbach, 1963). The results indicated poor reliability for both experienced (0.14 and 0.25) and inexperienced judges (0.25 to 0.33) for spontaneous speech and /a-i/ test. Relatively the inexperienced judges appear to be somewhat more reliable. The poor reliability in this study was partially accounted to the scale values used to rate the reliability as it is a 7 point scale. The lack of contrast in the voice quality among the subjects would make the judgment task more difficult and reduce reliability. Among the stimuli, the /a-i/ test indicated relatively good reliability than spontaneous speech. This was implied as /a-i/ test is free from the effect of articulatory variables than spontaneous speech. The variability in the articulation often interferes with the perception of nasality. Hence, the authors concluded that caution should be taken while taking clinical decisions in the management based on perceptual evaluation of hypernasality.

As the reliability of perceptual judgments were varying with respect to training factor and other clinical settings, Counihan and Cullinan (1970) carried out a study to investigate the reliability of hypernasality judgement made in a clinical setting without special pre-training. The specific purposes were to determine the reliability of experienced and inexperienced judges, individually and as groups, in rating perceived nasality from a sample of spontaneous speech and during the production of the /a-i/ vowel combination. Also to analyze recommendations for help made by the judges on the bases of the speech samples they obtained. The study included 17 children with CLP in the age range of six years of age and above. A spontaneous speech sample and /a-i/ test (Jonson, Darley, & Spriestersbach, 1963) were used for the assessment of resonance. Two groups of four judges, experienced and inexperienced provided ratings of perceived nasality on a seven point rating scale and indicated a yes or no judgment regarding the need for help. These data were analyzed to determine the reliability of individual and average judgments of perceived hypernasality without special pre-training, in a clinical setting. Neither experienced nor inexperienced judges were able to rate hypernasality reliably within the conditions of this study. Therefore, the authors concluded that much caution should be used in making decisions concerning speech lessons or physical management on the basis of hypernasality ratings made in a clinical setting without special pre-training.

The perception of hypernasality varies with the stimulus due to the effect of articulation. Sherman (1970) correlated the degree of nasality with the extent of articulation disorder in speech of children with cleft palate. The study included 154 speech samples each consisted of set of 13 sentences randomly recorded and randomly presented for perceptual evaluation. The perceptual evaluation was performed on the first 5 sec duration of each sample using 7 point rating scale. These speech samples were rated by 37 speech language pathologists separately for articulation disorder initially followed by rating of nasality. During the nasality rating task the samples were played backward to avoid the effect of defective articulation. The results indicated moderate correlation (0.34) between defective articulation rating and nasality. The results were attributed to the limited speech samples used for rating. They concluded that functionally there exists correlation between defective articulation and nasality.

Mayo, Dalston, and Warren (1993) conducted a retrospective study to analyze the nature of resonance judgements made by experienced speech language pathologists during assessment of the resonance disorders in very young children with unoperated and repaired cleft of palate. The study included 293 nonsyndromic children with secondary cleft palate, 219 were between one to two years. Among these 83 had undergone primary palatoplasty and 136 were unrepaired cleft palate. The rest of 74 children were between 4 to 5 years old with repaired cleft palate. All these children had undergone a standard assessment protocol for articulation, language, and resonance. The resonance assessments were based on the perceptual ratings for severity of hypernasality and hyponasality. The results were analyzed retrospectively by clinicians for hypernasality. The hypernasality rating was based on six point equal appearing interval scale in which '1' represent normal and '6' denotes to severe oronasal imbalance. The scale from 2 to 5 represent mild, mild to moderate, moderate and moderate to severe hypernasality respectively. The speech sample used for rating was phonologic samples obtained in 30 minute direct one to one interaction with the child in a clinical setting. The clinicians rating 0 on scale indicates either clinician's inability or unwillingness to assess hypernasality. The results indicated that zero rating was obtained for 31% and 12% of children with unoperated and operated palatal cleft respectively in the age range of 1 to 2 year old. However, only 1.4% children were rated with zero for hypernasality assessment in older children (4-5 years). The study concluded that resonance evaluation in young children, regardless of surgical status may be compromised by acoustic features of voice and vocal tract resonances. The study also concludes that it is difficult for clinicians to derive representative phonological samples and assess hypernasality in young children (1-2 years).

The perceptual evaluation of hypernasality along with other speech measures considered for evaluating efficacy of surgical technique used in the closure of the CLP. Khosla, Mabry, and Castiglione (2008) investigated the outcomes of Furlow Z-plasty for primary cleft palate repair in 140 children in the age range of 2 to 12 year 4 months. The speech evaluation was performed using a standardized set of syllables appropriate to the child's developmental age. Hypernasality, nasal escape, and articulation errors were evaluated after surgical repair and were scored on a scale of 0 to 3 indicating none, mild, moderate, and severe respectively by assessing these primary symptoms on each postoperative visit. Then the total score for each child was verified. If the score was zero then it was considered as absence of VPD, the total score of 1 to 3 was mild, 4 to 6 was moderate, 7-9 was deemed severe VPD. Then the VPD was ranked on a scale 0 to 3 indicating none, mild, moderate, and severe based on various factors of speech assessment. The results indicated that 83% of the children had no evidence of hypernasality, 91% had no presence of nasal escape, and 69% had no articulation errors. Overall 85% of children's were not having velopharyngeal insufficiency, 2.1% of children required secondary posterior pharyngeal flap and 3.6% children'ss had oronasal fistulas. The study concluded that Furlow Z – plasty yielded good speech results in children with CLP with less number of fistula formation, velopharyngeal insufficiency, and the need for additional corrective surgery.

Paniagua, Signorini, De Costa, Collares, and Dornelles (2013) conducted a retrospective study and compared the velopharyngeal gap with the perceptual evaluation of speech parameters in 49 children with CLP. The speech evaluation included perceptual rating of severity of hyponasality and hypernasality using three point rating scale indicating mild, moderate and severe. The compensatory and obligatory articulatory errors were identified during speech analysis. The velopharyngeal gap was evaluated during the production of /s/ using videonasoendoscopy. The velopharyngeal gap size was analyzed and classified as no gap, small gap, moderate gap, large gap and very large gap. The results indicated that participants with moderate to severe hypernasality had severe VPD than with mild hypernasality. The presence of hypernasality along with the articulatory errors correlated with moderate to large VP gap. The study concluded that there was good correlation between perceptual evaluation and velopharyngeal gap.

Another study by Padilha, Dutka, Marino, Lauris, Silva, and Pegoraro-Krook (2015) investigated the differences in the auditory perceptual judgments of nasality between the live ratings and for the ratings of recorded speech. The study included retrospective findings of the perceptual assessment performed live by a speech language pathologist with the 100 speech recordings of low and high pressure consonants produced by children with repaired CLP aged 5 and 12 years. The results indicated absence of hypernasality in 69% of the children with RCLP during live assessment. In the remaining participants 23% exhibited mild and moderate in 8% of the children. In case of recoded samples, 50 % were identified as exhibiting hypernasality in high pressure consonants, and 62% in low pressure consonants. The results indicated statistically significant differences between the judgments for recorded samples of high pressure consonants and live judgments. There was 79% of agreement for high pressure consonants, and 80% for low pressure consonants within the moderate range. The study concluded that during live judgments most of them were rated as absence of hypernasality or presence of mild hypernasality compared to the judgments of recorded speech samples. However, the live judgments are not possible to reproduce, quantify and difficult to share with the team members.

From the review of literature, it can be noted that the perceptual evaluation has proven to be the preordained aspect of evaluation procedures. Though the perceptual evaluations are associated with many drawbacks, it still certainly is irrefutable aspect in analysis of speech of individuals with CLP. The perceptual evaluations can complement the objective evaluations which as amalgamated assessment procedure can provide detailed understanding about speech skills of an individual with CLP. Therefore, it has to be thoroughly reviewed and along with objective evaluation it can be manifest as ironclad assessment protocol.

**2.2. Objective Evaluation**

The speech of individual with CLP exhibiting errors in articulation, resonance, voice and speech intelligibility draws attention for evaluating the presence, extent, and location of abnormalities in VPD. The review of various studies which has employed perceptual evaluation protocols has revealed that the these measures are influenced by various factors such as stimuli, judges, rating scales, listening conditions, quality of recordings, and articulatory characteristics of speech in children with CLP. This often leads to differences in reliability measures (Watterson, Lewis, & Foley-Homan, 1999; Lewis, Watterson, & Houghton, 2003; Lohmander and Olsson, 2004; Sell, 2005; John et al., 2006). The challenges of auditory perceptual assessment have warranted for objective evaluation that can provide reliable measures. Kuehn and Moller, (2000) stated that no instrumental analysis can substitute the perceptual evaluation. However clinician can complement perceptual evaluation with instrumental evaluation. Hence, even though perceptual evaluation is considered as gold standard, 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).

The objective measures of hypernasality usually are focused on assessing velopharyngeal closure using direct and indirect assessment procedures (Shprintzen, 1995). Few of the direct imaging techniques provide dynamic and natural images of the anatomical structures of the larynx, pharynx, and nasal cavity. Hence this imaging method is considered as one of the potential method for evaluating VPD (Pontes & Behlau, 2005). These techniques provide information about the pattern of velopharyngeal closure and presence of VP gap. The abnormal VP closure patterns are usually evident during the speech production and are manifested as deviant resonance characteristics in speech. In such condition, frequent changes in the degree of soft palate movement and pharyngeal wall movements are documented (Kuehn & Henne, 2003; Shprintzen, 2004; Williams, Heningsson, & Pegoraro-Krook, 2004).

Several direct methods of visualization of the velopharyngeal valve techniques were used by researchers to evaluate velopharyngeal function. These include Multiview Videofluoroscopy, Videonasoendoscopy, Nasopharyngoscopy, Lateral Cephalogram of Nasopharyngography, Nasopharyngeal Fibroscope, and Magnetic Resonance Imaging. The indirect or nonvisual procedures used by researchers for speech and VPD evaluation are mirror fogging test, Nasometry, aerodynamic and acoustic investigations (Paniagua, et al., 2013). The indirect objective evaluations can be carried out by speech language pathologists to assess the different speech parameters. The studies reviewed have shown that the acoustic measures of speech were extensively studied by various researchers and many studies have employed acoustic measures to assess the speech of individuals with CLP.

### 2.2.1 Acoustic Measures of Speech

The present study have conferred various acoustic parameters by investigating parameters such as nasalance, one third octave spectral analysis, voice low tone to high tone ratio, perturbation measures to correlate with perceptual evaluation to derive multidimensional nasality severity index.  The following studies highlights the review related to acoustic analysis reported in children with CLP.

#### *Nasalance Measures of Speech*

Nasalance measure is widely used to assess the nasality. Among the indirect evaluation procedures, the concept of nasalance measures was explored widely during 1970's. The concept was largely based on the previous works pioneered by Fletcher (1970, 1973, and 1976) who developed TONAR II. Nasometer II is a PC-compatible hardware and software system that is used to assess and treat individuals with cleft palate, hearing impairment, motor speech disorders, and functional nasality problems. This was developed by Fletcher and Bishop (1973).

The Nasometer II uses an innovative headset device, worn by the subject, which separates the oral and nasal cavities with a baffle plate. The microphones are mounted on the top and bottom of the plate collect the acoustic energy generated during speech. The analog signal is then recorded and converted to digital signal before the computation of nasalance score by using formula (nasal energy/(nasal energy + oral energy)) x 100. A Nasalance value is an acoustic ratio score of acoustic energy emitted through oral cavity to the nasal cavity. The Nasometer was widely used by the investigators to derive nasalance scores in speech signal and eventually, many researchers published data regarding norms, reliability and compatibility with the perceptual evaluation of speech (Watterson, Lewis, & Brancamp, 2005; Bae, Kuehn, & Ha, 2007; Lewis, Watterson, & Blanton, 2008). These measures were used for diagnostic purposes and also to evaluate the efficacy of therapeutic intervention (MacKay & Kummer, 1994; Lewis, Watterson, & Quint, 2000; Bunton & Story, 2012; Lewis et al., 2000).

The various research studies have put forth many findings with regard to nasalance scores on various speech stimuli. However, there was a need to develop normative data for various different stimuli which would facilitate the usage of the normative data for routine clinical use. Using Nasometer, several investigators developed normative data for children as well as adult population. The normative data can also serve as baseline to check for post interventional measures. The normative data for nasalance in children was developed in Australian English speaking (Doorn & Purcell (1998), Irish (Sweeney, Sell, & Oregan, 2003), Flemish (Van Lierde, Wuyts, Bodt, & Cauwenberge, 2003), Swedish (Brunnegard & Van Doorn, 2009). The normative data would also help to differentiate between normal and abnormal nasality. Many researchers conducted study to develop normative data for nasalance scores across different languages for various stimuli. In Indian context, normative nasalance values were developed in Tamil (Sunitha, Roopa, & Prakash, 1994), Kannada (Jayakumar & Pushpavathi, 2003), Malayalam (Devi & Pushpavathi, 2009) and Hindi (Arya & Pushpavathi, 2009).

The normative data obtained was language specific and conflicting results were reported by various researchers on the influence of gender and stimuli on nasalance scores. While, Sunitha, Roopa, & Prakash (1994) reported that girls were found to have higher nasalance values than boys, findings of Jayakumar and Pushpavathi (2003) revealed that there was no gender based difference on nasalance scores. Some of the studies reported gender based difference on nasalance scores (Hutchinson, 1978; Sunitha, Roopa, & Prakash, 1994; Fletcher, 1978; Seaver, Dalston, Leeper, & Adams, 1991, Van Lierde, Wuyts, Bodt, De, & Van Cauwenberge 2001). There were also contradicting findings by some investigators reported that there was gender based difference on nasalance scores (Jayakumar & Pushpavathi, 2003; Sweeney, Grimaldi, Upheber, Kramer, & Dempf, 2004; Van Doorn, & Purcell, 1998; Van Lierde et al., 2003).

The studies carried out on nasalance have used different types of stimuli. The various stimuli include phonation of vowels, repetition of high pressure consonants, words, sentences (oral, nasal and oronasal) for children and passages (Zoo and Rainbow). The zoo passage (Fletcher, 1978) was traditionally used to assess nasalance as it consists of various oral consonants (stops, fricatives, and glides). The Zoo passage consists of 83 syllable length to obtain valid and stable measures. MacKay and Kummer (1994) developed Simplified Nasometric Assessment Procedure Test (SNAP Test) to remove the effect of vowel content on short stimuli. The studies were done on both pediatric and adult population. Some of the studies have also investigated the effect of gender on nasalance scores.

Lewis et al (2000) studied the effect of vowels on nasalance scores. They selected 38 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 sentences had different vowels: a high front vowel /i, I/, a high back vowel /u, U/, mixed vowel, low front vowel /ε, 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 also 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.

Brancamp, Lewis, and Watterson (2010) investigated the correlation between nasalance scores and perceived nasality using equal appearing interval scale and direct magnitude estimation measures. They selected 39 speakers for their study, out of whom, 25 speakers had history of hypernasality and 14 speakers had normal speech. The age ranges of speakers were from 3.8 years to 17.2 years. The judge chosen for their study had more than 30 years of experience in assessing the resonance disorders. They used turtle passage to obtain the speech sample from the speakers. The turtle passage consisted of 29 syllables and no nasal phonemes. The Nasometer II (Model 6400) was used to obtain the mean nasalance score for each speech sample. They established interrater reliability by using five point EAI scale where 1 represented normal resonance to 5 representing severe hypernasality. They selected a clinician with more than 15 years for rating nasality for inter-rater reliability task. The judge and the clinician also established interrater reliability for the DME scale by rating the samples using DME procedures. They applied separate bivariate correlations to assess the strength of the relationship between nasalance scores and nasality ratings made using EAI and DME scaling procedures. 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 of their study revealed that the magnitude of the correlation between nasalance scores and EAI ratings of nasality ($r = .63$) and between nasalance and DME ratings of nasality ($r = .59$) were not significantly different. They also reported that the nasometer test sensitivity and specificity for EAI-rated nasality were .71 and .73, respectively. The DME-rated nasality, sensitivity and specificity were found to be at .62 and .70, respectively. They convened that regression of EAI nasality ratings on DME nasality ratings did not depart significantly from linearity. Based on the findings of their study, they concluded that no difference was found in the relationship between nasalance and nasality when nasality was rated using EAI as opposed to DME procedures. The Nasometer test sensitivity and specificity were similar for EAI and DME-rated nasality. They illustrated that a linear model accounted for the greatest proportion of explained variance in EAI and DME ratings. They proposed that the clinicians should be able to obtain valid and reliable estimates of nasality using EAI or DME.

Bunton and Story (2012) examined the correlation of perceived nasality rated by five experienced listeners, nasalance scores and nasal port (velopharyngeal orifice) area for three simulated English vowels, /i/, /u/, and /ɑ/ using a computer model. The researchers used a computational model of speech production to generate vowel samples with varying degrees of nasal port coupling. Their study was based on the notion that the nasality exists on a continuum such that the listeners can detect different degrees of normal and abnormal nasality (Brancamp et al., 2010).  The results indicated significant correlation for nasalance and perceptual ratings of nasality were noted across the three vowels. The correlations with nasalance values were high for vowels /i/ and /u/ compared to low vowel /a/. The findings of their study were consistent with the previous studies for speech samples from speakers with and without velopharyngeal impairments, where it reported that the nasalance scores obtained from the high front vowel /i/ were markedly higher than low back vowel /ɑ/ in sentence level (MacKay & Kummer, 1994).

Watterson et al (1999) examined the stimulus length on nasalance values. They selected 25 children and adolescents in the age range of 5 years to 14 years with a median age of 7 years. The stimulus included 44 syllable passage (Karnell, 1995), 17 syllable passage, 6 syllable sentence and 2 syllable words. The Nasometer II was used to record and analyze the stimulus to obtain nasalance values. The results of their study indicated that the speech stimuli with 17 syllables and 6 syllable exhibited high criterion validity indicating that six syllable sentences could justifiably be substituted for a 44 syllable passage for clinical purposes.

Most of the studies (Watterson, Lewis, & Foley-Homan, 1998; Becknal, 2010) in measuring nasalance had placed emphasis on adult population and typically developing children. The studies assessing the nasalance values in children with CLP are very limited. The review of reliability of nasalance values showed a degree of variability questioning the effectiveness of nasalance of Nasometer to improve the assessment reliability (Brunnegard, 2008). Dalston, Warren, and Dalston (1991b) studied a series of 117 individuals with CLP (5 - 56 years; mean age 17 years) in an attempt to determine the extent to which acoustic assessments of speech made with a Nasometer corresponded with aerodynamic estimates of velopharyngeal area and clinical judgments of hypernasality. Nasometer data were obtained while children's read or repeated a standardized passage with no nasal consonants. Pressure-flow data were obtained from 96 of these subjects during repeated productions of the word "papa". Listener judgments were made in a clinical setting by using a 6-point equal appearing interval scale. Nasometer and pressure –flow results were not known to the senior author when making listener assessments. With a cutoff nasalance score of 32, the sensitivity of Nasometer ratings in correctly identifying the presence or absence of velopharyngeal areas in excess of 0.10 $cm^2$ was 0.78 and 0.79, respectively. They reported that the sensitivity and specificity of Nasometer in correctly identifying individuals with more than mild hypernasality in their speech was 0.89 and the specificity was 0.95. The results suggest that the Nasometer is an appropriate instrument that can be crucial in assessing individuals suspected of having VPD. It was proposed that nasometer is an effective tool in assessing nasalance scores. However, the perceptual evaluation of nasality also has to be taken into consideration for impeccable evaluation of nasality.

Hardin, Van Demark, Morris, and Payne (1992) conducted a study to investigate the relationship between nasalance values and perceived nasality in 74 subjects. Among these 51 participants were with cleft palate and 23 were participants without cleft palate. Twenty-nine participants with CLP in the age range of 7 to 15 years had undergone pharyngeal flap surgery. Nasalance measures were obtained for all these subjects using Nasometer II. The Nasometer as a screening tool was evaluated by measuring the sensitivity, specificity, and efficiency by using predictive analysis. The results of their study indicated good correlation between the nasalance values with the perceived listener judgments of hypernasality for the nonflap subjects. A sensitivity coefficient of 0.87 and a specificity coefficient of 0.93 were obtained for normal subjects. The efficiency of Nasometry was poorer for the flap subjects. The correspondence of nasalance values with the hyponasality was good in participants without cleft when the nasalance cut-off score of 50 was used. The classifications based on nasometry were in good correspondence with the perceptual judgments. The nasometry findings need to be in accordance with the perceptual ratings of nasality for a better assessment protocol to be established. In this regard, the following studies includes review on correlation of nasometry with perceptual evaluation.

Watterson, McFarlane and Wright (1993) evaluated correlation of nasalance values with the judgments of nasality in 25 children with repaired CLP in the age range of 3 – 14 years. They used different stimulus such as nonnasal passage which contained no nasal phonemes, the standard passage with 10% occurrence of nasal phonemes, and the nasal passage which approximately contained 35% of nasal phonemes. The results of their study indicated significant but modest correlation between judgments of nasality and measures of nasalance for the passage without nasal consonants (r = 0.49), but non-significant correlations for both the standard passage consisting of balanced number of nasal and oral consonants (r=0.24), and the nasal passage predominantly nasal consonants (r=0.20). The study concluded that significant correlation of mean nasalance with the perceived nasality was obtained only for the speech stimulus consisted of oral consonants. The outcome of the study varied based on the stimulus used in the study. The nasalance scores will be high if the stimulus includes nasal phonemes (Watterson, Hinton, & McFarlane, 1996) and high vowels (Galvao, 1998; Lewis, Watterson, & Quint, 2000; Kendrick, 2004).

In a similar study, Keuning et al (2002) correlated nasalance values and perceived nasality in 43 individuals (26 male &17 female) in the age range of 4 to 83 years with VPD. The perceptual rating was carried out by six experienced speech language pathologists for overall grade of severity, hypernasality, audible nasal emission, misarticulations associated with VPD and speech intelligibility. The stimulus they included for their study was two passages, one with normal distribution of phonemes in

Dutch language (11.67 % of phonemes were nasal) and another passage was free of nasal consonants (denasal text). The nasalance values were obtained using Nasometer model 6200. The results revealed that the correlation coefficient between the mean nasalance and the perceptual rating of hypernasality ranged among judges from 0.31 to 0.56 for nasal text speech samples and 0.36 to 0.60 for denasal text speech samples. There was poor correlation between nasalance values and perceived nasality. They attributed the poor correlation to the lack of expertise of SLP's in the area of perceptual analysis and Nasometry. The fairly low correlation coefficient between nasalance and perceptual rating may also be the result of random errors in measures and ratings. They noted that nasometer computes the nasalance from the difference in the oral-nasal intensity at 500 Hz (6 ± 150 Hz; Fletcher et al., 1989). The acoustic effects of hypernasality are not restricted to this frequency range (Watterson et al., 1993). Thus, the nasalance score does not include all of the acoustic information that is available to the listeners and may characterize only a part of the phenomenon of hypernasal speech. They concluded that nasometry procedure should not be used as a substitute for perceptual analysis; rather it has to be carefully incorporated into the series of assessment protocols along with perceptual analysis.

Sweeney and Sell (2008) conducted a study to evaluate the relationship between perceptual assessment and acoustic measurements of nasality using controlled speech stimuli. Fifty children with nasality in the age range of 4 to 15 years with mean age of nine year five months were assessed using the Temple Street Scale and nasalance values were obtained for specified speech samples using the Nasometer Model 6200. The relationship between the perceptual ratings and the Nasometry results were evaluated using correlation analysis, test sensitivity, specificity and overall efficiency. The results revealed that sensitivity of the Nasometer ranged from 0.83 to 0.88 and its specificity ranged from 0.78 to 0.95, while its overall efficiency was between 0.82 and 0.92. The study concluded reporting a strong relationship between perceptual and acoustics assessment of nasality.

However, there are discrepancies across studies on the correlation of speech based on nasalance values with perceptual judgments of nasality (Bressmann, Sader, Whitehill, Awan, Zeilhofer, & Horch, 2000). The discrepancy was attributed to the wide range of nasality exhibited by the normal speakers which makes the judges difficult to rate the perceived nasality.

To overcome this limitation, Bressmann et al (2000) proposed two new simple measures derived from mean nasalance data. Those are nasalance distance (range between maximum and minimum nasalance) and nasalance ratio (minimum nasalance divided by maximum nasalance). Their preliminary study included 133 individuals with cleft palate in the age range of 10 years to 66 years with mean age of 17 years. Among these 87 were male and 46 were females. The nasalance values were measured using Nasal view system. The nasalance ratio and distance were measured for non nasal and nasal sentences in children with marked hypernasality and borderline hypernasality. The individuals were classified based on perceived severity of hypernasality in spontaneous speech sample by a speech language pathologist. The results of their study revealed that, for the sentence stimuli sensitivity and specificity of derived measures in correspondence with perceived classification ranged from 64.4% to 89.6% and from 91.2% to 94.1% respectively. The study concluded that the proposed two new measurements can be used for routine clinical examinations. However, their preliminary study did not explore the effect of gender on nasalance distance and ratio.

The effect of gender on the nasalance distance and ratio was explored by Sweeney, Grimaldi, Upheber, Kramer and Dempf (2004) who conducted a study on 125 German-speaking individuals (51 females and 74 males) with CLP with a mean age of 14 years. The aim of the study was to measure nasalance values in various individuals with different types of repaired CLP and to compare the nasalance distance and ratio measures across the gender. Among these individuals 18 had unilateral cleft lip, 66 were with complete unilateral CLP, 25 with isolated cleft palate, and 16 with complete CLP. The nasalance measures were evaluated by using modified Heidelberg Rhinophonia Assessment Form in Nasal View. The nasalance distance and ratio were computed for oral and nasal sentences and oro-nasal reading passages. The results indicated no significant differences in nasalance distance and ratio in relation with gender. Hence, the study concluded the derived measures are not affected by the gender.

The nasalance values varies with respect to the language and dialect (Seaver, Dalston, Leeper, & Adams, 1991; Leeper, Rochet, & Mackay, 1992; Nichols, 1999; Van Lierde, Van Borsel, Moerman, & van Cauwenberge, 2002) or gender (Van Lierde, Wuyts, De Bodt, & Van Cauwenberge, 2001; Prathanee, Thanaviratananich, Pongjunyakul, & Rengpatanakij, 2003) and age (Haapanen, 1991; Van Lierde et al., 2003; Hirschberg, Bok, Juhasz, Trenovszki, Votisky, & Hirschberg, 2006). However, the contradictory findings also indicate no differences with regard to dialect, gender or age as reported by few researchers (Kavanagh, Fee, Kalinowski, Doyle, & Leeper, 1994; Van Doorn & Purcell, 1998; Nichols, 1999; Sweeney et al., 2004; Mishima, Sugii, Yamada, Imura, & Sugahara, 2007). the various studies, it was found that the nasalance measures of speech provided a better understanding about nasality parameters; it was recommended by various authors that the perceptual evaluation has to be included in the assessment to give immaculate understanding of cleft palate speech.

***One third octave spectral analysis and VLHR***

The spectrographic analysis (Fant, 1970) is one of the objective measures of speech. The spectrographic analysis has been used to explore the spectral and temporal parameters of speech of individuals with CLP (Beddor & Hawkins, 1990; Kataoka, 1996; 2001; Vogel, 2009; Gopi Sankar & Pushpavathi, 2014). However, there are other acoustic measures which are not explored much. The other salient acoustic parameters such as one third octave analysis and VLHR are not studied extensively in these children, but these parameters are considered as potential parameters for differentiating hypernasality from normal speech. The following section highlights the available review on these parameters.

The acoustic analysis of speech signal provides the graphical representation of speech in terms of spectrograms. The spectrum provides information relating to the energy spread over frequencies in a given interval of time. The horizontal axis in the spectrogram provides information regarding time and vertical axis regarding the frequency components of speech signal analyzed. The degree of darkness over the spectrogram refers to the energy component in speech signals. The spectrographic analysis of nasal speech indicated predominant energy at low frequencies, spectral prominence around 1000Hz, broadened formant bandwidth, and additional spectral peaks between the formants. The formants, voice onset time, burst duration and various temporal characteristics were analyzed in children with CLP (Glass, 1984; Vasanthi, 1999; Gamiz, Calle, Amador & Mendoza, 2006). 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 acoustic analysis of speech indicated increased peak amplitudes around first formant region in speech of children with repaired CLP (Dickson, 1962; Fant, 1970; Kent, Liss, & Philips, 1989). Kataoka (1988) investigated the variations in spectral amplitude at one third octave frequency bands. The researcher selected this particular bandwidth conferring with the fact that the critical band of frequencies used by human ear in analyzing speech (Pols, Vander Kamp, & Plomp, 1969). Kataoka, Michi, Okabe, Miura, and Yoshida (1996) conducted a preliminary study on assessing 17 typically developing children and 16 children with hypernasality in the range of 5-15 years using one-third-octave spectra analysis. The investigators obtained power spectra from children's production of Japanese vowel /i/. The spontaneous speech sample was also recorded for perceptual analysis. The spectral amplitudes at the frequency bands of every one third of an octave were evaluated. They also recruited 20 (8 Maxillofacial surgeons and 12 Engineering students) judges to rate the sample for perceptual analysis. The judges were provided with 5 point interval scale with 0 as normal and 4 as severe hypernasality. The results revealed an increase in power level between the first and second formant, and a reduction in the power level of second and third formant regions among the utterances judged to be hypernasal. The intra judge reliability measures ranged from 0.80 to 0.94 for perceptual analysis task. The authors concluded that there was a high correlation between the perceptual ratings and the $1/3^{rd}$ octave spectra analysis.

They attributed these findings to the physical properties of the nasal cavities and oronasal coupling. They also noted that the physical properties of the nasal chamber would have an influence over formants and antiformants. They inferred that this noninvasive procedure can be used in routine clinical use as there was a good correlation between the perceptual and the one third octave analysis method.

However, the variations in judgments for the one third spectral analyses cannot be overruled. This variability needs to be examined for reliability purposes. The examiners were also keen to investigate the variations in the spectra leading to the unreliable judgments or inconsistent responses from the judges. One such research study was carried out by Kataoka, Zajac, Mayo, Lutz, and Warren (2001) who investigated the variations in listener's perception of vowel / I / based on the acoustic and perceptual factors of speech. The study included 22 children with CLP and 6 children without CLP. The age range of the children selected for their study was 5 to 16 years, with a mean age of 9 years. The speech samples were divided into two groups based on 10 listeners ratings; the group 1 (n=14) that received variable ratings among listeners or inconsistent ratings from each listener (i.e., unreliable ratings) and the group 2 (n=14) that received similar ratings among listeners and consistent ratings from each listener (i.e., reliable ratings). These two groups were subjected for perceptual evaluation (3 experienced judges in first group, 7 speech pathology graduate students in another group) using 5-point equal appearing interval scale for voice quality and hypernasality. The frequencies ranging from 250 Hz to 8 kHz were subjected to the 1/3rd octave spectra analysis. The results of their study indicated reliable and consistent ratings in perceptual evaluation indicating significant spectral change (greater than 20 dB in the spectral component of Fn between F1 and F2) in majority of the subjects. Based on the findings of their study, they concluded that in the speech of CLP the first segment should be perceived as more hypernasal followed by the middle and the last segments. They also noted that the deviated spectral change and voice quality can influence severity of the perceived hypernasality.

Kataoka, Warren, Zajac, Mayo, and Lutz (2001) conducted a study to examine the influence of acoustic characteristics on listener's perception of hypernasality in vowel /i/. The study included five preschool children without CLP and 32 children with cleft palate. Spontaneous speech of these children was rated for perceived hypernasality by four experienced speech language pathologists on six point equal appearing interval scale. When the average 1/3-octave spectra from the hypernasal group and the normal resonance group were compared, spectral characteristics of hypernasality revealed an increase in amplitudes between $F_1$ and $F_2$ and decreased amplitudes in the region of $F_2$. Based on the findings, 36 speech samples with manipulated spectral characteristics were used to minimize the influence of voice source characteristics of perceived hypernasality. The results revealed a high correlation (r=0.84) between the amplitudes of $1/3^{rd}$ octave bands (1k, 1.6k, & 2.5 kHz) and the perceptual ratings. Increased amplitudes of bands between $F_1$ and $F_2$ (1 k & 1.6 kHz) and decreased amplitude of the band of $F_2$ (2.5 kHz) was associated with an increasing perceived hypernasality. The authors concluded that the amplitude of the three 1/3-octave bands is appropriate acoustic parameters to quantify hypernasality in the isolated vowel /i/.

Weerasinghe, Sato, and Kawaguchi, (2006) examined the characteristics of spectrum of hypernasality in relation to formant amplitudes for the vowel /a/ for children with repaired CLP and the relationship of hypernasality with other acoustic parameters. They selected 53 children with repaired cleft palate who were divided into two groups, based on perceptual speech rating: moderate to severe hypernasality (n = 33) and mild hypernasality (n = 20). The control group comprised 20 children without cleft palate. The sound segments /ka/ containing the vowel 'a' were recorded, digitized, and analyzed to identify formant pattern, breathiness values, and amplitudes for one-third octave band frequency spectra using computer software for their study. The results of their study revealed differences in frequency values obtained between the hypernasal groups and normal children for the fundamental frequency (F0) and formants F1 and F2 were not statistically significant. The significant differences in breathiness values were obtained for children with moderate to severe hypernasality and those with mild hypernasality compared with normal children. The spectral analysis revealed an increase in amplitudes in frequency bands between F1 and F2 and spectral dips at 630 to 800 Hz band and at F2 with an additional Fn peak at 800 to 1000 Hz band in subjects with moderate to severe hypernasality. They concluded that the formant amplitude measurement using one-third octave frequency band spectral analysis revealed characteristic features for the hypernasal vowel 'a' as an increase in amplitudes in some frequency bands and an additional spectral peak Fn between F1 and F2.

Along with this method ($1/3^{rd}$ octave spectra analysis) Lee, Yang, and Kuo (2003) introduced voice low tone to high tone ratio (VLHR) a new quantitative index based on voice spectrum analysis to evaluate nasal obstruction. VLHR is defined as the division of low frequency power (LFP) into high frequency power (HFP) of the sound power spectrum and was expressed in decibels (Lee et al., 2003). The cut-off frequency to divide high and low frequencies was calculated by multiplying fundamental frequency ($F_0$) with square root of (4x5). Lee, Wang, Yang, and Kuo (2006) conducted a study to estimate correlation of VLHR with the nasalance measures. The voice spectrum is divided into low-frequency power (LFP) and high-frequency power (HFP) by a specific cut-off frequency (600 Hz). Voice signals of the sustained vowel /a:/ and its nasalization in 8 participants (3 females and 5 males) in the age range of 35-55 years with hypernasality were collected for analysis of nasalance and VLHR. The correlation of VLHR with nasalance scores was significant ($r = 0.76$, $p < 0.01$). The simultaneous recordings of nasal airflow temperature with a thermostat and voice signals in another eight healthy participants showed a significant correlation between temperature, rate of nasal airflow, and VLHR ($r=0.76$, $p<0.01$). The authors concluded that VLHR is a potential quantitative index of hypernasal speech and can be applied in either basic or clinical studies.

Lee, Wang, Yang, and Kuo (2006) reported that hypernasality is usually associated with various speech disorders and it can potentially affect speech intelligibility. A recently developed quantitative index called voice low tone to high tone ratio (VLHR) was used to estimate nasalization. The voice spectrum is divided into low-frequency power (LFP) and high-frequency power (HFP) by a specific cutoff frequency

(600 Hz). VLHR is defined as the division of LFP into HFP and is expressed in decibels. Voice signals of the sustained vowel [a:] and its nasalization in eight subjects with hypernasality was collected for analysis of nasalance and VLHR. The correlation of VLHR with nasalance scores was significant ($r=0.76$, $p<0.01$), and so was the correlation between VLHR and perceptual hypernasality scores ($r=0.80$, $p<0.01$). The simultaneous recordings of nasal airflow temperature with a thermistor and voice signals in another 8 healthy subjects showed a significant correlation between temperature rate of nasal airflow and VLHR ($r=0.76$, $p<0.01$), as well. The authors concluded that VLHR may become a potential quantitative index of hypernasal speech and can be applied in either basic or clinical studies.

The 1/3$^{rd}$ octave spectra analysis and VLHR were used to objectively measure the hypernasality using the voice spectrum. Vogel, Ibrahim, Reilly and Kilpatrick (2009) compared these (1/3$^{rd}$ octave spectra analysis and voice low tone to high tone ratio) two quantitative acoustic measures of nasality in children with CLP and healthy controls. Fifty participants (23 children with CLP and 27 age and gender matched healthy controls) aged ranged between 4 to 12 years produced a variety of high and low vowels. They were rated for severity of nasality exhibited in speech using perceptual ratings and acoustic analysis was performed to find the spectral changes across the children. Two objective measures of nasality 1/3$^{rd}$ octave spectra analysis and the voice low tone high tone ratio were used in acoustic analysis. The results revealed that only 1/3$^{rd}$ octave spectra analysis differentiated between participants with hypernasal speech and those perceived to have normal nasal resonance. Significant differences were also observed between varying levels of perceived severity of vowels within nonnasalized phonemic environments in the contexts of /pIt/ and /tIp/. The authors concluded that perceptual judgments remain the primary means of evaluating levels of nasality in children with CLP. However, the development and validation of easy-to-use objective techniques remains an important goal for effective clinical and empirical practice.

The review of literature has shown that there are significant correlations between VLHR and nasalance and hypernasality ratings in vowels (Tsai, Wang, & Lee, 2012).

The correlation was investigated in their study by using connected speech material. The Zoo Passage, the Rainbow Passage, the English nasal Sentences, the Mandarin nonnasal sentences, and the Mandarin nasal sentences were used to acquire VLHRs, nasalance scores, and perceptual judgments of nasality. The passages were recorded twice for averaging, and the cut-off frequencies from 200 Hz to 1200 Hz were used to survey for the presence of optimal correlations with VLHR. They selected 10 native Mandarin speakers with an English learning history of over 8 years for their study. The age range of the subjects selected for their study was 22 to 24 years. The findings of their study revealed significant correlations of VLHR with nasalance (rho = .76, p, .001, Spearman rank correlation) and nasality ratings (rho = .81, p, .001) using a cut-off frequency of 300 Hz for the English passages. They noted that, for the Mandarin sentences, the optimal correlations of VLHR with nasalance (rho = .83, p, .001) and nasality ratings (rho = .79, p, .001) were identified using a cut-off frequency of 500 Hz. They concluded that the significant correlations of VLHR with nasalance and perceptual ratings of nasality using connected speech showed that these approaches have a potential value in terms of basic and clinical application. The one third octave spectral analysis and voice low tone high tone ratio are proved to be potential parameters to use as diagnostic protocols in children with CLP. Hence the present study considered these parameters in the construction of NSI.

***Perturbation Measures (Jitter and Shimmer)***

The children with CLP do exhibit voice disorders. They exhibit hoarseness, strained, tensed voice quality, variations in pitch, restricted range of pitch and loudness (Hess, 1959; Bzoch, 1965; D'Antonio, Muntz, Province, & Marish, 1988). It has been reported by Warren, Wood & Bradley (1969) that increased respiratory effort can lead to vocal abuse which is most often seen in children with VPD, wherein they increase respiratory effort in order to build adequate intraoral pressure. Moreover, they need extra effort to attain normal intensity level due to acoustic damping in the nasal tract (Curtis, 1968). Specifically, it was noted that for nasalized vowels opening phase was reduced due to altered vocal cord vibrations as reported by Hamlet (1973). The authors attributed the results to the increased force during vocal fold adduction without vocal effort in the presence of nasalization. Leder and Lerman (1985) also reported that children and adults with hypernasal speech exhibited inappropriate vocal cord adduction and voicing during the production of voiceless stop plosives. They speculated that transglottal pressure changes due to inadequate velopharyngeal function are facilitating the phonation. They tend to reduce nasal air emission by performing inappropriate voice changes.

Altered vocal cord vibrations are nothing but perturbations which are defined as cycle-to-cycle variation in fundamental frequency (jitter) and amplitude (shimmer). The various research studies (Hamlet, 1973; Leder & Lerman, 1985) evaluated variations in vocal fold vibratory patterns in terms of changes in acoustic properties during speech production. The voice perturbations are one of the frequently used acoustic measures in objective analysis of speech parameters. Zajac and Linville (1989) conducted a study on 10 children with VPD to investigate the voice perturbations of children in the age range of 8 to 12 years with perceived nasality and hoarseness. The speech samples considered were steady state vowels /i/, /a/, and /u/. The sentences dominated with nasal and oral consonants were recorded. The electroglottograph was used to derive the perturbation measures of the speech stimuli. The study required three SLP's to rate on perceived nasality on a seven point equal interval rating scale. The findings of their study indicated that jitter values were significantly greater in children with VPD than children without VPD. The study concluded that increased jitter measures are evident in children exhibiting hypernasality.

Lewis, Andreassen, Leeper, Macrae, and Thomas (1993) evaluated the voice characteristics in children with CLP and associated VPD. The study included 27 children with CLP in the age range of 4 to 16 years and control group. They evaluated the perturbation measures (jitter and shimmer) using a computerized software for voice analysis. The results of their study indicated significantly increased jitter and shimmer measures in the voice samples of children with CLP than the controls. The authors concluded that presence of velopharyngeal incompetence can vary the laryngeal physiology which can further lead to increased perturbations in voice.

To investigate variations in voice quality in individuals with CLP Van Lierde et al (2003) conducted a study aiming to see the gender differences in voice quality among children with CLP. As a part of the study they measured the Dysphonia Severity Index (DSI) in 28 children in the age range of 8.1 to 12.6 with mean age of 9.6 having unilateral/bilateral cleft lip/palate and compared them with controls. As a part of DSI calculation, jitter was evaluated using *Multi Dimensional Voice Program* (MDVP). The results of the study indicated increased jitter percentage in children with CLP than participants without cleft lip and palate. The researchers correlated the increased jitter percentage with the findings of the previous studies (Leder & Lerman, 1985; Brooks & Shelton, 1963; McWilliams, Lavorato, & Bluestone, 1973; D'Antonio et al., 1988) indicating the presence of hoarseness and roughness in the voice of children with CLP.

Gopikishore, Deepa Anand and Arsha (2014) examined the acoustic characteristics as a part of their study on 30 children with RCLP in the age range of 4-14 years. Their study also included 40 typically developing as control group. They assessed many acoustic parameters like DSI, MPD, Jitter % and cepstral analysis was also done. The participants of their study were asked to phonate vowel /a/ at their comfortable pitch and loudness for analysis of the above mentioned acoustic parameters. The results of their study indicated that jitter % was found to be higher in children with CLP than compared to the control group. Their findings were also in accordance with the findings of Zajac and Linville (1989), Lewis, et al (1993), and Van Lierde et al (2003). The reviewed studies convene that perturbation measures also play a key role in assessing speech parameters in children with CLP.

### 2.2.2 Aerodynamic Measures of Speech

Speech is considered as the product of coordination of respiratory laryngeal and phonatory systems. In order to understand the speech characteristics in children with CLP it is essential to explore the dynamics of aerodynamic aspects in children with CLP. However, considerable attention has not been given in understanding the aerodynamic investigation in children with CLP. The below mentioned studies have considered the aerodynamic parameter as one of the potential parameter in differentiating the hypernasality from normal resonance.

Aerodynamic parameters are influenced by a number of anatomical features and physiological events, such as the driving pressure arising from the respiratory system, the constriction, size and timing of movements of the vocal cords, together with the size, shape and biomechanical properties of the vocal tract as a whole (Miller & Daniloff, 1993). When the aerodynamic properties are affected, it has an impact on different subsystems responsible for speech production. The result of that impact will be manifested in terms of hypernasality, nasal air emission, breathy voice, etc.

***Nasal air emissions***

The individuals with VPD generally exhibit nasal air emissions, hypernasality, weak pressure consonants, and of compensatory articulations (Trost, 1981). Nasal air emission is indicated with various terminologies in the literature (Trost, 1981) such as nasal “hisses”, “snort” and “rustles” etc. McWilliams et al. (1990) described perception of various types of nasal emissions as a continuum of perceptual phenomenon ranging from inaudible to audible and turbulent. The nasal air emission is described as “extra” noise associated with intranasal resistance downstream of the velopharyngeal portal.

Most often the nasal air emission is usually associated with VPD and evaluated based on auditory perceptual rating scale. However the ability to successfully detect the abnormal function of velopharyngeal port require considerable amount of expertise in perception. Hence, most of the researchers suggest complementing auditory perceptual evaluation with objective measures. In such situations the ability to quickly and accurately screen for VPD has colossal importance. This in turn can play a crucial role in coordinating with SLP’s or other health care professionals for timely intervention.

Various VPD screening assessment modalities exist. However, they are limited to the extent of resources available, time consumption, and clinical expertise. Especially when screening preschoolers or toddlers in a school setting for various speech, language, voice, resonance and hearing disorders, there is a need for an easy to use screening tool.

The mirror fogging test can be used as a screener for VPD as it provides highly sensitive and specific information regarding VPD (Van Lierde et al 2007; Bettens, Wuyts, Graef, Verhegge, & Van Lierde 2013). The administration of this test requires placing a small mirror below the columella above the upper lip while pressure consonants were produced. During the production of pressure consonants the release of the oral consonants is only possible with the presence of high pressure in the oral cavity. If the mirror placed below the nostrils indicates condensation on the mirror due to nasal air leakage, it implies presence of VPD.

The nasal patency has been measured by some researchers using Glatzel mirror to measure the nasal patency. The presence of nasal airflow gets reflected as condensation on the mirror during the production of speech. Brescovici and Roithmann (2008) used Glatzel Mirror (GM) to verify the reproducibility and the correlation between the intra-subject condensation area and subjective perception of nasal patency. Twenty five adults with mean age of 31 years (22-47 years) were evaluated with the GM for five consecutive minutes, every half an hour for 4 hours; every day, beginning in the early afternoon, every five consecutive weeks. A visual analogue scale was used to evaluate nasal patency perception in all periods. The findings of their study have shown that correlation coefficient (right + left areas) found between the condensation area and the subjective perception was $r = 0.04$ ($p = 0.37$). On the left side it was $r = 0.08$ ($p = 0.09$) and on the right side $r = 0.05$ ($p = 0.28$). The mean unilateral variation coefficient was less than 15% and the total was less than 12%, regardless of the time period interval between test and re-test. The author concluded that significant correlation between the subjective perception of breathing and the condensation area was observed. Their findings also revealed that unilateral variability was higher than the total (right + left area) and the test variability was the same between the different time periods of measurements.

However, contradicting findings to the above mentioned studies have been reported by Pochat et al (2012) who used Glatzel mirror in objective evaluation of nasal airflow. The aim of the study was to investigate the nasal patency before and after rhinoplasty in 20 adults (14 females & 6 males) without CLP by using subjective and objective evaluation. The efficacy of the surgery was evaluated by using questionnaire focusing on the functional results of the surgery along with the objective evaluation is by using Glatzel mirror test. The pre and post operative subjective and objective data was correlated. The results indicated statistically significant difference between pre and post operative scores based on subjective analysis i.e., questionnaire. Statistically significant differences were not obtained in the nasal airflow measures based on Glatzel mirror values. Also there was no significant correlation between subjective and objective measures. Hence based on the findings, they concluded that, use of Glatzel mirror is lacking in determining the patient reported improvements in breathing following rhinoplasty, which suggested that Glatzel mirror is a less sensitive tool in detecting small post surgical changes in nasal airways.

Van Lierde, Wuyts, Bonte, and Cauwenberge (2007) used Glatzel mirror effectively to evaluate the nasal emissions based on the condensation on the mirror in children with CLP. The study included 21 children in the age range of 5.4 to 16.3 years, with a mean age of 11 years and a control group of 25 typically developing children. The nasal emissions during the production of vowel /a/ were evaluated using Glatzel mirror. The study reported significant differences in the amount of condensation exhibited by children with CLP from controls. The results were attributed to the presence of inappropriate movements of velum in terms of degree or timing resulting in nasal air escape through nasal passage during the oral sound productions. Hence they concluded that the Glatzel mirror can be used to evaluate the presence of nasal emissions in children with CLP.

In another study by Bettens et al (2013) evaluated the effect of age and gender on nasal emissions in 74 children (37 boys and 37 girls) without CLP in the age range between 4-12 years (mean age-8 years) was investigated. The Glatzel mirror was held under the nose of the subject to visualize nasality in the form of condensation and children were instructed to phonate vowel /a/. The degree of condensation is rated in terms of 0-4 rating scale, where 0 represents no condensation and 4 indicating severe condensation on the mirror. The results of the present study indicated no condensation in

71 children and light condensation in three children. Hence the age and gender effect could not be determined or compared statistically. The findings of the study revealed no condensation in majority (71) of the children and the examiners negated the influence of temperature, air moisture and tilting errors on amount of condensation. These results were in contradiction to the study by Foy (1910) who indicated the effect of environmental variables on the amount of condensation on Glatzel mirror. This has developed keen interest in researchers to explore the contribution of mirror fogging test in evaluation of VPD.

Chow, Brandt, Dworschak-Stokan, Doyle, Matic and Husein (2015) evaluated the validity of mirror fogging test as a screening tool for VPD by comparing with auditory perceptual assessment and Nasometry. Their study included 60 participants, 40 of who were reported to exhibit VPD and the remaining were tested negative for VPD with a mean age of 10 years. The VPD positive group (19 males; 21 females) and non VPD (16 males; 4 females) were subjected to mirror fogging test during production of words “mommy” (nasal word) and “puppy” (oral word). The mirror was placed under the nostrils and presence of fogging was considered as positive for VPD and absence was considered as negative for VPD. The perceptual assessment was performed for single words, syllables, sentences, automatic speech and conversational speech. The score above 1 was considered as positive for VPD. The scoring was performed on a 6-point rating scale indicating 1 as normal and 6 as severe for hypernasality, hyponasality, audible nasal emission, articulatory proficiency and overall intelligibility. Nasometry was performed using the Simplified Nasometric Assessment Procedures – Revised (SNAP-R) test -2005. The scoring above normative values of nasalance were considered as a positive result indicative of VPD. The results indicated sensitivity and specificity of nasometry as 0.95 and 0.90 respectively. The sensitivity and specificity of the mirror – fogging test was 0.95. The study reported that the group which was tested positive for mirror fogging test was exhibiting significantly increased auditory perceptual scores on hypernasality. The study concluded that mirror fogging test can be a complimentary addition to the variety of clinical examinations such as nasometry and auditory perceptual speech assessments. The mirror fogging test can only act as an indicator to detect nasal air emission.

However, there are other aerodynamic parameters which provide information about the respiratory support required to build up adequate oral pressure.

### *Maximum Phonation Duration*

Maximum phonation duration (MPD) is a common assessment procedure of speech disorders. The specific contributions of the respiratory and phonatory components of the speech-production mechanism can be determined by this parameter. MPD is the maximum time (in seconds) for which a person can sustain a vowel sound when produced on one deep breath at a relatively comfortable pitch and loudness. It is a simple test used to measure glottic efficiency. Children with CLP tend to exhibit hoarseness, breathiness, tense and strained voice with variations in pitch and loudness (Zajac & Linville, 1987) and are also reported to have vocal nodules or polyps (McWilliams Bluestone, & Musgrave, 1969).

The individuals exhibiting normal or disordered laryngeal mechanism might exhibit reduced maximum phonation duration (Tait, Michel & Carpenter, 1980). The children with CLP are unable to use the air supplied efficiently in the presence of VPD leading to shorter than the expected phonation duration. The MPD can be a simple measure of glottic efficiency. The maximum phonation duration time is defined as maximum duration for which an individual can sustain phonation on one single deep breath at relatively comfortable pitch and loudness (Arnold, 1958). MPD provides the information about the coordination of laryngeal system with the respiratory system. This also indicates the ability to maintain continuous speech by the individual. The studies based on MPD are often conducted in typically developing children and adults. However, limited studies were conducted in children with CLP.

Van Lierde, Claeys, Bodt, and Van Cauwenberge (2004) investigated maximum phonation duration as a part of study conducted to evaluate the vocal quality by measuring Dysphonia Severity Index in 28 children with CLP in the age range of 8 to 12 years. Maximum phonation duration of vowel /a/ was evaluated across the children with CLP. The results indicated differences in MPD measures of CLP (12.4 sec) with the normative data (18.9 sec). The reduced MPD in children with CLP was attributed to the loss of intraoral pressure even in the presence of increased respiratory effort due to the presence of VPD. However, as the standard deviation in both the groups is around 6.5 sec the differences in MPD across the groups were not statistically significant.

Van Lierde, Wuyts, Bonte, and Van Cauwenberge (2007) evaluated MPD for the production of /s/ across 21 children with CLP in the age range of 5.4 to 16.3 years (15 boys and 6 girls) with a mean age of 11 years and 25 without cleft palate with a mean age of 10.8 years (range 6.8-15.8 years; 15 boys and 10 girls). The study results indicated significant differences (reduced duration in children with CLP) in the maximum duration for the production of /s/ across children with CLP and TDC. The obtained results were attributed to the presence of phoneme- specific velopharyngeal gap in children with CLP during the production of /s/. These results were contradicting to Van Lierde et al (2004) and the authors attributed to the change in the stimuli used for measuring the maximum phonation duration. As children with CLP will have great difficulty in sustaining the production of /s/ than vowel /a/ due to the differences in the complex articulatory constriction and regulation of respiratory air during production.

Bettens et al (2013) studied the maximum duration of /s/ production in children without CLP across the age and gender as a part of large study. Their study included 37 boys and 37 girls in the age range of 4 years to 12 years with a mean age of 8years. The maximum duration for production of /s/ phoneme was determined for 3 times by prolonging the phoneme /s/ in sitting position. The results of the study indicated significant effect of age and no effect of gender on maximum duration of phoneme /s/. The results were attribute to the increase in size, surface and shape of infraglottic and supraglottic resonating structures and cavities with age, but there till puberty these structural changes are very limited between boys and girls. Hence, there was no effect of gender on the maximum duration of /s/ production.

Another study by Gnanavel, Satish, and Pushpavathi (2013) investigated the maximum phonation duration for vowel /a/ in 12 children (6 females and 6 males) with VPD in the age range of 7-12 years. The MPD was recorded using adobe audition software and longest phonation of vowel /a/ among three trails were considered for analysis. The results of the study indicated significant reduced MPD by children with CLP than the established normative data. This could be due to loss of intra oral breath pressure in the presence of inefficient velopharyngeal mechanism.

The above studies provide an insight on usefulness of evaluating MPD in CLP. The studies indicating reduced MPD reveals laryngeal pathologies in children with CLP. These can further be considered with perceptual analysis and stroboscopic findings in order to arrive at conclusion. Even though there are few studies on MPD in children with CLP, the studies have considered MPD as a part of DSI and NSI. The limited studies on this parameter calls for MPD as an assessment tool in children with CLP.

***Laryngeal Aerodynamics of Speech***

In order to understand the speech characteristics it is essential to explore the dynamics of aerodynamic aspects and to correlate with other systems. The review of literature has revealed that various aerodynamic measures are used to analyze speech of individuals with CLP. Aerodynamic parameters are influenced by a number of anatomical features and physiological events, such as the driving pressure arising from the respiratory system, the constriction, size and timing of movements of the vocal cords, together with the size, shape and biomechanical properties of the vocal tract as a whole (Miller & Daniloff, 1993).

McWilliams, Bluestone, and Musgrave (1969) reported that some children with velopharyngeal inadequacy may use "generalized laryngeal tension" as a compensatory valving strategy, "even in the absence of glottal fricatives and plosives". They believed that children with borderline velopharyngeal function would be most likely to engage in this type of compensatory laryngeal activity (McWilliams, Bluestone, & Musgrave, 1969).

The laryngeal airway resistance was considered as an influenced aerodynamic measure. Zajac (1995) studied the laryngeal airway resistance (LAR) during vowel production in 10 children without cleft palate and 14 children with cleft palate and adequate velopharyngeal function, in the age range of 7 years 9 months to 11 years. The children with cleft palate were further grouped into incomplete and complete velopharyngeal closure. They were instructed to perform syllable repetition task while occluding the nostrils and targeting typical adult speech. The pressure levels while speaking were predetermined to match the normative range. The children were trained to produce /pi/ at the predetermined effort level of 6.5 to 7.5 $cmH_2O$ by using feedback techniques. The LAR was evaluated under self determined error and predetermined effort levels across all the children. The results indicated significantly increased LAR across all the children at predetermined effort levels. During the production of syllable at predetermined levels children with incomplete VP closure exhibited relatively increased LAR on unoccluding the nostrils. However, these differences were not statistically significant. Further, studies were conducted to investigate the effect of muscular effort during speech on LAR.

Guyette, Sanchez, and Smith (2000) conducted a study on thirty six children with cleft palate, ten with incomplete VP closure where the VP areas were greater than $5mm^2$ and twenty six with complete VP closure indicating VP areas less than $1mm^2$. The average age of children in incomplete closure group was 9.94 years and complete closure group was 10.03 years. They were asked to repeat /ipipipipipipipi/ at a rate of 1.5 syllables per second. The pressure flow equipment was used and airflow was detected using a pneumotach screen connected to a pressure transducer. The results indicated that laryngeal airway resistance (LAR) and transglottal pressure were significantly higher and transglottal airflow was significantly lower in individuals with cleft palate exhibiting incomplete closure. They attributed this to the velopharyngeal insufficiency which demands for increased muscular effort at the laryngeal level to compensate for the potential nasal air escape while speaking.

Gopikishore, Deepa Anand, and Arsha (2014) examined the laryngeal airway resistance as a part of their study on 30 children with RCLP. Their study also included 40 typically developing as control group. They measured the subglottal air pressure, mean airflow rate using Aeroview 1.4.4 (Glottal Enterprises, USA). The participants were asked to repeat CV syllables /pa/ 6-7 times into the circumvented mask of Aeroview at a comfortable pitch and loudness level. They ensured to obtain good wave morphology for each of the recordings done. The laryngeal aerodynamic measures were compared between the two groups by using one way MANOVA statistical measures. The Mann Whitney U test was also applied to find out gender differences in the parameters assessed. The results of their study revealed that the laryngeal airway resistance was higher in the clinical group than compared to the control group. However, the difference was not statistically significant. These findings were attributed to the compensatory mechanism taking place at the laryngeal level, where individuals with VPD use greater adductory force on their laryngeal structures. The higher laryngeal airway resistance may be due to the fact that children with cleft in order to compensate for the air leakage at the velopharyngeal port using increased muscular effort. The findings of their study was in accordance with the results of the study done by Kuehn and Moon (1995) who used electromyographic measures to examine the laryngeal airway resistance. They reported greater physiological effort for levator activities for velopharyngeal closure during speech.

The above studies have found that children with CLP exhibit variation in laryngeal aerodynamics. The influence of extent of VPD on laryngeal aerodynamics is studied by Brustello, Fukushiro, and Yamashita (2010) on children and adults exhibiting VPD. They conducted a study to explore whether individuals with marginal VPD modify the laryngeal resistance as a strategy to achieve complete velopharyngeal closure during speech. The study was conducted on nineteen individuals with cleft palate in the age from 12 to 47 years and 18 age and gender matched individuals with no abnormalities. The laryngeal resistance, intraoral air pressure, and oronasal airflow were obtained through aerodynamic analysis using PERCI-SARS (Perceptual Efficiency Ratings Computed Instantaneously-Speech Aeromechanic Research System, MicroTronics Corp., Chapel Hill, NC) system during the production of the syllable /pa/. The results indicated that the individuals with marginal velopharyngeal closure did not modify laryngeal resistance and exhibited slightly lower laryngeal resistance values than individuals without cleft. They attributed this to the variations in the oro-nasal flow, resulting from the physiological adjustments which can occur as a compensatory strategy. They also noted that individuals with marginal VPD try to maintain levels of intraoral air pressure for the stable production of speech, which may manifest in increased laryngeal airflow (Warren, 1986). The decrease in resistance at some point in the vocal tract can also result in increased airflow required to maintain the stable levels of air pressure. The above studies indicate that the aerodynamic aspects will play a vital role in describing the speech in CLP. In view of this it is essential to explore this parameter and include in construction of Nasality Severity Index.

The above review section mainly highlighted the review pertaining to different acoustic, aerodynamic, and laryngeal parameters and perceptual analysis of speech in children with CLP. These parameters have been investigated and compared across typically developing children in several studies. However, refined evaluation protocol need to be developed by including the various objective and perceptual measures.

This has led to the construction of an index by Van Lierde, Wuyts, Bonte, and Cauwenberge (2007). The nasality severity index (NSI) reflects the multidimensional nature of resonance. This index is derived from noninvasive as well as non disruptive assessment techniques of the articulatory, phonatory or resonatory processes for the overall evaluation of nasality. The objective and subjective assessment techniques were used to determine the nasalance, nasality and aerodynamic measures in 21 children (15 boys and 6 girls) with cleft palate age ranging from 5.4 to 16.3 years, with a mean age of 11 years and a control group of 25 children without cleft palate. Stepwise logistic regression was used to determine the optimal index. The NSI consists of a linear combination of four variables, where each variable has a different weight. The 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). NSI sensitivity is reported to be 88% and specificity is 95%. The clinical use of NSI has shown it to be an efficient and practical tool to describe the presence of hypernasality. The implementation of the NSI helps clinicians to quantitatively assess the severity of nasality disorders beside the perceptual judgments. The variables included in the 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.

Followed by the development of nasality severity index (NSI), Bettens, Wuyts, Graef, Verhegge, and Van Lierde (2013) attempted to evaluate the effect of age and gender on the NSI developed to evaluate nasality. The study included 74 typically developing children with equal number of boys and girls aged 4-12 years. Nasalance scores were obtained on Nasometer, maximum duration time of vowel /a/ was calculated, mirror fogging test using Glatzel mirror was performed to visualize nasality, which is represented as condensation. The NSI was calculated with the obtained measures. The results indicated significant age effect indicating increased NSI with increasing age, and there were no statistically significant differences with respect to gender differences. The study concluded that NSI varies with age but not across the gender.

However, overcoming the advantages of the NSI equation, there are some limitations. The same index cannot be generalized to individuals with other languages due to the variations in the phonetic structure of the language. The stimulus used for the construction of this index involved oral and oronasal sentences in Dutch language. The nasality severity index (Van Lierde, et al., 2007) was developed based on the data obtained in the Dutch language. The differences exist in various aspects like: number of vowels, consonants, stop consonants, fricatives and affricates, consonant cluster combinations, occurrence of sounds in different word positions, etc. the differences are tabulated in table 2. (Source: http://en.wikipedia.org/wiki/Dutch_language, & http://www.omniglot.com/writing/dutch.html).

Table 2

*Differences in Dutch and Kannada language.*

| Variable | Dutch | Kannada |
|---|---|---|
| Vowels | N= 17 | N= 11 |
| Consonants | N= 28 | N= 32 |
| Stop consonants (unaspirated) | N= 5 (/p/, /b/, /t/, /d/, /k/,/g/,/ʔ/) | N=8 (/p/, /b/, /t̥/, /d̥/, / t̪/, / d̪/, /k/, /g/) |
| Fricatives | N= 9 (/f/, /v/, /s/, /z/, /ʃ/, /ʒ/, /x/, /ɦ/, /h/, /ʁ/, /ʝ/, /ç/, /ɣ/, /ʝ/, /x/, /χ/) | N= 5 (/s/, /ʃ/, /h/, /f/, /v/) |
| Affricates | Absence of affricates. | N= 2 (/ʧ/, /ʤ/) |
| Posterior place of articulation | Uvulars (/ʁ/, /ʀ/), Glottals (/ʔ/, /ɦ/, /h/) | Not Present |

Another limitation of the study conducted by Van Lierde, et al. (2007) was considering only 5 variables (nasalance percent of oral text, Glatzel value of /a/, maximum duration time (seconds), nasalance % of /a/, nasalance percent of oronasal text) to differentiate individuals with hypernasality from TDC. Among these, three variables are just based on mean nasalance values. But as mentioned in the literature, there are other few more potential acoustic (nasalance distance, nasalance ratio, voice low tone to high tone ratio, 1/3$^{rd}$ octave analysis, jitter, and shimmer) and aerodynamic variables (subglottal pressure, mean airflow rate, & laryngeal airway resistance) that can be used to differentiate individuals with hypernasality from TDC.

Another major limitation of the study is not including equal number of children in group with cleft lip and palate based on severity of hypernasality exhibited. There was no mention regarding details of the number of children included in cleft group based on severity in the article published. On personal communication with the author it was found that only one individual with moderate hypernasal was included into the twenty one children with cleft palate. So the authors only correlated the derived NSI values with and without perception of hypernasality and commented on severity based on the trend observed across the groups. Hence could not derive any cutoff values with respect to the severity of hypernasality exhibited as there were limited number of children with cleft based on severity.

Hence, the present study attempts to construct nasality severity index that reflects the overall severity of nasality perceived based on an integration of aerodynamic and acoustic measurements in Kannada speaking children with repaired cleft lip and palate. To incorporate the perceptual nature of nasality assessment, the index is also based on perceptual severity ratings of nasality, rather than just on the differentiation between normal and hypernasal speech. So the index not only differentiates normal from hypernasal speech, but also provides information on the severity of perceived hypernasality.

# CHAPTER III

# METHOD

## 3.1 Participants

The study includes both subjective and objective measures of nasality in children with RCLP. The details of the participants for the study were obtained from the database of unit for structural orofacial anomalies (U-SOFA) and Plastic surgery unit, Vikram Hospital, Mysuru. For the purpose of data collection, 220 parents of children with RCLP were contacted through phone calls and by sending post cards. These patients were availing various diagnostic and therapeutic services at AIISH. However, 93 children with RCLP reported for follow-up. Based on the inclusion and exclusion criteria, the present study considered 70 Kannada speaking children with RCLP in the age range of four to twelve years. Various speech samples of children with RCLP were recorded and subjected to perceptual evaluation by three experienced speech language pathologists. The judges analyzed the speech sample based on perceived nasality using a standardized rating scale (detail explanation in 2.6). Based on perceptual evaluation, three children who exhibited normal nasal resonance were not considered and sixty seven children with RCLP were considered for further analysis. Based on the results obtained, the 33 children with RCLP were considered for group Ia (mild hypernasal) and 34 children with RCLP were considered under group Ib (moderate to severe hypernasal). The age and gender matched 35 typically developing children (TDC) exhibiting normal resonance were considered as group II.

### 3.1.1 Participants Selection Criteria

The following criteria's were considered for selecting the participants in the present study.

Inclusion criteria for Group I (Children with RCLP)

- The children with RCLP/ repaired cleft palate/ repaired soft palate.

- Children in the age range of four to twelve years.
- Children with Kannada as their native language.
- Children with normal cognitive and mental abilities were considered based on reports by psychologist.
- Children were screened for hearing abilities and children with less than 20 dB hearing thresholds in the poorer ear were included for the study.
- The children from lower to middle socio economic background were selected based on re-adapted version of National Institute of Mental Health (NIMH) Socioeconomic Status Scale, (Venkatesan, 2006).

Inclusion Criteria for Group II (TDC)

- Children who passed informal screening for speech and hearing disorders by a qualified SLP.
- Children with hearing sensitivity in normal limits with no middle ear pathologies.
- Children in the age range of four to twelve years
- Children with Kannada as their native language
- Children exhibiting 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 any associated syndromes, congenital heart defects or disorders based on the reports of the pediatrician or physician.
- Children with unrepaired cleft lip and palate/ cleft palate, submucous palate, facial clefts.

- Children with secondary pharyngeal surgeries.
- Children with history of frequent ear discharge, upper respiratory tract infection, disorders related to ear, throat and nose pathologies based on the reports of otorhinolaryngologist.
- Children associated with neuromotor dysfunction such as dysarthria and apraxia were not considered.
- Children attained puberty were not considered (based on appearance of secondary sexual characteristics and voice characteristics among males).

Exclusion criteria for group II

- 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

The demographic details of the participants under each group are shown in table 3.

Table 3

*Details of the participants included in the study*

| Participants | | Age (years) | | | Gender | | Socio Economic Status | | Severity of Nasality |
|---|---|---|---|---|---|---|---|---|---|
| | | Range | Mean | SD | Male | Female | Lower | Middle | |
| RCLP | Group Ia | 4 to 12 | 8.73 | 2.43 | 17 | 16 | 18 | 15 | Mild |
| | Group Ib | 5 to 11 | 9.24 | 2.35 | 15 | 19 | 18 | 16 | Moderate to Severe |
| TDC | Group II | 6 to 12 | 9.31 | 2.17 | 18 | 17 | 15 | 20 | Normal |

*Note.* RCLP = children with repaired cleft lip and palate; TDC = typically developing children, Group Ia = mild hypernasal, Group Ib = moderate to severe hypernasal, Group II = normal nasality, SD = standard deviation.

## 3.2 Ethical Consideration

This study was conducted with the clearance from AIISH Bio Behavioral Ethics Committee. A written consent from the parents/ caregivers was obtained. They were provided with information about the aim, objectives, method of the research and approximate duration of testing.

## 3.3 Procedure

The construction of multidimensional measure that reflects overall severity of perceived nasality is based on the integration of perceptual, acoustic, and aerodynamic measures of nasality. Thus the study includes both subjective and objective measures of nasality. The study was conducted in four phases as described below.

### 3.3.1 Phase 1: Evaluation of perceptual, acoustic, and aerodynamic parameters related to nasality

The first step involved was identification of acoustic and aerodynamic parameters differentiating children with hypernasality and normal nasality. The review of articles was done to identify the potential acoustic and aerodynamic parameters differentiating normal resonance from hypernasality. Hence, the review highlighted a total of 67 measures which were significant in differentiating normal from hypernasal speech. Those measures were considered for investigation in the present study. These measures were based on the results of the studies by Dalston and Warren, 1986, Zajac and Linville, 1989, Dalston, et al., 1991, Zajac, 1995, Bressmann, et al., 2000, Guyette, et al., 2000, Lee et al., 2006, Lewis, et al., 2007, Vogel et al., 2009, and Brustello et al, 2010**.** Out of 67 measures, 59 were derived from four acoustic parameters and eight parameters were derived from five aerodynamic measures. The parameters evaluated have been mentioned in the table 4. The perceptual, acoustic and aerodynamic measures were evaluated across group Ia and group Ib (children with RCLP). The acoustic and aerodynamic measures of nasality were obtained in group II (TDC). However, the perceptual evaluation of nasality was not performed to children included into group II as they exhibited normal nasality. The procedure of perceptual and instrumental analysis is discussed under two subsections.

Table 4

*Acoustic and aerodynamic measures*

| S. No. | Parameters | No. of measures extracted | Measurements |
|---|---|---|---|
| | | **Acoustic Measures** | |
| 1. | Nasalance | Seven | Nasalance measures of /a/,/i/,oral, nasal, oronasal sentences, ND, NR. |
| 2. | $1/3^{rd}$ octave spectra analysis | Forty Four | /a/, /i/, /pit/, /tip/ for 11 frequency bands between 396Hz to 4000Hz. |
| 3. | Voice Low Tone to High Tone Ratio | Four | /a/, /i/, /pit/, /tip/ |
| 4. | Jitter and shimmer | Four | Jitter of /a/ & /i/<br>shimmer of /a/ & /i/, |
| | | **Aerodynamic Measures** | |
| 5. | Nasal Emissions | Three | /a/, /i/, /s/ |
| 6. | Maximum Phonation Duration (MPD) | Two | Phonation of /a/ & /s/ |
| 7. | Subglottal Pressure (SGP) | One | Repetition of /papapapapapapapapa/ |
| 8. | Mean Airflow Rate (MAFR) | One | Repetition of /papapapapapapapapa/ |
| 9. | Laryngeal Airway Resistance (LAR) | One | Repetition of /papapapapapapapapa/ |

### *Classification of Participants with RCLP Based on Perceptual Analysis*

The purpose of perceptual evaluation is to classify the children with RCLP into different groups based on severity of nasality. The details of the procedure are as follows.

#### *Stimuli*

The spontaneous speech sample (on self-introduction, school, leisure activities and picture description) for duration of five to ten minutes and repetition of five oronasal and five oral sentences in Kannada language (Jayakumar & Pushpavathi, 2005) were considered as stimuli for the perceptual evaluation of nasality. The speech sample were audio and video recorded from all the participants. A minimum of 50 to

60 words were elicited for the analysis from the spontaneous speech sample. In case if spontaneous speech could not be elicited from participants then picture description task was used to elicit speech. The picture description task consists of eliciting words with pressure consonants (ex: playground concept - the pictures containing children playing cricket, girls playing skipping). The oronasal sentences are balanced with oral and nasal consonants whereas oral sentences dominantly consist of oral consonants. The oral and oronasal sentences were modeled by a 27 year female investigator, who could enunciate the Kannada sentences fluently.

***Recording***

The participants were seated comfortably in an upright position on a chair in a quiet room condition. The speech samples were recorded using *Sony handy cam (Model no: DCR-SR88).* The recording was done by placing the handy cam at a distance of 2 feet from the participant as shown in figure 1. The stimulus consists of spontaneous speech, oral and oronasal sentences. During the recording, the participants were instructed to speak at comfortable loudness and pitch levels. The recording of the stimuli was carried out with an inter stimulus interval of approximately 5 seconds. After completion of the entire recording, the investigator rechecked the recorded samples and saved them in the hard disk of a HP computer with Windows 7 operating system before the participant left the recording room premises.

*Figure 1:* A child seated for video recording of a speech sample.

### *Material*

The speech samples (spontaneous speech, oral sentences and oronasal sentences) elicited from participants were audio video recorded. The standardized perceptual rating scale developed by Henningsson, Kuehn, Sell, Sweeney, Trost-Cardamone, and Whitehill (2007) was used to rate the samples by three experienced SLP’s. This scale was used to achieve consistency and uniformity in reporting speech outcomes in individuals with CLP. This was developed to evaluate the characteristics of speech production in individuals with CLP regardless of the language or languages spoken. The present study used this protocol to assess the perceived nasality in speech of cleft lip and palate. The perceptual rating classifies the data onto a 4-point rating scale that reflects increasing severity of hypernasality from 0 through 3, where 0 = within normal limits (WNL), 1 = mild, 2 = moderate, 3 = severe. The description is provided in table 5 which was provided to speech language pathologists (SLP’s) who were selected as judges.

Table 5

*Severity ratings and corresponding descriptors for hypernasality*

| Severity Rating | Descriptors |
|---|---|
| 0=WNL | • Nasality does not exceed nasality heard in regional speech and there is no perceptual evidence of cleft type speech |
| 1=Mild | • Nasality exceeds regional speech nasality<br>• There is increased nasality heard on high vowels primarily<br>• There is inconsistent or intermittent increased nasality across vocalic segments<br>• Nasality is perceived as socially acceptable in most circles<br>• Patient or parent are satisfied with individual's speech resonance<br>• Speech specialist probably would not recommend physical management after instrumental assessment |
| 2=Moderate | • Hypernasality is perceived as pervasive and draws attention to itself and away from the message.<br>• There is increased nasality heard on high and low vowels<br>• Most vowels retain their identity<br>• Speech is socially unacceptable<br>• The speech specialist probably would recommend physical management after instrumental assessment |
| 3=Severe | • Hypernasality is perceived and interferes with speech understandability.<br>• There is increased nasality heard on vowels and some voiced consonants<br>• Some vowels may lose their identity<br>• Nasality is socially very unacceptable<br>• The speech specialist definitely would recommend physical management after instrumental assessment |

The first phase included classification of the participants with RCLP, the stimuli were given to three SLP's for classification. The following procedure was used for classification.

***Selection of speech samples for familiarization task***

Fifteen speech samples of children with RCLP were randomly selected and presented to three experienced SLP's in the age range of 31 to 40 years. The speech samples included were spontaneous speech, oral and oronasal sentences. The judges were instructed to rate the samples using standardized four point rating scale (0=normal, 1=mild, 2=moderate, 3=severe) proposed by Henningsson et al. (2007).

Out of these samples two samples in each severity category accounting for a total number of 8 samples, which were best agreed between the judges were finalized for familiarization task. Out of these, two normal, two mild, two moderate and two severe degree of nasality were selected for familiarization task. These reference samples were not included in the final perceptual task.

***Familiarization to judges***

The study included three SLP's for performing the perceptual evaluation of nasality across different stimuli. These three judges were fluent Kannada speakers in the age range of 28 to 32 years. These three judges were post graduate qualified SLP's. All of them were working in the area of CLP for clinical and research purpose. To familiarize the judges, prior to the actual perceptual task they were provided with eight reference speech samples depicting the severity of nasality. These samples were randomized and presented to the judges. The detail description of rating scale ranging from 0 to 3 given by Henningsson, et al., (2007) was given to the judges along with the format description mentioned in the table 3. The judges were requested to rate the speech sample for perceived nasality. The perceptual score of the judges for each speech sample was compared with the predetermined ratings given to the speech samples by the expert judges. The feedback was given to the judges to correct their errors. Once they got familiarized to perceive the severity of hypernasality indicated in these samples, then the actual samples were included into the perceptual evaluation were played for analysis.

***Procedure***

The obtained audio-visual speech samples were subjected to perceptual analysis. In order to acquire valid perceptual rating, the samples were rated by three experienced judges for perceived severity of nasality. The perceptual analysis was done separately by the three judges. The three judges were seated before a multimedia computer consisting of Intex headphones to perform the perceptual rating task after getting familiarized with the samples. The description of rating scale ranging from 0 to 3 was given to the judges and explained before performing the actual perceptual rating task. The judges were asked to listen, analyse and finally rate the samples based on severity of the nasality perceived. The speech samples were presented at comfortable listening level. The audio-visual speech samples were played thrice. The participants were grouped based on consensus in the rating obtained from any two judges for perceived nasality. The speech samples of participants rated by the judges as mild were considered as Group Ia. The speech samples of participants rated as moderate and severe were together considered as Group Ib. The details of participants with RCLP exhibiting hypernasality and TDC were as shown in Appendix A

**Instrumental Analysis**

Subsequent to the classification of the participants with RCLP, all the participants including TDC were subjected to evaluation of different types of acoustic and aerodynamic measures. The acoustic and aerodynamic measures of hypernasality are discussed in detail under subheadings a) Nasalance measures b) Perturbation measures (Jitter & Shimmer) c) Voice low tone to high tone ratio d) One third octave spectra analysis e) Nasal emission measures f) Maximum duration time, and g) Aerodynamic laryngeal analysis. These objective measures were obtained from participants of Group Ia, Group Ib and Group II.

***Acoustic Measures***

***Nasalance measure for vowel /a/, /i/, oral, nasal and oronasal sentences***

Nasalance is the objective measure of nasality derived from the ratio of nasal to nasal-plus-oral acoustic energy during speech using Nasometer. This measure was derived by calculating the proportion of the nasal energy in speech from separate measurements of nasal and oral sound pressure level from Nasometer (Fletcher, 1970, 1976).

Nasometer II 6400 as shown in figure 2 was used in the present study for obtaining mean nasalance values of speech stimuli. The Nasometer was calibrated each day by the investigator prior to the data collection according to the instructions provided by the manufacturer.

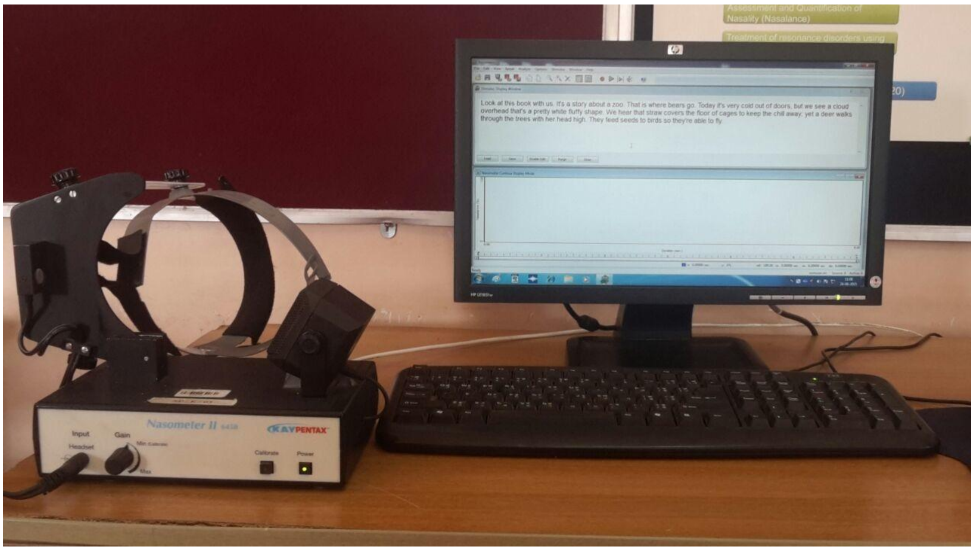


*Figure 2.* Nasometer II 6400 with screen, setupbox and headgear

Stimuli: The nasalance values of vowels (/a/ & /i/) and sentences (five oral, five nasals, & five oronasal) were considered for obtaining nasalance values. The standardized Kannada oral and nasal sentences (Jayakumar & Pushpavathi, 2005) were used for the study. The sentences were of six to ten syllables in length. The oral sentences were loaded with only oral consonants along with the vowels. The nasal sentences were loaded dominantly with nasal consonants and oronasal sentences were balanced approximately with the same percentage of oral and nasal consonants. The list of stimuli is given in the Appendix B.

Instructions: The participant was seated comfortably in an upright position. Nasometer headgear was placed on the participants and further adjusted to avoid discomfort. The placement has been shown in figure 3. The phonation of vowels (/a/ & /i/) and production of sentences were demonstrated prior to the recording session by the investigator. All the participants were instructed to phonate the vowels thrice at their comfortable vocal pitch and loudness level. The vowels were repeated thrice with an inter stimulus duration of three seconds to obtain valid nasalance measures. The sentences had to be repeated in the similar manner. The sentences were recorded only once, as the variability in the nasality measures was reported to be less if the length of the stimulus is around six syllables (Watterson, Lewis, & Foley-Homan, 1999). These samples were audio recorded in the computer using Nasometer software and saved separately for further analysis. The investigator listened to the sample before allowing the participant to leave the recording room.

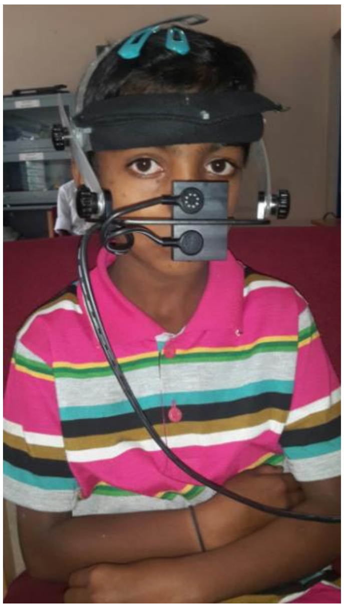

*Figure 3.* A child wearing head gear of Nasometer in upright position.

Analysis: The speech stimulus was recorded on system for analysis of nasalance. The Nasogram of the speech stimuli appears on the Nasometer screen. The part of the stimulus required for analysis was selected using cursors on the screen from onset to the offset of the stimulus as shown in figure 4. The vowels were produced thrice and the average of the nasalance measures of three productions was calculated for each vowel. The mean nasalance values of each sentence was measured and documented as shown in the figure 5. Twenty five percent of the participants were randomly selected for measuring test retest reliability. The measures were repeated again after a gap of 5 minutes in the same session on the same day without replacing the headgear and the stimuli was analyzed to obtain mean nasalance values.

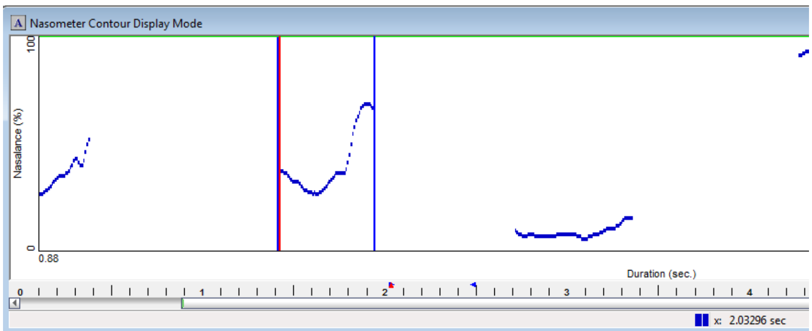


*Figure 4:* Nasogram with the cursors on onset and offset of stimuli.

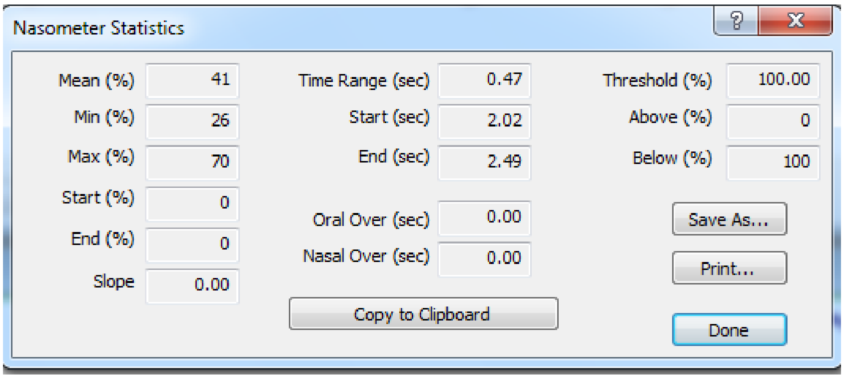


Figure 5: Mean nasalance values obtained using Nasometer

***Measuring the nasalance distance and nasalance ratio***

Another acoustic parameter considered for analysis is 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 derived from the following formulas proposed by Bressmann et al. (2000). Nasalance distance was calculated as difference between maximum nasalance and minimum nasalance. Nasalance ratio was estimated as ratio of minimum nasalance to maximum nasalance.

Procedure: The nasalance values were derived from Nasometer for oral sentences and nasal sentences as mentioned above. The mean of the nasalance values of both oral and nasal sentences were considered to obtain derived nasalance measures. The mean of nasalance values of five oral sentences and five nasal sentences was calculated to measure nasalance distance and nasalance ratio. Nasalance distance for sentences was calculated the difference between mean nasalance values of nasal sentences to mean nasalance value of oral sentences. Nasalance ratio for sentences was derived by taking the ratio of mean nasalance values of oral sentences to mean nasalance value of nasal sentences.

***One-third octave spectra analysis***

One third octave spectra analysis includes analyzing the spectral band energy at an interval of one third's of an octave from 100 Hz to 16000 Hz (Kataoka, Michi, Okabe, Miura, & Yoshida, 1996).

Instrumentation: A desktop computer was used which had windows 7 operating system. An omni-directional distortion free *I BALL* microphone was connected to the desktop. The *Praat* software was also installed in the desktop to record and edit the data required for one third octave spectra analysis. *MATLAB* software was used to obtain one third octave spectra analysis.

Stimuli: The speech sample used for evaluation of one-third octave spectral analysis was phonation of vowels /a/, /i/ and /i/ in the nonnasalized CVC contexts (/pit/ & /tip/). To analyze the one third octave spectra, vowel /i/ was used widely in the context of CVC syllables (/pit/ & /tip/). The production of /i/ in (/pit/ & /tip/) was considered to evaluate the effect of nasality on /i/ in the context of CVC.

Instructions: The participants were seated in front of a microphone in a quiet room as shown in figure 8. The investigator provided the model of stimulus production and ensured the correct production of stimulus from participants by multiple repetitions before recording. The participants were instructed to phonate steady state vowels (/a/ & /i/), and /i/ in a nonnasalized CVC contexts (/pit/ & /tip/) thrice at a comfortable pitch and loudness with an interstimulus duration of 10-15 seconds.

Procedure: Each stimulus was recorded separately using *Praat software* and the steady state portion of middle 500 millisecond section for vowels (/a/ & /i/) and 50 milliseconds of vowel /i/ in CVC syllables /pit/ and /tip/ were selected for one third octave spectra analysis. The edited stimuli was subjected to detailed analysis by using the *MATLAB 7.0 version software*, and the amplitudes at one third octave spectral intervals were obtained which are depicted in figure 6. Overall, amplitudes at 23 one-third octave bands (over a frequency range of 100–16,000 Hz) were obtained. Each average long-term RMS value of one-third octave band pass was obtained by summation and averaging components over one-third octave intervals with center frequencies ranging from 100 Hz to 16,000Hz. One third octave spectra analysis was calculated for frequency bands between 100–16,000 Hz on all samples (/a:/, /i:/, /pIt/, /tIp/). However, based on previous studies statistical analysis was performed only on those frequency bands (between 396 Hz and 4000 Hz) that had demonstrated sensitivity to hypernasality (Kataoka, Warren, Zajac, Mayo, & Lutz, 2001; Lee, Yang,

& Kuo, 2003). The frequency bands considered for analysis were 396Hz, 500Hz, 630Hz, 793Hz, 1000Hz, 1259Hz, 1587Hz, 2000Hz, 2519Hz, 3174Hz, and 4000Hz. To measure the reliability of acoustic measurements twenty five percent of the original data recorded was reanalyzed by the same investigator and compared that results with the remaining complete data used in the study.

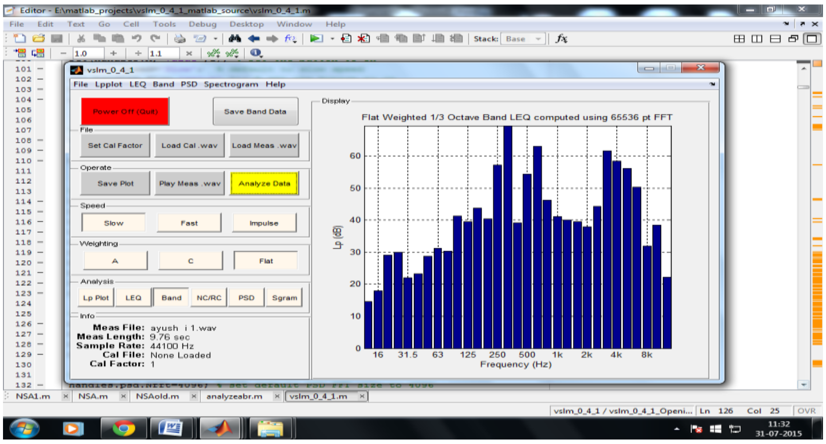


*Figure 6.* One third octave analysis of spectrum using MATLAB software.

***Voice low tone to high tone ratio (VLHR)***

VLHR was defined as the division of low-frequency power section (LFP) into high frequency power section (HFP), expressed in decibels and calculated using the equation VLHR = 10 x log10 (LFP/HFP) (Lee, Wang, Yang, & Kuo, 2006). The LFP is defined as the summation of the power from 50 Hz to 600Hz and HFP is defined as the summation of the power from 600 Hz to 8063 Hz. The voice low tone to high tone ratio measures were calculated by dividing the speech spectrum into LFP and HFP artificially with the cutoff frequency of 600 Hz (Lee et al., 2003).

Instrumentation: A desktop computer was used which had windows 7 operating system. An omni-directional distortion free *I BALL* microphone was connected to the desktop. The *Praat* software was also installed in the desktop to record and edit the data required for VLHR analysis. *MATLAB* software was used to obtain VLHR measures. *MATLAB* is a high level language of technical computing which uses various algorithms to explore signal, image processing, communications, control systems, and computational finance.

Stimuli: The speech sample consisted of phonation of vowel /a/, /i/ and vowel /i/ in the nonnasalized Consonant-Vowel-Consonant (CVC) contexts (/pit/ & /tip/). The production of /i/ in (/pit/ & /tip/) was considered to evaluate the effect of nasality on /i/ in the context of CVC. The stimulus included bilabial and alveolar stop consonants to minimize the effect of coarticulation on the movement of velum during the production of vowel /i/ in the context of CVC syllables.

Instructions: The participants were seated in front of a microphone in a quiet room as shown in figure 8. The investigator modeled the stimulus production and ensured the correct production of stimulus from participants by multiple repetitions before recording. The participants were instructed to phonate steady state vowels (/a/ & /i/), and /i/ in a nonnasalized CVC contexts (/pit/ & /tip/) thrice at a comfortable pitch and loudness separately with an interstimulus duration of 10-15 seconds.

Procedure: Each stimulus was recorded separately using *Praat software* and the steady state portion of middle 500 millisecond section for vowels (/a/ & /i/) and 50 milliseconds of vowel /i/ in CVC syllables /pit/ and /tip/ was selected for VLHR analysis. The edited stimuli was subjected to analysis through the *MATLAB 7.0 version software*, and obtained the VLHR (ratio of energy concentration at low to high frequency region) was obtained as shown in figure 7. To measure the test retest reliability of acoustic measurements, twenty five percent of the original data recorded was reanalyzed by the same investigator and compared that results with the complete data used in the study.

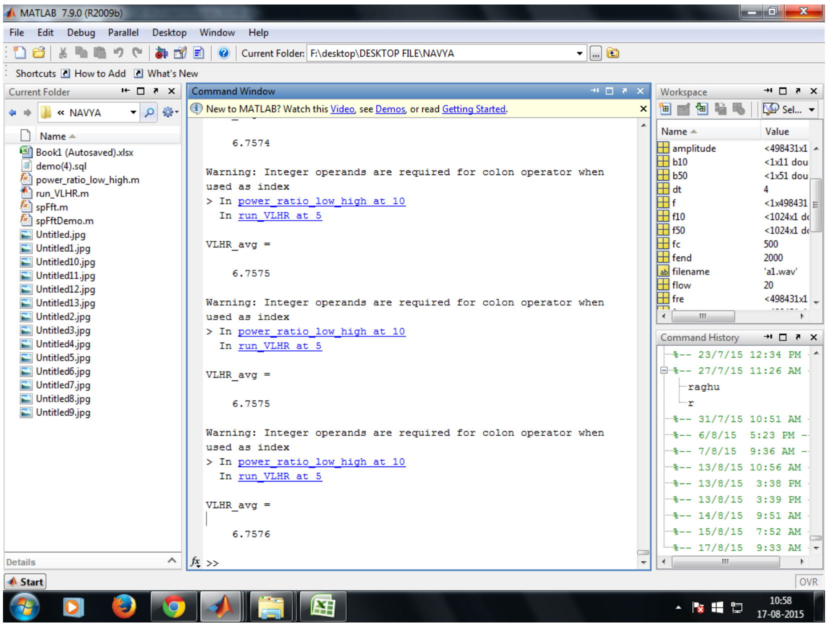


*Figure 7.* VLHR obtained using *MATLAB* software.

***Jitter and shimmer measures***

Vocal perturbations are defined as the cycle-to-cycle variation in fundamental frequency (Jitter) and amplitude (Shimmer) (Farrus et al., 2007). These measures have shown to reflect the regularity of vocal cord oscillations.

Instrumentation: Omni-directional distortion free *I BALL* microphone was connected to desktop computer installed with *Praat version 5.4.17* software, (Boersma, & Weenink, 1993) to record and edit the data required for perturbation analysis. *VAGHMI - VagPro_Diagnostics Version 4.2*. (Voice Speech Systems, Bangalore) was used to extract the jitter and shimmer measures.

Stimuli: Vowel /a/ & /i/ were used as stimuli. Approximately 5 seconds of steady state condition of these vowels were selected to derive the perturbation measures of jitter and shimmer.

Instructions: To measure the above mentioned parameters of perturbations, the participants were made to sit comfortably in a quiet room in front of a desktop connected with omni-directional distortion free *I BALL* microphone as shown in figure 8. They were demonstrated and instructed to produce the steady state vowels (/a/ & /i/) for approximately 5 seconds at comfortable pitch and loudness. The participants were given trial before the actual recordings and then instructed to produce the vowels thrice while recording.

*Figure 8.* Recording of Audio sample using *PRAAT* software

Procedure: The vowels /a/ and /i/ were recorded thrice and saved separately. The inter stimulus duration between the recordings was approximately 15 seconds. The recorded stimulus was played once to verify whether the intended speech stimulus was completely recorded and saved. Using *Praat 5.4.17* Version software the three second steady state portion at the mid of the vowel was selected and saved as shown in figure 9 for further analysis.

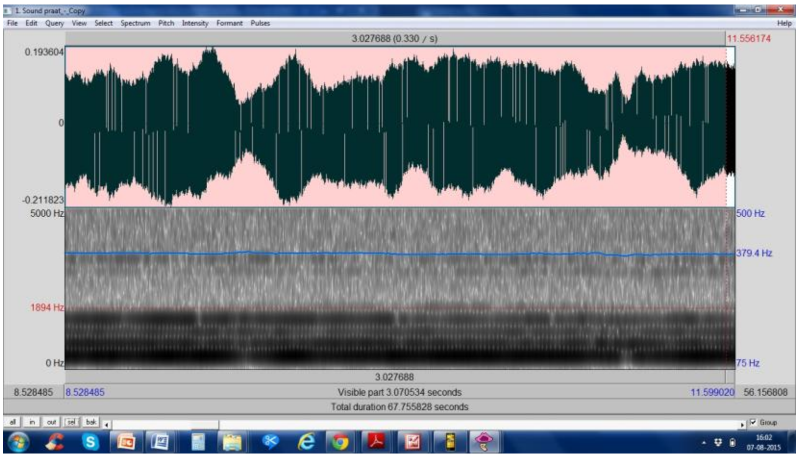


*Figure 9.* Selection and editing stimulus using *PRAAT* software

The saved stimulus was considered for perturbation analysis using diagnostic module of *VAGHMI* as shown in figure 10. The data was collected from all the participants across the groups and each participant's data was saved separately. The recording in the Praat software was performed at 44000Hz. To analyze the stimuli using VAGHMI software, the stimuli had to be converted to 16000Hz. Hence it was converted using VAGHMI software before performing the analysis. Then the stimulus was evaluated for jitter and shimmer measures. The three trail recordings of each stimuli were evaluated separately for jitter and shimmer measures. The average of these three trail measures of jitter and shimmer were obtained for both the vowels (/a/ & /i/). To measure the test retest reliability of acoustic measurements, twenty five percent of the original data recorded was reanalyzed by the same investigator and the results were compared with the complete data used in the study.

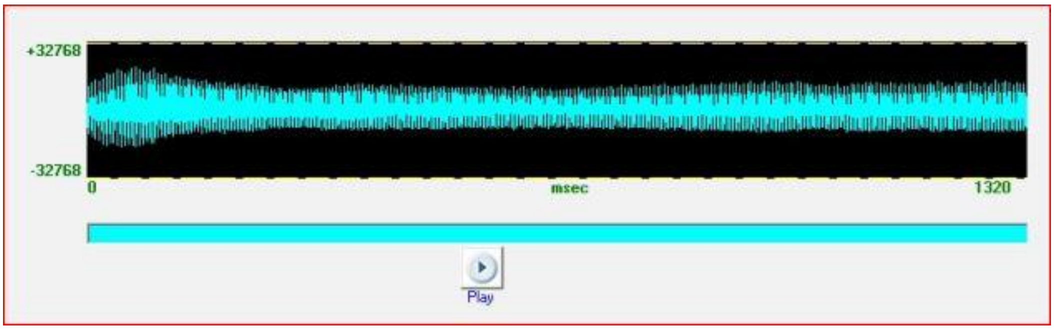


*Figure 10.* Analysis of stimuli using VAGHMI diagnostic software

**Aerodynamic Measures**

***Nasal Emission Measures (NEM)***

Nasal emission is the abnormal passing of air via the nasal route during speech sound production requires intra oral breath pressure such as plosives and fricatives (Baken & Orlikoff, 2000). The escaping air tends to reduce the oral air pressure and impede the proper production of the consonant. Nasal emissions were analyzed by using the mirror-fogging test proposed by Glatzel (Foy, 1910), which was used for measuring the nasal air emission in the participants included in the study. The stimuli considered for nasal emission analysis was prolongation of the vowels /a/, /i/, and production of fricative /s/ for five seconds.

Instrumentation: Glatzel mirror was used for analysis of nasal emission and it consists of four concentric circles, where each circle represents a degree of condensation from 0 to 4 (0 = no condensation, 1 = mild condensation, 2 = moderate condensation, 3 = moderate to severe condensation 4 = severe condensation) as shown in figure 11.

Instructions: The participants were instructed to prolong and sustain the vowels /a/, /i/, and fricative /s/ for five seconds. The participant was instructed to produce each stimulus thrice with an inter stimulus duration of 10-15 seconds between the each production to allow the condensation to evaporate completely.

Procedure: The participant was comfortably seated in an upright position on the chair and fans were switched off in the room for better visualization of the condensation on mirror during the emission from nose. The Glatzel mirror was placed in below columella on upper lip of the participant as shown in figure 12. The production of stimulus was demonstrated by the investigator and instructed the participant. The Glatzel mirror was cleaned following each recording using a dry cotton ball to ensure better condensation. The degree of condensation on Glatzel mirror held under the nose is the indication on the amount of nasal airflow during phonation of vowels and fricative. Phonation of each sound was analyzed separately based on five point rating scale. To measure test-retest reliability of Glatzel test, the test was repeated on 25 % of the participants with an interval of one week.

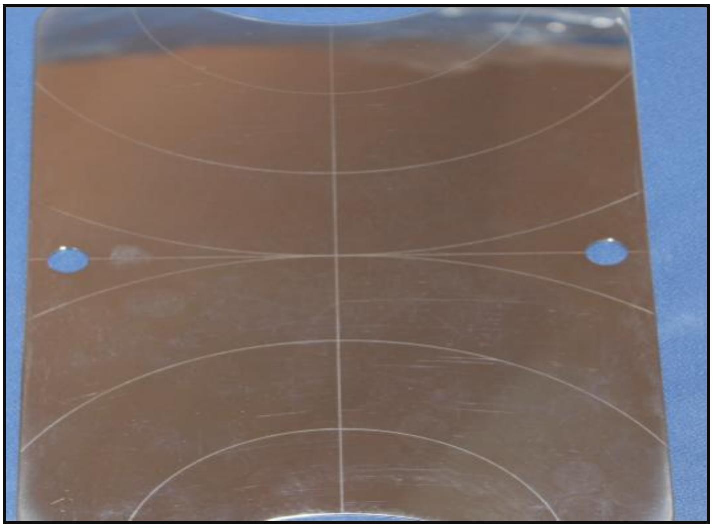

*Figure 11:* Glatzel mirror used for mirror fog test.

*Figure 12*: Glatzel mirror below columella indicating condensation on mirror.

***Maximum phonation duration (MPD)***

The MPD is defined as the greatest length over which production can be sustained for vowel /a/ and voiceless sound /s/ (Tait, Michel, and Carpenter, 1980). The MPD was measured on the bases of three test trails with the vowel /a/ and voiceless sound /s/.

Instrumentation: To measure maximum phonation duration stop watch was used. The stop watch was turned on immediately during the initiation of production and turned off by the end of production.

Instructions: The participants were instructed to sit in an upright position on a chair and take deep breath before sustaining the vowel and fricative to the maximum duration possible. The task was modeled by the investigator to the participants.

Procedure: The participants were demonstrated and instructed to prolong the phonation of vowel /a/ and production of /s/ sustained at habitual loudness in a free field (without any mouthpiece) for three times. During the phonation, the participant was visually encouraged for optimal performance of the task at a comfortable pitch and loudness. Among the three trails, the trail with maximum duration was considered as MPD of the specific vowel and fricative. To measure test-retest reliability, MPD was measured again in 25% of the participants with an interval of one week.

### *Laryngeal aerodynamic parameters (SGP, MAFR, LAR)*

A specific volume of air and pressure are required to set the vocal folds into vibration. Laryngeal aerodynamics (LA) analysis provides the information regarding the pressure and airflow changes as a result of voice production at the level of glottis. This provides information regarding the coordination of respiratory and laryngeal system to produce voice. During voice production glottis transforms the aerodynamic energy into acoustic energy. The regular LA analysis includes measures of MAFR, SGP and LAR. The mean airflow rate is defined as the volume of airflow in 1 second across the vocal folds during the phonation and denoted as ratio of volume to time (l/s or ml/s or cc/s). The sub glottal pressure is defined as the amount of pressure exerted on vocal folds during the adduction stage and is denoted in cm $H_2O$. The laryngeal airway resistance is defined as the ratio of mean airflow rate to the sub glottal pressure and denoted as l/s/cm $H_2O$.

Instrumentation: The instrument *Aeroview version 1.4.4* was used to obtain SGP, MAFR and LAR. The instrument consists of pressure and airflow transducers mounted onto the face mask, the computer interface and the dedicated application software for analyzing the data. The mask consists of pressure and airflow transducers as shown in figure 13. The mask was cleaned using the cotton dipped in Dettol, without touching the mesh mounted on the mask.

Instructions: The participant was then instructed to produce the repetitions of nine CV syllables /papapapapapapapapa/ into the mask at a comfortable pitch and loudness. The participants were asked to produce CV syllables with equal stress on each syllable. To ensure equal rhythm, investigator demonstrated the production until participants produced the syllable trails at the appropriate rate.

Procedure: The participant was instructed to hold the mask firmly against the face so that nose and mouth were covered tightly and with the intraoral tube placed between the lips and above the tongue as shown in figure 14. The participant was demonstrated and instructed the production of /papapapapapapapapa/. The recordings with syllable production rate of 2.0–3.5 per second were considered for measuring the ESGP, MAFR and LAR. Three practice trails were given before the actual recording. The recorded signal with peaks appeared on the computer screen as shown in figure

15. Three peak to peak measurements were made and their average value was obtained to get the mean of sub-glottic pressure (SGP), mean airflow rate (MAFR), and laryngeal airway resistance (LAR) values. Test retest reliability was performed on 25% of the randomly selected data with an interval of minimum 2 weeks. The summary of the acoustic, aerodynamic parameters considered for the study and instruments used to measure has been accounted in table 6.

*Figure 13:* Aeroview mask along with pressure and airflow transducers.

*Figure 14:* Data collection using Aeroview

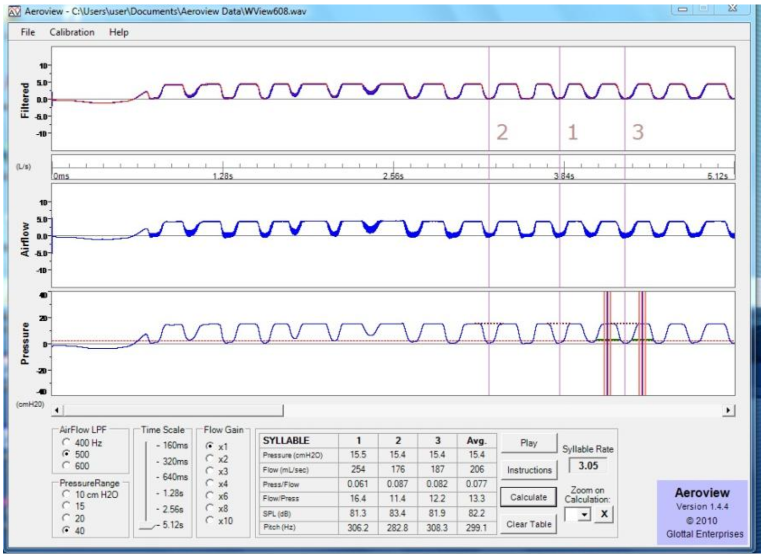


*Figure 15:* Aeroview screen while measuring laryngeal aerodynamics

Table 6

*Instruments used to measure acoustic and aerodynamic parameters*

| S. No. | Parameters | Instruments |
|---|---|---|
| 1 | Nasalance | *Nasometer (Model 6400 II, Kay Pentax, New Jersey)* |
| 2 | 1/3rd octave spectra analysis | *MATLAB 7.0 version software* |
| 3 | Voice Low Tone to High Tone Ratio | *MATLB 7.0 version software* |
| 4 | Jitter and shimmer | *VAGHMI (VagPro _Diagnostics Version 4.2) by* Dr. Anandapadmanabha, Banglore. |
| 5 | Nasal Emissions | *Glatzel mirror* |
| 6 | Maximum Phonation Duration (MPD) | *Stop watch* |
| 7 | Subglottal Pressure (SGP) | *Aeroview 1.4.4 version, Glottal Enterprises* |
| 8 | Mean Airflow Rate (MAFR) | *Aeroview 1.4.4 version, Glottal Enterprises* |
| 9 | Laryngeal Airway Resistance (LAR) | *Aeroview 1.4.4 version, Glottal Enterprises* |
| 10 | Speech video recording | *Sony handy cam with 60X optical zoom, bearing model no. DCR-SR88.* |
| 11 | Audio recording | *Praat version 5.4.17 software* (Boersma, & Weenink, University of Amsterdam) & *i ball distortion free omni directional microphone* |

### 3.3.2 Phase 2: Development of NSI.

The nasality severity index was developed based on subjective and objective measures of nasality. The acoustic and aerodynamic parameters were considered as objective measures. The acoustic, aerodynamic measures included in the study and instruments used for measurement and recording have been put forth in table 4. The subjective measures of nasality were based on perceptual evaluation. The perceptual analysis was performed by qualified SLP's after undergoing familiarization task. Based on the perceptual evaluation by using 4-point standardized rating scale (Henningsson, et al., 2007), children were divided into three groups – mild hypernasal (Group Ia), moderate to severe hypernasal (Group Ib), and normal resonance (Group II).

The construction of index required two or more groups based on which the different parameters had to be compared. Hence, a group of TDC and other groups with RCLP were considered for the construction and validation of NSI. The construction of NSI was based on integration of the objective measures derived from acoustic (59) and aerodynamic measures (2) which were subjected to discriminant analysis. Among aerodynamic measures nasal emissions evaluated using Glatzel test were not considered, as the analysis included subjective judgments of condensation of air on the Glatzel mirror. The laryngeal aerodynamic parameters (SGP, MAFR & LAR) were also not included during construction of NSI. Because these parameters could not be extracted from all the children with RCLP, only few children (twelve in mild hypernasal and seven in moderate to severe hypernasal group) were able to maintain the pressure required during recording of speech stimuli for analysis using Aeroview. All TDC were able to maintain the pressure required for evaluating the laryngeal aerodynamic parameters. However, the nasal emission measures and laryngeal aerodynamic measures were analyzed and compared across the groups using appropriate statistical procedures even though they were not included in the construction of NSI. The data obtained from each parameter across the groups were compiled and compared. The discriminant analysis was used to obtain the weighted combination of parameters for formulating the nasality severity index.

### 3.3.3 Phase 3: Evaluate the classification accuracy of NSI.

The overall percent of the participants correctly classified by the index derived from discriminant analysis can be affected by chance agreement. Hence, Kappa, an index that corrects for chance agreements was computed to evaluate the accuracy of the discriminant functions derived in classifying the individuals into groups based on the predicted independent variables. Kappa is calculated based on the predicted group membership obtained from the discriminant analysis.

### 3.3.4 Phase 4: Validation of NSI.

To estimate the validity of NSI, the index was verified with another group of fifteen participants who were not considered as participants for the construction of NSI. Validation measures included five participants under each group - mild hypernasal (Group Ia), moderate to severe hypernasality (Group Ib), normal (Group II) – who were divided based on the perceptual measures using 4-point rating scale (Henningsson et al., 2007). The acoustic and aerodynamic measures included in the construction of NSI were evaluated for all the fifteen participants. The obtained measures were used to calculate the NSI based on the discriminant functions obtained and participants were grouped accordingly. The group membership based on NSI was crosschecked with the perceptual evaluation and verified.

## 3.4 Statistical Analysis

The data obtained by all these measures were subjected to appropriate statistical analysis using Statistical Package for Social Science (SPSS), Version 21. The normality of the data within each group was analyzed using Shapiro - Wilk test. The test result indicated skewed data for few variables ($p<0.05$), hence box plots were drawn for all the variables and outliers were identified in each group and removed from the analysis. The participants, indicated as outliers frequently across all the variables were not considered for further analysis. Across the variables five participants from each mild (33) and moderate group (34) and four participants from control group (35) were removed. Shapiro-Wilk test revealed normality across the groups for all the variables ($p > 0.05$) following the removal of outliers. The data from 23 in mild hypernasal group, 24 in moderate to severe hypernasal (group Ib) and 26

TDC (group II) were used to derive the index. Apart from these subjects, to validate the index 15 participants with RCLP were considered (five in each group).

Multivariate analysis was administered to find the main effect of group on dependent variables (Nasalance, jitter, shimmer, VLHR, one third octave spectra analysis, MPD, LAR, SGP, and MAFR). Post hoc multiple comparison was carried out using Duncan's test followed by MANOVA. The Glatzel test was based on ordinal data. Hence, Kruskal Wallis and Mann Whitney test were administered to evaluate the differences across the groups based on Glatzel test. The Kappa measures were used to perform inter and intra rater reliability measures. Then Spearman's rank order correlation was used to analyze the correlation between objective measures and perceptual ratings. Nasality Severity Index was constructed to be analogous to discriminate analysis. The individuals were classified by using two linear combinations of quantitative predictors called as discriminant functions (Green & Salkind, 2008) to construct the nasality severity index. Classification accuracy based on index was evaluated using Kappa calculations from discriminant analysis.

# CHAPTER IV
# RESULTS AND DISCUSSION

## 4.1 Perceptual Evaluation of Hypernasality

The speech of children with RCLP was subjected to perceptual evaluation by three experienced speech language pathologists. The hypernasality was rated based on a four point rating scale for spontaneous speech, repetition/ reading of oral and oronasal sentences for 70 children with RCLP. A consensus agreement by any two out of three judges on a stimulus parameter was obtained to group the participants based on the stimuli. The final grouping was performed based on consensus of the judges indicating three as normal nasality, 33 as mild hypernasal, 23 as moderate hypernasal, 11 as severe hypernasal groups. Table 7 depicts the distribution of the participants based on the nasality across the stimulus.

### 4.1.1 Inter and Intra Judge Agreement

The inter and intra judge agreement of perceptual evaluation of hypernasality in children with RCLP was analyzed. The inter and intra judge reliability measures indicated statistically significant moderate reliability among the ratings of judges with Kappa scores ranging from 0.42 to 0.61 across the stimuli.

Table 7

*Frequency of the sample distribution based on speech stimuli.*

| Degree of | Stimulus | | |
|---|---|---|---|
| Hypernasality | SS | OS | ONS |
| Normal | 02 | 04 | 02 |
| Mild | 33 | 31 | 33 |
| Moderate | 22 | 25 | 26 |
| Severe | 13 | 10 | 09 |

*Note.* SS = spontaneous speech, OS= oral sentences, ONS =oronasal sentences.

### Discussion

Perceptual evaluation is 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, perceptual evaluation remains the primary means of evaluating the nasality in children with repaired/ unrepaired CLP. There are various types of rating scales used to report the speech outcome in individuals with repaired/unrepaired CLP (Kummer, Clark, Redle, Thomsen, & Billmire, 2011). To obtain consistency in evaluating and reporting perceived speech outcomes universally, Henningsson et al. (2007) developed a standardized four point equal interval rating scale to indicate nasal resonance. The scale “0” to “4” denotes different degrees of nasality.

The present study was aimed at evaluating severity of hypernasality based on perceptual evaluation. The children were selected based on perceptual judgment of nasality using four point rating scale. The children were grouped into TDC, mild and moderate to severe hypernasal groups. 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. The intra and inter judge reliability measures denote the reliability between all the ratings given by various judges (Kreiman et al., 1993). In the present study, results indicated moderate reliability between the ratings of judges and there were no significant differences across the stimuli. The moderate reliability can be due to the difficulties in perceiving hypernasality with same severity by various judges, as speech is a complex task. The results are in accordance with the findings of Counihan and Cullinan (1970) who reported that there were no reliable judgements attained by the judges for perceptual evaluation of nasality in spontaneous speech sample. The study done by Bradford, Brooks, and Shelton (1964) which had used vowels and connected speech as their stimulus for perceptual evaluation of nasality reported that higher reliability was noted for vowels than connected speech. This notion was also observed in the study done by Watterson et al., (2007) who reported poor to moderate reliability on perceptual ratings of hypernasality by two expert listeners. They used low back and high front vowels as stimuli and reported no significant differences in nasality ratings across stimuli. The results were attributed to the difficulty in judging hypernasality as speech is a multidimensional task.

The differences in perception of nasality across various studies documented were attributed to the type of speech samples considered (Carney and Sherman, 1971), experience of judges (Dalston & Warren, 1986; Schmelzeisen et al., 1992), phonetic context (Fletcher et al., 1976; Watterson et al., 1996) and types of rating scales (Bzoch, 1989; Karling et al., 1993). Along with these parameters the differences in intra reliability can be due to the variations in the time span between the judgments on rating the samples (Kreiman et al., 1993). In addition, the presence of misarticulations may also reduce or increase the perception of hypernasality (Fletcher et al., 1989; McWilliams et al., 1990).

In contrast, few other studies (Tsai, 2007 & Vogel et al., 2009) indicated moderate to good inter and intra judge agreement for various oral and nasal passages. The findings of Vogel et al. (2009) indicated reliability ratings ranging from 0.66 to 0.91 for passages with varying proportion of nasal phonemes. There were differences in the reliability ratings with respect to present study, even though the age range of the participants and rating scales used in the study by Vogel et al. (2009) were similar. The variations can be due to the differences in the stimulus (combination of vowels, syllables, sentence repetitions, and reading three passages) used for rating perceived nasality. The results of study conducted by Tsai (2007) indicated intra judge reliability ratings by two judges for spontaneous speech sample of children with RCLP as 0.74 and 0.90 and inter judge reliability was 0.91. The differences across the studies were attributed to the methodological variations. The ratings of the study by Tsai (2007) are based on two judges and the rating scale used was visual analog scale ranging from 0mm indicating “no nasal resonance” to 100mm representing “the most nasal resonance”.

The finding of the present study was in accordance with many studies (Counihan & Cullinan, 1970; Bradford et al., 1964; Watterson et al., 2007) and it was also contradicting to results of some studies (Tsai, 2007; Vogel et al., 2009). The diversity in the findings can be attributed to perceptual variations in the listener’s judgement. This dilemma was highlighted by Stevens (1974) who indicated that the listeners showed bias toward subdividing the lower end of the scale into small intervals, thus “equal appearing” intervals are not necessarily equal for the entire scale.

## 4.2 Test for Normality of the Quantitative Data

The obtained quantitative data was subjected to Shapiro-Wilk (S-W) test to evaluate whether the data follows normal distribution. This test determine whether the sample considered from a population has a specific distribution (Chakravart, Laha, and Roy, 1967). The vertical difference between the theoretical and empirical cumulative distribution function was formulated. This S-W statistic infers about the distribution of sample. The Null hypothesis ($H_0$) assumes the sample follows normal distribution. Alternate hypothesis ($H_1$) assumes that the sample is not following normal distribution. The null hypothesis will be accepted if the test is not statistically significant ($p>0.05$). The alternative hypothesis will be accepted if the test is statistically significant ($p<0.05$). If the data follows normal distribution then parametric tests will be administered to evaluate the data. The data not following the normal distribution was subjected to nonparametric tests. The results of one sample S-W test indicated that the data followed normal distribution ($p>0.05$) as depicted in tables 8,9,10,11,12,13,14, 15,17,18 for mean nasalance values, derived nasalance measures, one third octave spectra analysis of /a/, /i/, and /i/ in the context of CVC syllables (/pit/ & /tip/), voice low tone to high tone ratio, jitter, shimmer, maximum phonation duration, and laryngeal aerodynamic parameters. The results indicated that measures of nasal emission were not following normal distribution ($p < 0.05$) as depicted in table 16.

Table 8

*S-W test for mean nasalance values across groups*

| Participants | S-W Test | Stimuli | | | | |
|---|---|---|---|---|---|---|
| | | /a/ | /i/ | Oral | Nasal | Oronasal |
| Group Ia | *p*-value | .91 | .66 | .99 | .75 | .93 |
| Group Ib | *p*-value | .83 | .92 | .95 | .57 | .63 |
| Group II | *p*-value | .53 | .93 | .50 | .55 | .86 |

*Note.* Group Ia = mild hypernasal, Group Ib = moderate to severe hypernasal, Group II = TDC, S-W = Shapiro-Wilk

Table 9

*S*-W *test for of derived nasalance measures*

| Participants | S-W Test | Nasalance Distance | Nasalance Ratio |
|---|---|---|---|
| Group Ia | *p*-value | .63 | .52 |
| Group Ib | *p*-value | .93 | .68 |
| Group II | *p*-value | .74 | .94 |

*Note.* Group Ia = mild hypernasal, Group Ib = moderate to severe hypernasal, Group II = TDC, S-W = Shapiro-Wilk.

Table 10

*S-W test for one third octave spectra analysis of vowel /a/*

| Frequency (Hz) | Participants | | |
|---|---|---|---|
| | Group Ia (*p*-value) | Group Ib (*p*-value) | Group II (*p*-value) |
| 396 | .977 | .988 | .889 |
| 500 | .870 | .632 | .424 |
| 630 | .619 | .940 | .957 |
| 793 | .399 | .794 | .970 |
| 1000 | .661 | .675 | .965 |
| 1259 | .545 | .938 | .860 |
| 1587 | .319 | .479 | .978 |
| 2000 | .534 | .399 | .884 |
| 2519 | .528 | .953 | .975 |
| 3174 | .605 | .727 | .964 |
| 4000 | .565 | .126 | .802 |

*Note.* Group Ia = mild hypernasal, Group Ib = moderate to severe hypernasal, Group II = TDC.

Table 11

*S-W test for one third octave spectra analysis of vowel /i/*

| Frequency (Hz) | Participants | | |
|---|---|---|---|
| | Group Ia (*p*-value) | Group Ib (*p*-value) | Group II (*p*-value) |
| 396 | .445 | .748 | .889 |
| 500 | .860 | .424 | .880 |
| 630 | .542 | .668 | .992 |
| 793 | .278 | .216 | .979 |
| 1000 | .322 | .554 | .639 |
| 1259 | .394 | .933 | .891 |
| 1587 | .693 | .355 | .819 |
| 2000 | .463 | .607 | .880 |
| 2519 | .979 | .714 | .905 |
| 3174 | .745 | .775 | .809 |
| 4000 | .314 | .817 | .885 |

*Note.* Group Ia = mild hypernasal, Group Ib = moderate to severe hypernasal, Group II = TDC.

Table 12

*S-W test for* one third octave spectra analysis of vowel /i/ in /pit/.

| Frequency (Hz) | Participants | | |
|---|---|---|---|
| | Group Ia (*p*-value) | Group Ib (*p*-value) | Group II (*p*-value) |
| 396 | .855 | .969 | .336 |
| 500 | .868 | .918 | .561 |
| 630 | .995 | .819 | .921 |
| 793 | .997 | .303 | .807 |
| 1000 | .391 | .731 | .952 |
| 1259 | .673 | .172 | .944 |
| 1587 | .356 | .909 | .804 |
| 2000 | .468 | .939 | .554 |
| 2519 | .588 | .985 | .732 |
| 3174 | .565 | .771 | .641 |
| 4000 | .786 | .516 | .795 |

*Note.* Group Ia = mild hypernasal, Group Ib = moderate to severe hypernasal, Group II = TDC

Table 13

*S-W test for one third octave spectra analysis of vowel /i/ in /tip/*

| Frequency (Hz) | Participants | | |
|---|---|---|---|
| | Group Ia (*p*-value) | Group Ib (*p*-value) | Group II (*p*-value) |
| 396 | .879 | .949 | .879 |
| 500 | .858 | .886 | .635 |
| 630 | .997 | .686 | .933 |
| 793 | .457 | .847 | .951 |
| 1000 | .441 | .888 | .677 |
| 1259 | .577 | .908 | .782 |
| 1587 | .396 | .585 | .587 |
| 2000 | .295 | .828 | .842 |
| 2519 | .351 | .984 | .561 |
| 3174 | .147 | .736 | .562 |
| 4000 | .446 | .842 | .682 |

*Note.* Group Ia = mild hypernasal, Group Ib = moderate to severe hypernasal, Group II = TDC

Table 14

*S-W test for VLHR.*

| Participants | S-W test | Stimuli | | | |
|---|---|---|---|---|---|
| | | /a/ | /i/ | /pit/ | /tip/ |
| Group Ia | *p*-value | .38 | .86 | .77 | .85 |
| Group Ib | *p*-value | .82 | .96 | .99 | .47 |
| Group II | *p*-value | .66 | .99 | .47 | .30 |

*Note.* Group Ia = mild hypernasal, Group Ib = moderate to severe hypernasal, Group II = TDC, S-W = Shapiro-Wilk

Table 15

*S-W test for of jitter and shimmer of vowels*

| Participants | S-W test | Jitter /a/ | Jitter /i/ | Shimmer /a/ | Shimmer /i/ |
|---|---|---|---|---|---|
| Group Ia | *p*-value | .85 | .06 | .45 | .55 |
| Group Ib | *p*-value | .13 | .82 | .06 | .13 |
| Group II | *p*-value | .49 | .90 | .84 | .96 |

*Note.* Group Ia = mild hypernasal, Group Ib = moderate to severe hypernasal, Group II = TDC, S-W = Shapiro-Wilk

Table 16

*S-W test for nasal emission measures across the groups*

| Participants | S-W test | Stimuli | | |
|---|---|---|---|---|
| | | /a/ | /i/ | /s/ |
| Group Ia | *p*-value | .001* | .041* | .223 |
| Group Ib | *p*-value | .004* | .020* | .145 |
| Group II | *p*-value | .000* | .000* | .000* |

*Note.* S-W = Shapiro-Wilk, *$p < 0.05$.

Table 17

*S-W test for MPD of /a/ and /s/ across the groups*

| Participants | S-W test | Stimuli | |
|---|---|---|---|
| | | /a/ | /s/ |
| Group Ia | *p*-value | .174 | .386 |
| Group Ib | *p*-value | .366 | .328 |
| Group II | *p*-value | .161 | .820 |

*Note.* Group Ia = mild hypernasal, Group Ib = moderate to severe hypernasal, Group II = TDC, S-W = Shapiro-Wilk

Table 18

*S-W test for laryngeal aerodynamic parameters*

| Participants | S-W test | SGP | MAFR | LAR |
|---|---|---|---|---|
| Group Ia | *p*-value | .982 | .828 | .218 |
| Group Ib | *p*-value | .983 | .746 | .910 |
| Group II | *p*-value | .359 | .138 | .057 |

*Note.* Group Ia = mild hypernasal, Group Ib = moderate to severe hypernasal, Group II = TDC, SGP = sub-glottal pressure, MAFR = mean airflow rate, LAR = laryngeal airway resistance, S-W = Shapiro-Wilk.

## 4.3 Evaluation of Various Acoustic Parameters across Groups

### 4.3.1 Mean nasalance values

The nasalance values were measured using Nasometer 6400 II for all the participants. The participants were instructed to repeat the stimulus thrice. The mean of three trials was considered as nasalance value for that particular stimulus. Table 19 and figure 16 depicts the results of mean and SD of nasalance values across the stimuli with respect to three groups. The increased mean nasalance values were found in children with RCLP (Group Ia & Ib) than TDC across all the stimuli. TDC exhibited increased nasalance values for sentences than vowels. Among the children with RCLP, group Ia (mild hypernasal) exhibited reduced mean nasalance values than group Ib (moderate-severe hypernasal). The increased nasalance values were observed in nasal sentences than oronasal and oral sentences, among vowels increased nasalance was noticed in vowel /i/ than /a/. In group I among all the stimuli vowel /i/ had high nasalance value, followed by nasal sentences, oronasal sentences, oral sentences. The nasalance values of vowel /i/ were relatively increased than the sentences across all the groups except in group II (TDC) exhibited reduced mean nasalance values for vowel /i/ than nasal and oronasal sentences.

Table 19

*The mean and SD of the nasalance values (%) across the groups*

| Participants | Stimuli | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | /a/ | | /i/ | | Oral | | Nasal sentences | | Oronasal sentences | |
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| Group Ia | 19.77 | 8.13 | 57.30 | 21.92 | 33.01 | 10.81 | 51.06 | 9.40 | 48.53 | 7.26 |
| Group Ib | 23.9 | 12.29 | 66.61 | 16.35 | 43.64 | 11.27 | 57.26 | 8.45 | 57.02 | 8.48 |
| Group II | 6.32 | 2.33 | 24.28 | 5.87 | 15.69 | 4.89 | 52.06 | 5.90 | 48.09 | 6.11 |

*Note.* Group Ia = mild hypernasal RCLP, Group Ib = moderate to severe RCLP, Group II = TDC, SD = standard deviation.

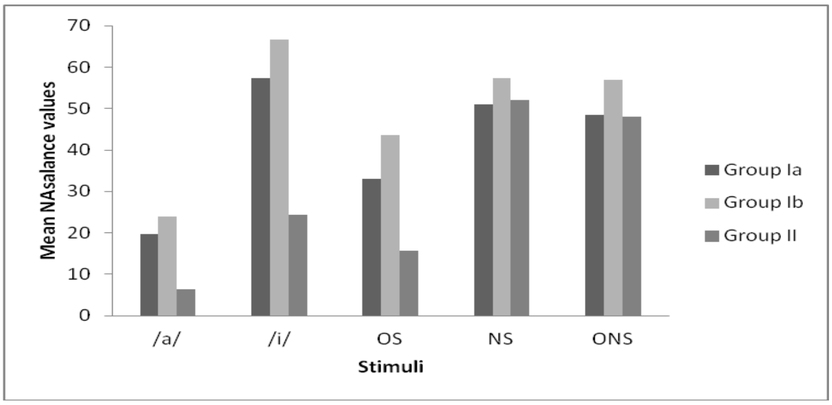


*Figure 16*. The mean nasalance values (%) across the groups.
Group Ia = mild hypernasal RCLP, Group Ib = moderate to severe RCLP,
Group II = TDC.

The results of MANOVA indicated significant differences between the groups for all the stimuli [ /a/ - {$F(2,73) = 29.50$, $p < 0.01$}, /i/ - {$F(2,73) = 49.55$, $p < 0.01$}, oral sentences - {$F(2,73) = 57.37$, $p < 0.01$}, nasal sentences - {$F(2, 73) = 4.16$, $p < 0.05$}, oronasal sentences - {$F(2,73) = 11.47$, $p < 0.01$}]. To find homogeneous subsets of groups, post hoc multiple comparisons were carried out using Duncan's test. The post hoc analysis revealed significant differences between each subset of three groups for mean nasalance values of vowel /i/ and oral sentences at 0.05 level of significance. The mean nasalance values of vowel /a/ were significantly different between TDC and hypernasal groups. Among nasal and oronasal sentences, TDC and mild hypernasal group were significantly different from moderate to severe hypernasal group at 0.05 level of significance.

### 4.3.2. Nasalance Distance and Nasalance Ratio

The nasalance values calculated for oral and nasal sentences were considered to extract the nasalance distance (ND) and nasalance ratio (NR) using the following formulae.

- Nasalance Distance for sentences = Mean nasalance value of nasal sentences – Mean nasalance value of oral sentences.

- NR for sentences = Mean nasalance value of oral sentences / Mean nasalance value of nasal sentences

***ND and NR across stimuli and groups***

The ND and NR were calculated for all the children across the groups. Table 20 and figure 17 and 18 indicates the mean and SD of ND and NR for sentences with respect to groups. The ND was high in TDC compared to children with RCLP. Among the children with RCLP, high ND was exhibited by mild hypernasal group than moderate to severe hypernasal group. The group with moderate to severe hypernasal exhibited increased NR followed by mild hypernasal group and TDC. The SD of ND and NR were relatively more in children with RCLP than TDC.

Table 20

*Mean and SD of ND and NR*

| Participants | Nasalance Distance | | Nasalance Ratio | |
|---|---|---|---|---|
| | Mean | SD | Mean | SD |
| Group Ia | 18.16 | 9.50 | 0.65 | 0.16 |
| Group Ib | 12.53 | 7.77 | 0.74 | 0.11 |
| Group II | 36.59 | 4.07 | 0.30 | 0.07 |

*Note.* Group Ia = mild hypernasal, Group Ib = moderate to severe hypernasal, Group II = TDC, SD = standard deviation.

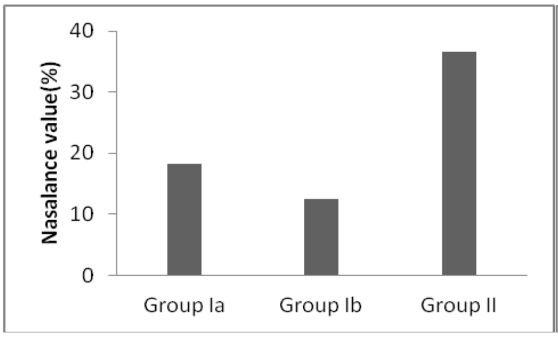


*Figure 17.* Nasalance Distance

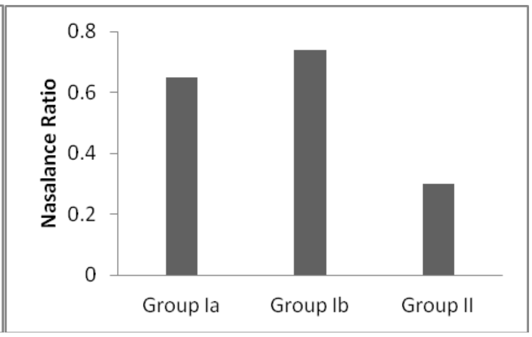


*Figure 18.* Nasalance Ratio

*Note.* Group Ia = mild hypernasal, Group Ib = moderate to severe hypernasal, Group II = TDC.

The results of MANOVA indicated highly significant difference between the groups for mean of ND {$F(2,73) = 73.48$, $p < 0.01$} and NR {$F(2,73) = 93.03$, $p < 0.01$}. To find homogeneous subsets of groups, post hoc multiple comparisons was carried out using Duncan's test. The test revealed significant differences across the three groups for ND and NR.

### ***Correlation of mean and derived nasalance values with perception of nasality***

The table 21 indicates correlation of perception of nasality exhibited by RCLP and TDC with mean nasalance values (/a/, /i/, oral, nasal and oronasal sentences) and derived nasalance values (ND & NR). The correlation coefficients were significant across all the stimuli used to compute mean nasalance values, ND, and NR at 0.05 level of significance. Among vowels nasalance of /i/ indicated high correlation than /a/, in sentences nasalance of oral sentences exhibited high correlation followed by oronasal and nasal sentences. The nasalance values of oral sentences, NR, vowel /i/, and /a/ were indicating high correlation followed by oronasal and nasal sentences with the perceptual rating of hypernasality. ND and NR exhibited significant negative and positive correlation respectively with the perceived nasality.

Table 21

*Correlation of mean and derived nasalance values (ND & NR) with perceived nasality*

| Parameters | SCC | *p* – value |
|---|---|---|
| /a/ | 0.623 | 0.00 |
| /i/ | 0.691 | 0.00 |
| Oral sentences | 0.798 | 0.00 |
| Nasal sentences | 0.290 | 0.01 |
| Oronasal sentences | 0.412 | 0.00 |
| Nasalance Distances | -0.771 | 0.00 |
| Nasalance Ratio | 0.788 | 0.00 |

*Note.* SCC = Spearman correlation coefficient

### ***Test-retest reliability measures of mean nasalance values***

The test – retest reliability was measured for nasalance values of /a/, /i/, oral, nasal, and oronasal sentences for 25 % of the entire sample across the groups. Reliability measures were carried out using Cronbach's alpha co-efficient for the above mentioned variables. Table 22 illustrates the Cronbach's alpha co-efficient for mean nasalance values across all the stimuli ranging from 0.56 to 0.95. Test-retest reliability measures indicates moderate to good test retest reliability of nasalance values. Among stimuli sentences exhibited relatively good reliability across the groups except for oral sentence in mild hypernasal group.

Table 22

*Test-retest reliability measures of mean nasalance values*

| Participants | Stimuli | | | | |
|---|---|---|---|---|---|
| | /a/ | /i/ | Oral | Nasal | Oronasal |
| Group Ia | 0.844 | 0.961 | 0.643 | 0.887 | 0.915 |
| Group Ib | 0.895 | 0.943 | 0.958 | 0.917 | 0.911 |
| Group II | 0.567 | 0.659 | 0.880 | 0.951 | 0.792 |

*Note.* Group Ia = mild hypernasal RCLP, Group Ib = moderate to severe RCLP, Group II = TDC.

### *Discussion*

Hypernasality is a characteristic feature of speech in individuals with repaired/unrepaired CLP, hampering the intelligibility of speech. Hypernasality is defined as unacceptable voice quality manifested due to inappropriate acoustic coupling of the nasal airway to the vocal tract (Bressmann, et al., 1999). Nasalance is the ratio of nasal to nasal-plus-oral acoustic energy and is used to determine the degree of nasal coupling in speech (Fletcher & Frost, 1974). It is popularly measured using commercially available instrument - Nasometer II.

The results of the present study indicated that increased nasalance values in children with RCLP than TDC across all the stimuli, thus rejecting the first null hypothesis which stated no differences in nasalance values across the groups. The increase in nasalance values can be attributed to the inappropriate coupling of oral and nasal cavities resulting in oronasal imbalance during the production of oral speech. The oronasal coupling resulting in hypernasality can be explained as the degree of nasal resonance in speech was controlled by the magnitude of velopharyngeal (VP) closure. The results are in accordance with the findings of various studies (Hardin, Van Demark, Morris, & Payne, 1992; Sweeney & Sell, 2008) indicating significant increase in nasalance values of children with RCLP than TDC.

The results also indicated that children with moderate to severe hypernasal group exhibiting significantly high nasalance values than mild hypernasal group. The difference can be due to the variations in the degree of velopharyngeal gap. To achieve VP closure, the velum should elevate, posterior-lateral pharyngeal walls need to contract and move anteriorly to form the sphincter for closing the nasopharynx (Thorp, Vimik, & Stepp, 2013). The perception of the nasality varies with the size of the velopharyngeal gap (Fletcher 1976). The results of the present study are in support with the findings by Dalston, et al. (1992) and Sweeney and Sell (2008) who reported increased nasalance scores in individuals with RCLP with the increased perception of hypernasality due to the presence of VPD. In contrast, Wattersson et al. (1993) reported no statistically significant differences in nasalance values with the increased perception of nasality even though high nasalance values were indicated.

Among the sentence stimuli used to measure nasalance values, nasal sentences exhibited higher nasalance value followed by oronasal sentences, oral sentences. The higher nasalance value for nasal sentences may be due to the predominantly embedded nasal consonants in their construction. During the production of nasal consonants velum will be in lower position by the activity of palatoglossus muscle and palatopharyngeus allowing the air to escape freely through the nasal cavity. The oronasal sentences are balanced for approximately same percentage of oral and nasal consonants, however, the nasalance of oronasal sentences is almost similar to that of nasal sentences in the present study. The increased nasalance values of oronasal sentences can be due to the coarticulation effect on vowels and oral consonants preceding the nasal consonants. Additionally, the height of the tongue and position of the velum during the production of the nasal consonants will carry over nasal component to the adjacent vowel by manipulating the velopharyngeal coupling. These exhibit perceptually increased nasality on vowels in the context of nasal consonants than in isolation. The results supports the findings of Bell-Berti et al. (1978), who reported that vowels preceding nasals exhibited lower position of velum than the same vowels in an oral environment. Ohman (1966) stated that the properties of vowels reflect few of the observed characteristics of the coarticulated consonants. This might have lead to elevated nasalance of oronasal sentences due to the effect of coarticulation in the context of nasal consonants.

Among the vowels, mean nasalance value was high for vowel /i/ compared to /a/ across the groups. The nasalance value of hypernasal group was more than TDC for vowel /i/ followed by vowel /a/. The higher nasalance for /i/ can be the result of the articulatory pattern leading to higher nasal acoustic energy. This acoustic transmission is due to the area of the palatal surface exposed to acoustic energy, which is more for high vowels than low vowels (Gildersleeve-Neumann & Dalston, 2001; Bundy & Zajac, 2006). The results are in agreement with the findings of several studies (Mackay & Kummer, 1994; Lewis, et al., 1999; Gildersleeve -Neumann & Dalston, 2001; Gopi Sankar & Pushpavathi, 2008; Bunton & Story, 2012; Madhu Sudarshan, Sheela, & Gopi Kishore, 2012) who reported increased nasalance values for vowel /i/. Moore and Sommers (1973) also reported that production of vowel /i/ demands for tight velopharyngeal seals leading to greater velar excursion.

Galvao (1998) reported increase of nasalance with the increase in vowel height. The authors stated that high vowels have more constriction in the oral cavity, resulting in increased air escape through the nasal cavity. The increased nasal intensity for high vowel /i/ was also reported by Lewis et al. (2000). He attributed increased nasalance on vowel /i/ to the articulatory dynamics. In normal adults during the production of high vowels greater VP closure force is reported than low vowels. The findings of their study was in accordance with the study done by Kendrick (2004) who reported higher nasalance value for vowel /i/ and attributed to the strong effect of horizontal position of the tongue during its production. The study reported by Gopi Sankar and Pushpavathi (2008) was also in agreement with the findings of the above mentioned studies which indicated increased nasalance for high vowel /i/ than vowel /a/. The rationale behind this was explained as the production of /i/ imposes relatively increased resistance to airflow than production of /a/ resulting in low oral and high nasal energy.

The range of nasalance values exhibited by TDC and RCLP was used to derive the parameters ND and NR (Bressmann et al, 2000). The results indicated increased ND in TDC followed by children with mild hypernasal and moderate-severe hypernasal. These differences across the groups were found to be statistically significant. The ND is the difference between the nasalance values of nasal and oral sentences. Therefore, higher ND in TDC can be due to larger difference in their mean nasalance value of oral and nasal sentences. Whereas, the lesser difference in mean nasalance values of oral and nasal sentences would have lead to lower ND in the hypernasal groups.

The results of NR indicated an inverse pattern with lesser NR value for TDC followed by mild hypernasal and moderate-severe hypernasal. As NR is the ratio of mean nasalance values of oral and nasal sentences, higher values in the numerator for participants under hypernasal group lead to high NR than participants under TDC. The significantly reduced difference in mean values of oral and nasal sentences in hypernasal speakers can be attributed to the low ability to differentiate oral and nasal sounds. The ratio computed from the same measurements results in inverted relationship. The results are in accordance with the study by Bressmann et al. (1999) who reported high values of ND with lesser NR for individuals with normal resonance followed by borderline hypernasality and marked hypernasality.

One of the objectives of the study was to correlate the nasalance values of vowels /a/ and /i/ with the perceived nasality. The present study reported correlation coefficients of 0.62 and 0.69 for vowels /a/ and /i/ respectively, indicating high correlation for /i/. These findings are in accordance with the study by Bunton and Story (2012) who also reported high correlation for vowel /i/ than /a/. The perception of nasality in /i/ depends on the oral and nasal impedance and respiratory effort. As the oral impedance is high for /i/, significant amount of sound energy gets diverted to the nasal cavity making it nasalized. This increases perceived nasality as well as nasalance and aids in good correlation between them. Similarly Watterson et al. (1996) and Dalston et al. (1999a) reported high correlation coefficients of 0.70 and 0.82 respectively between nasality and nasalance values. Whereas, few others studies (Paynter, et al. 1991; Watterson et al. 1993) quoted weaker correlation ranging from 0.20 to 0.66. The correlation would have been affected by the evaluation procedures. The nasalance values extracted from Nasometer are based on the filtered speech signal with cut off frequency of 350 Hz to 650 Hz (Fletcher et al. 1989). However, the stimuli used for perceptual evaluation consisted of non altered speech spectrum, which was either spontaneous speech or sentences. The speech characteristics such as co-articulation may be recognized as an important carrier of information in speech and has an impact on speech intelligibility. The auditory cues may be pivotal in perceptual speech evaluation (Fletcher et al. 1989).

To evaluate the relation between perceived nasality and nasalance values in sentences spearman rank correlation was used. High correlation was noticed for oral sentences (0.790), followed by oronasal (0.412) and nasal sentences (0.290). The low correlation of nasalance measures and perceived nasality across the groups for oronasal and nasal sentences can be due to similar mean nasalance scores exhibited for stimuli used across the groups, thus rejecting the second null hypothesis, which stated no significant correlation between nasalance values with the perceived nasality. This can be due to the presence of nasal consonants in nasal and oronasal sentences leading to reduced differences in perceived nasality across the groups. Similar results were reported by Watterson et al. (1993) indicating modest correlation between nasalance and perceived nasality of sentences. The authors reported that high correlation was exhibited by non nasal passage (0.49), followed by standard passage (0.24) than nasal passage (0.20). The authors inferred that high correlation is observed if the stimulus is free of nasal consonants (oral sentences). The results of the present study, however, are in contrast to the study done by Keuning et al. (2002) who reported low correlation coefficient (0.54) for speech samples free of nasal consonants than speech with normal distribution of phonemes (0.61). They hypothesized that misarticulations might be more in speech samples with oral consonants resulting in difficulty to differentiate hypernasality from articulatory disturbances, thus influencing the perceptual analysis of nasality.

The correlation analysis of derived nasalance measures and ND indicated high negative correlation in contrast to high positive correlation between NR and nasalance measures. The negative correlation with ND can be due to the decrease in the difference between the nasalance values of oral and nasal sentences with increasing hypernasality. The positive correlation with the NR can be due to the increase in the mean nasalance values of oral sentences with the increased severity of nasality. The studies correlating these derived nasalance measures with perceived nasality are sparse. A study by Swennen et al. (2004) reported no significant differences in ND and NR measures between the children with varying type and extent of CLP. However, the derived measures were not correlated with the perceived nasality.

The nasalance values measured using Nasometer were subjected to repeated measures on the same subject using same stimulus on the same day to evaluate test retest reliability. The results indicated moderate to good test retest reliability across the groups in the present study. Relatively high reliability was obtained for sentences than isolated vowels, implying that the variation in mean nasalance values is less for sentences. The high reliability measures can be due to the increased length of the stimuli. The result derive support from the findings of Watterson, Lewis, and Foley-Homan (1999) who reported good test retest reliability of nasalance values for sentences having length of more than six syllables.

### 4.3.3 One Third Octave Spectra Analysis

***Mean of one third octave spectra analysis of vowel /a/ across the groups***

The one third octave spectra analysis was measured across all the subjects for vowels /a/, /i/, and /i/ in the context of /pit/ and /tip/. The one third octave spectra analysis of vowel /a/ was measured across all the groups and the mean values were calculated. Table 23 and figure 19 indicates the mean and SD of one third octave spectra analysis for vowel /a/ across the groups. Overall the groups exhibited increased energy concentration at 1000Hz, 1259Hz, and 1587Hz than in the other frequency regions computed. However, in general minimal differences in energy concentration across the groups observed for all the frequencies. The children with RCLP (Group Ia & Ib) had reduced mean of one third octave spectra analysis than TDC for 1000 Hz, 1259Hz, 1587Hz, 3174Hz, and 4000Hz. The amplitude at 396 Hz, 500Hz, 630Hz, and 793Hz across the groups were almost same. This indicates the spectral amplitude was high at mid and high frequencies in TDC except for 2000Hz and 2519Hz. Children with moderate-severe hypernasal group exhibited relatively high spectral energy than children with mild hypernasal group across all the frequencies, except at high frequencies 3174 Hz and 4000 Hz.

Table 23

*Mean and SD of one-third octave analysis of vowel /a/.*

| Frequency (Hz) | Amplitude (dB) | | | | | |
|---|---|---|---|---|---|---|
| | Group Ia | | Group Ib | | Group II | |
| | Mean | SD | Mean | SD | Mean | SD |
| 396 | 38.90 | 14.48 | 39.60 | 11.52 | 39.49 | 10.20 |
| 500 | 47.67 | 13.44 | 50.44 | 9.42 | 50.49 | 11.02 |
| 630 | 48.77 | 15.60 | 52.01 | 10.17 | 50.84 | 11.85 |
| 793 | 51.66 | 13.65 | 55.11 | 9.36 | 55.01 | 8.28 |
| 1000 | 53.99 | 12.44 | 58.20 | 8.63 | 61.83 | 8.31 |
| 1259 | 55.14 | 10.33 | 59.01 | 9.61 | 60.01 | 9.63 |
| 1587 | 53.56 | 12.3 | 58.87 | 8.69 | 61.06 | 8.52 |
| 2000 | 47.98 | 12.70 | 53.74 | 10.10 | 49.06 | 12.18 |
| 2519 | 40.27 | 12.62 | 44.10 | 8.49 | 40.09 | 8.93 |
| 3174 | 39.10 | 14.95 | 38.49 | 11.43 | 45.16 | 8.97 |
| 4000 | 40.45 | 14.59 | 37.69 | 14.55 | 48.16 | 10.08 |

*Note.* Group Ia = mild hypernasal, Group Ib = moderate to severe hypernasal, Group II = TDC, SD = standard deviation.

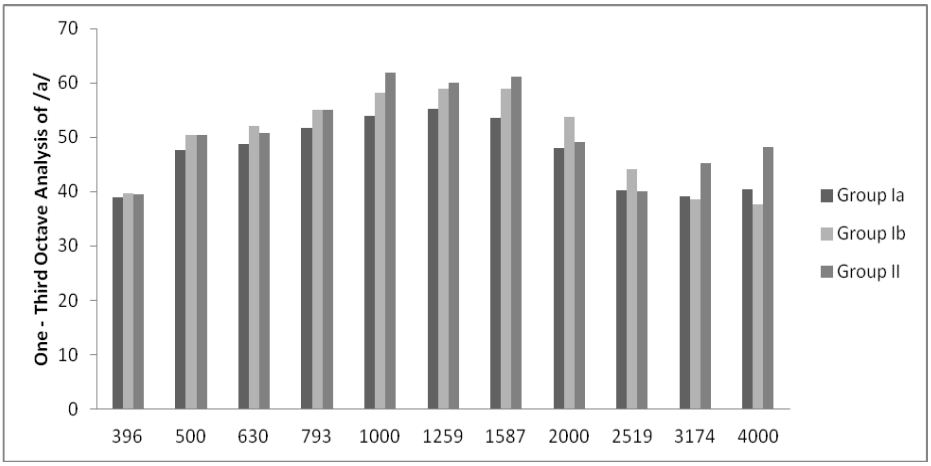


*Figure 19.* One third octave analysis for /a/ across groups. Group Ia = mild hypernasal, Group Ib = moderate to severe hypernasal, Group II = TDC.

The MANOVA results indicated significant differences in one third octave spectral measures for vowel /a/ in 1000 Hz, 1587 Hz, and 4000Hz across the groups at 0.05 level of significance as depicted in table 24.

Table 24

*One third octave spectra analysis of vowel /a/ differentiating the groups*

| MANOVA | Spectral Frequency (Hz) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 396 | 500 | 630 | 793 | 1000 | 1259 | 1587 | 2000 | 2519 | 3174 | 4000 |
| F(2,73) | .02 | .47 | .39 | .81 | 3.82 | 1.63 | 3.71 | 1.62 | 1.21 | 2.41 | 4.28 |
| *p*-value | .97 | .62 | .67 | .44 | .02* | .20 | .02* | .20 | .30 | .09 | .01* |

*Note*. MANOVA = Multivariate Analysis, *$p < 0.05$.

To find the differences within the subsets of three groups, post hoc multiple comparisons were performed using Duncan's test. The post hoc analysis revealed significant differences in energy concentration at 1000 Hz and 1587 Hz for vowel /a/ between mild hypernasal and TDC. The significant difference was noticed for 4000 Hz between the TDC and children with RCLP ($p < 0.05$).

### *Correlation of one third octave spectra analysis of /a/ with perceived nasality*

The table 25 indicates correlation of perceived nasality exhibited by children with RCLP and TDC with one third octave spectra analysis of vowel /a/ across all the frequencies. The correlation coefficients were significant ($p < 0.05$) for vowel /a/ at 3174Hz (-0.23) and 4000Hz (-0.30). The significant negative correlation indicates the reduced amplitude at high frequencies with the increase in perceived hypernasality.

Table 25

*Correlation of one third octave spectra analysis of /a/ with perceived nasality*

| Stimulus | Frequency (Hz) | SCC | *p*–value |
|---|---|---|---|
| Vowel /a/ | 396 | 0.004 | 0.976 |
| | 500 | -0.001 | 0.794 |
| | 630 | 0.040 | 0.740 |
| | 793 | -0.003 | 0.977 |
| | 1000 | -0.159 | 0.179 |
| | 1259 | -0.056 | 0.638 |
| | 1587 | -0.115 | 0.334 |
| | 2000 | 0.159 | 0.180 |
| | 2519 | 0.176 | 0.136 |
| | 3174 | -0.232 | 0.049* |
| | 4000 | -0.309 | 0.008* |

*Note.* $^*p < 0.05$, SCC = Spearman correlation coefficient

### *Test-retest reliability measures of one third octave analysis for vowel /a/*

The test - retest reliability for measuring one-third octave spectra analysis of vowel /a/, was performed for 25 % of the entire sample across the groups. Reliability measures were carried out using Cronbach's alpha co-efficient for the above mentioned variables. Table 26 illustrates the Cronbach's alpha co-efficient for one-third octave spectra analysis for vowel /a/ which is ranged from 0.43 to 0.98 across the groups and stimuli. The test reliability was good for all the frequencies across the groups except on 1259 Hz for group Ib and 2519 Hz for group Ia. Among the groups the test - retest reliability measures were relatively good for TDC than children with RCLP.

Table 26

*Test-retest reliability measures of one third octave spectra analysis for vowel /a/*

| Participants | Spectral frequencies (Hz) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 396 | 500 | 630 | 793 | 1000 | 1259 | 1587 | 2000 | 2519 | 3174 | 4000 |
| Group Ia | .921 | .892 | .958 | .940 | .934 | .980 | .873 | .865 | .433 | .888 | .846 |
| Group Ib | .947 | .874 | .919 | .870 | .751 | .493 | .888 | .995 | .973 | .898 | .816 |
| Group II | .956 | .979 | .949 | .878 | .922 | .874 | .919 | .945 | .803 | .964 | .886 |

*Note.* Group Ia = mild hypernasal, Group Ib = moderate to severe hypernasal, Group II = TDC.

***Mean of one third octave spectra analysis of vowel /i/ across the groups***

The one third octave spectra analysis of vowel /i/ was measured across all the groups and the mean values were calculated. Table 27 and figure 20 depicts the mean and SD of one third octave spectra analysis for vowel /i/ across the groups. All the groups exhibited increased energy concentration at mid and high frequencies (396Hz, 500Hz, 630Hz, 3174Hz, & 4000Hz) than other frequencies computed. However, in general minimal differences in energy concentration across the groups were observed for 500Hz and 2519Hz. The TDC exhibited increased energy concentration in high frequencies (2519Hz, 3174Hz and 4000Hz) than children with RCLP. However, the differences between TDC and mild hypernasal group were minimal. The moderate to severe hypernasal group exhibited reduced amplitude at high frequencies than mild hypernasal and TDC.

Table 27

*Mean and SD of one-third octave analysis of vowel /i/*

| Frequency (Hz) | Amplitude in (dB) | | | | | |
|---|---|---|---|---|---|---|
| | Group Ia | | Group Ib | | Group II | |
| | Mean | SD | Mean | SD | Mean | SD |
| 396 | 42.76 | 13.32 | 46.62 | 14.55 | 42.24 | 15.64 |
| 500 | 48.46 | 12.62 | 49.68 | 11.30 | 48.32 | 14.28 |
| 630 | 47.43 | 15.42 | 53.15 | 10.91 | 46.11 | 13.08 |
| 793 | 40.73 | 12.99 | 48.42 | 10.63 | 41.09 | 9.35 |
| 1000 | 36.75 | 13.26 | 43.56 | 9.25 | 35.01 | 8.59 |
| 1259 | 32.87 | 13.69 | 42.25 | 8.30 | 34.21 | 9.72 |
| 1587 | 32.86 | 12.65 | 39.50 | 9.28 | 32.78 | 9.71 |
| 2000 | 31.57 | 12.05 | 36.11 | 9.14 | 32.66 | 9.33 |
| 2519 | 35.71 | 12.74 | 39.88 | 7.80 | 41.08 | 9.19 |
| 3174 | 45.46 | 14.86 | 47.38 | 6.50 | 54.70 | 9.51 |
| 4000 | 47.25 | 14.65 | 48.92 | 8.13 | 53.17 | 9.67 |

*Note.* Group Ia = mild hypernasal, Group Ib = moderate to severe hypernasal, Group II = TDC, SD = standard deviation.

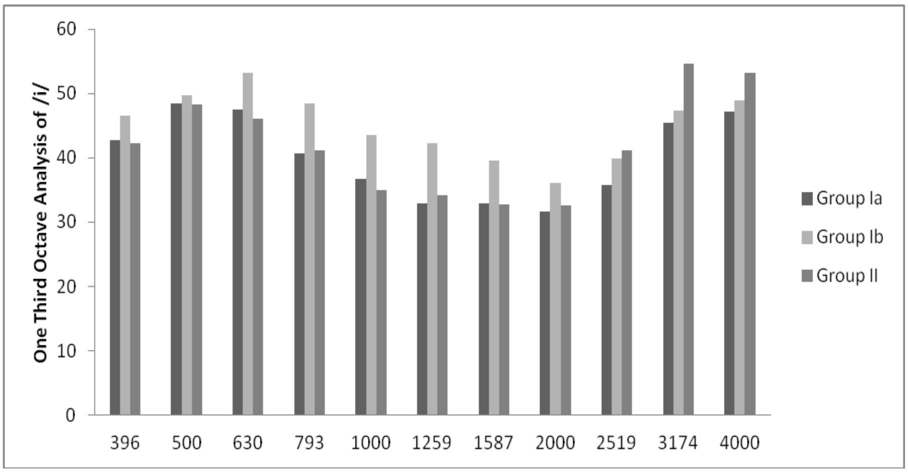


*Figure 20. One third octave analysis for /i/ across groups.* Group Ia = mild hypernasal, Group Ib = moderate to severe hypernasal, Group II = TDC.

The MANOVA results indicated significant differences in one third octave spectral measures for 793 Hz, 1000 Hz, 1259 Hz, 1587 Hz, and 3174 Hz ($p < 0.05$) across the groups as depicted in table 28.

Table 28

*One third octave analysis of vowel /i/ differentiating the groups*

| MANOVA | Spectral Frequencies (Hz) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 396 | 500 | 630 | 793 | 1000 | 1259 | 1587 | 2000 | 2519 | 3174 | 4000 |
| F(2,73) | .65 | .08 | 1.96 | 3.73 | 4.56 | 5.33 | 3.20 | 1.28 | 1.87 | 5.12 | 1.88 |
| *p*-value | .52 | .92 | .14 | .02* | .01* | .00* | .04* | .8 | .16 | .00* | .15 |

*Note*. MANOVA = Multivariate analysis, *$p < 0.05$.

To find homogeneous subsets of groups, post hoc multiple comparisons was carried out using Duncan's test. The post hoc analysis revealed significant differences between mild hypernasal and moderate to severe hypernasal and also between TDC and moderate to severe hypernasal group in 793 Hz, 1000 Hz, 1587 Hz, and 3174 Hz for vowel /i/ ($p < 0.05$).

***Correlation of one third octave spectra analysis of vowel /i/ with perceived nasality***

The table 29 indicates correlation of perceived nasality exhibited by children with RCLP and TDC with one third octave spectra analysis of vowel /i/ across the frequencies 396Hz, 500Hz, 630Hz, 793Hz, 1000Hz, 1259Hz, 1587 Hz, 2000Hz, 2519Hz, 3174Hz, and 4000Hz. The correlation coefficients were significant ($p < 0.05$) for vowel /i/ at 793Hz (0.25), 1000Hz (0.35), 1259Hz (0.33), 1587Hz (0.29) and 3174Hz (-0.31) ranging from -0.31 to 0.35. The significant positive correlation at mid frequencies and negative correlation at high frequencies is observed. The correlation coefficient indicates the perception of nasality in the speech can have moderate influence on the measures of one third octave spectral energy.

Table 29

*Correlation of one third octave spectra analysis of /i/ with perceived nasality*

| Stimulus | Frequency (Hz) | SCC | *p*–value |
|---|---|---|---|
| Vowel /i/ | 396 | 0.102 | 0.39 |
| | 500 | 0.050 | 0.67 |
| | 630 | 0.195 | 0.09 |
| | 793 | 0.258 | 0.02* |
| | 1000 | 0.358 | 0.00* |
| | 1259 | 0.334 | 0.00* |
| | 1587 | 0.290 | 0.01* |
| | 2000 | 0.153 | 0.19 |
| | 2519 | -0.040 | 0.73 |
| | 3174 | -0.313 | 0.00* |
| | 4000 | -0.181 | 0.12 |

*Note.* *$p < 0.05$, SCC = Spearman correlation coefficient

***Reliability measures of one third octave analysis for vowel /i/***

The test - retest reliability for measuring one-third octave spectra analysis for vowel /i/ was performed for 25 % of the entire sample across the groups. Reliability measures were carried out using Cronbach's alpha co-efficient for the above mentioned variables. The test - retest reliability of one-third octave spectra analysis for vowel /i/ was good for children with RCLP than TDC across the frequencies ranged from 0.73 to 0.97. The TDC also exhibited good reliability across the frequencies except at 630 Hz and 4000 Hz as depicted in table 30.

Table 30

*Test-retest reliability measures of one third octave spectra analysis for vowel /i/*

| Participants | Spectral Frequency (Hz) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 396 | 500 | 630 | 793 | 1000 | 1259 | 1587 | 2000 | 2519 | 3174 | 4000 |
| Group Ia | .92 | .75 | .86 | .82 | .91 | .95 | .94 | .96 | .95 | .92 | .92 |
| Group Ib | .91 | .94 | .86 | .86 | .86 | .84 | .90 | .94 | .97 | .73 | .92 |
| Group II | .89 | .82 | .52 | .81 | .88 | .74 | .92 | .85 | .97 | .80 | .58 |

*Note.* Group Ia = mild hypernasal, Group Ib = moderate to severe hypernasal, Group II = TDC.

### ***Mean of one third octave spectra analysis of vowel /i/ in /pit/ across the groups***

The one third octave spectra analysis of vowel /i/ in /pit/ was measured across all the groups and the mean values were calculated. Table 31 and figure 21 depicts the mean and SD of one third octave spectra analysis for vowel /i/ in /pit/ across the groups. Over all the groups exhibited decreased energy concentration at all the frequencies except 1000Hz, 1259Hz, 1587Hz, and 2000Hz. Minimal differences in energy concentration across the groups were observed for 630 Hz. There was no consistent trend noticed in amplitude across the frequencies and groups. However, TDC exhibited similar amplitudes at low and mid frequencies and increased amplitudes at high frequencies only for 2519Hz, 3174Hz, and 4000Hz than children with RCLP. Then relatively lower amplitude at one third octave spectral frequencies for /i/ was observed in mild hypernasal group across the frequency range than other groups. Among the children with RCLP, moderate to severe hypernasal group indicated increase in amplitudes across frequency range than mild hypernasal group. The increase in amplitude was indicated by moderate to severe hypernasal group for 396Hz, 793Hz, 1000 Hz, 1259 Hz, and 1587Hz than mild hypernasal and TDC.

Table 31

*Mean and SD of one-third octave analysis of vowel /i/ in /pit/.*

| Frequency (Hz) | Amplitude (dB) | | | | | |
|---|---|---|---|---|---|---|
| | Group Ia | | Group Ib | | Group II | |
| | Mean | SD | Mean | SD | Mean | SD |
| 396 | 47.06 | 18.09 | 58.64 | 8.91 | 54.89 | 10.91 |
| 500 | 42.16 | 15.88 | 49.28 | 8.00 | 51.54 | 9.44 |
| 630 | 50.23 | 13.60 | 50.91 | 12.16 | 50.54 | 10.55 |
| 793 | 42.36 | 17.44 | 51.56 | 8.91 | 47.50 | 8.11 |
| 1000 | 37.42 | 14.68 | 45.97 | 6.86 | 40.40 | 7.38 |
| 1259 | 35.85 | 14.00 | 44.76 | 5.31 | 41.26 | 7.22 |
| 1587 | 33.63 | 15.09 | 41.07 | 4.78 | 39.83 | 6.23 |
| 2000 | 33.27 | 14.89 | 40.70 | 7.89 | 43.43 | 8.16 |
| 2519 | 39.68 | 17.49 | 46.50 | 11.77 | 53.65 | 9.75 |
| 3174 | 45.70 | 16.44 | 50.57 | 10.13 | 60.11 | 7.78 |
| 4000 | 44.85 | 16.53 | 51.45 | 10.10 | 54.18 | 9.01 |

*Note.* Group Ia = mild hypernasal, Group Ib = moderate to severe hypernasal, Group II = TDC, SD = Standard deviation.

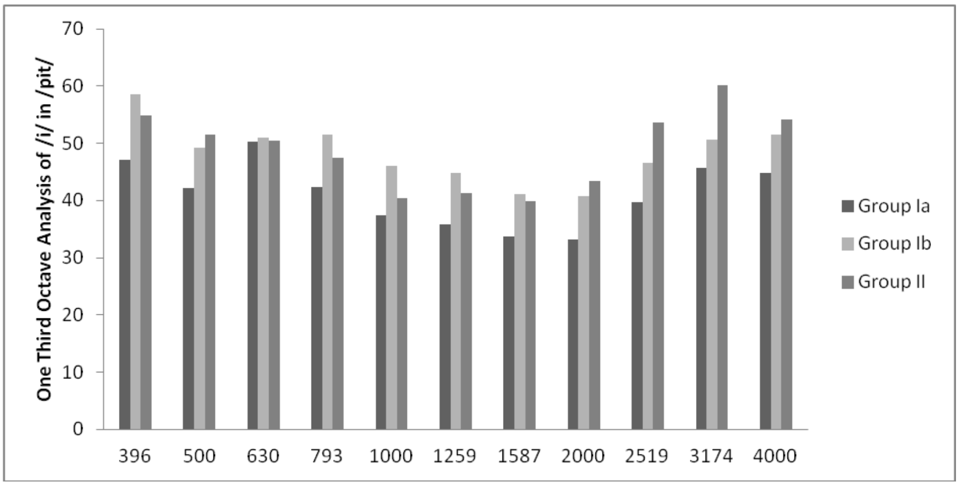


*Figure 21*. One third octave analysis for /i/ in /pit/ across groups. Group Ia = mild hypernasal, Group Ib = moderate to severe hypernasal, Group II = TDC.

The MANOVA results indicated significant differences in one third octave spectral measures for most of the frequencies except 630 Hz and 2000 Hz across the groups at $p < 0.05$ level of significance as depicted in table 32.

Table 32

*One third octave analysis of vowel /i/ in /pit/ differentiating the groups*

| MANOVA | Frequencies | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 396 | 500 | 630 | 793 | 1000 | 1259 | 1587 | 2000 | 2519 | 3174 | 4000 |
| F(2,73) | 4.76 | 4.34 | .01 | 3.43 | 4.33 | 5.27 | 4.01 | 5.81 | 6.78 | 9.46 | 3.72 |
| *p*-value | 0.01* | 0.01* | 0.98 | 0.03* | 0.00* | 0.00* | 0.02* | 0.05 | 0.00* | 0.00* | 0.02* |

*Note.* MANOVA = Multivariate analysis, *$p < 0.05$

To find homogeneous subsets of groups, post hoc multiple comparisons was carried out using Duncan's test. The subset indicates set of any two groups. The post hoc analysis revealed significant differences between mild hypernasal with moderate to severe hypernasal and TDC for 396 Hz, 500 Hz, and 1587 Hz. Among mild and moderate to severe hypernasal groups significant differences in amplitude were noticed at 793 Hz, 1000 Hz, 1259 Hz, 2519 Hz, and 4000 Hz ($p < 0.05$).

***Correlation of one third octave spectra analysis of vowel /i/ in /pIt/ with perceived nasality***

The table 33 indicates correlation of perceived nasality exhibited by children with RCLP and TDC with one third octave spectra analysis of vowel /i/ in /pit/ across the frequencies 396Hz, 500Hz, 630Hz, 793Hz, 1000Hz, 1259Hz, 1587 Hz, 2000Hz, 2519Hz, 3174Hz, and 4000Hz. The correlation coefficients were significant ($p < 0.05$) for vowel /i/ in the context of /pIt/ at 1000Hz (0.26), 2519Hz (-0.25), 3174Hz (-0.38) indicating negative correlation at high frequency bands and poor positive correlation at mid frequencies.

Table 33

*Correlation of one third octave spectra analysis of /i/ in /pit/ with perceived nasality*

| Stimulus | Frequency (Hz) | SCC | *p*–value |
|---|---|---|---|
| Vowel /i/ in /pit/ | 396 | 0.108 | 0.361 |
| | 500 | -0.056 | 0.637 |
| | 630 | -0.001 | 0.992 |
| | 793 | 0.140 | 0.239 |
| | 1000 | 0.266 | 0.023* |
| | 1259 | 0.173 | 0.142 |
| | 1587 | 0.062 | 0.603 |
| | 2000 | -0.171 | 0.148 |
| | 2519 | -0.255 | 0.029* |
| | 3174 | -0.382 | 0.001* |
| | 4000 | -0.096 | 0.421 |

*Note.* *$p < 0.05$, SCC = Spearman correlation coefficient

***Test-retest reliability measures of one third octave analysis of vowel /i/ in /pit/***

The test - retest reliability of one-third octave spectra analysis for vowel /i/, was performed for 25% of the entire sample across the groups. Reliability measures were carried out using Cronbach's alpha co-efficient for the above mentioned variables. Table 34 indicates the Cronbach's alpha co-efficient for one-third octave spectra analysis for vowel /i/ in /pit/ with perceived nasality ranged from 0.66 to 0.99 across the groups and stimuli. The test - retest reliability was good at most of the frequencies except for moderate hypernasal group at 1587 Hz.

Table 34

*Test-retest reliability measures of one third octave spectra analysis for vowel /i/ in /pit/*

| Participants | Spectral Frequencies (Hz) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 396 | 500 | 630 | 793 | 1000 | 1259 | 1587 | 2000 | 2519 | 3174 | 4000 |
| Group Ia | .90 | .99 | .88 | .98 | .94 | .95 | .93 | .92 | .98 | .97 | .88 |
| Group Ib | .89 | .83 | .93 | .84 | .91 | .79 | .66 | .83 | .94 | .81 | .85 |
| Group II | .73 | .88 | .96 | .78 | .82 | .96 | .89 | .95 | .96 | .95 | .96 |

*Note.* Group Ia = mild hypernasal, Group Ib = moderate to severe hypernasal, Group II = TDC.

***The mean of one third octave spectra analysis for vowel /i/ in /tip/ across the groups***

Table 35 and figure 22 depicts the mean and SD of one third octave spectra analysis of vowel /i/ in /tip/ across the groups. Over all the groups exhibited increased energy concentration at all the frequencies except 1000Hz, 1259Hz, and 1587Hz. However, in general minimal differences in energy concentration across the groups was observed at 630 Hz and 4000 Hz. The TDC exhibited increased amplitude across frequencies than mild hypernasal group except at 630 Hz. The energy concentration was more in children with moderate hypernasal group at 396Hz, 793Hz, 1000 Hz, 1259 Hz, 1587 Hz and 2000 Hz than mild hypernasal groups and TDC.

Table 35

*Mean and SD of one-third octave analysis of vowel /i/ in /tip/*

| Frequency (Hz) | Amplitude (dB) | | | | | |
|---|---|---|---|---|---|---|
| | Group Ia | | Group Ib | | Group II | |
| | Mean | SD | Mean | SD | Mean | SD |
| 396 | 45.96 | 18.03 | 59.42 | 8.76 | 54.74 | 11.12 |
| 500 | 40.82 | 14.72 | 46.56 | 10.30 | 50.94 | 9.24 |
| 630 | 52.41 | 17.07 | 52.41 | 9.58 | 51.78 | 11.34 |
| 793 | 44.46 | 16.48 | 54.31 | 10.40 | 46.97 | 7.81 |
| 1000 | 37.67 | 15.34 | 47.33 | 7.06 | 41.22 | 6.96 |
| 1259 | 36.19 | 15.41 | 42.78 | 9.25 | 41.82 | 5.87 |
| 1587 | 34.44 | 15.80 | 40.94 | 6.92 | 38.03 | 6.12 |
| 2000 | 35.25 | 16.94 | 42.07 | 7.27 | 40.54 | 6.55 |
| 2519 | 42.26 | 17.94 | 45.29 | 8.42 | 52.26 | 8.14 |
| 3174 | 47.07 | 17.92 | 49.15 | 9.41 | 59.88 | 7.19 |
| 4000 | 46.78 | 17.52 | 51.59 | 10.71 | 53.95 | 7.29 |

*Note*. Group Ia = mild hypernasal, Group Ib = moderate to severe hypernasal, Group II = TDC, SD = standard deviation.

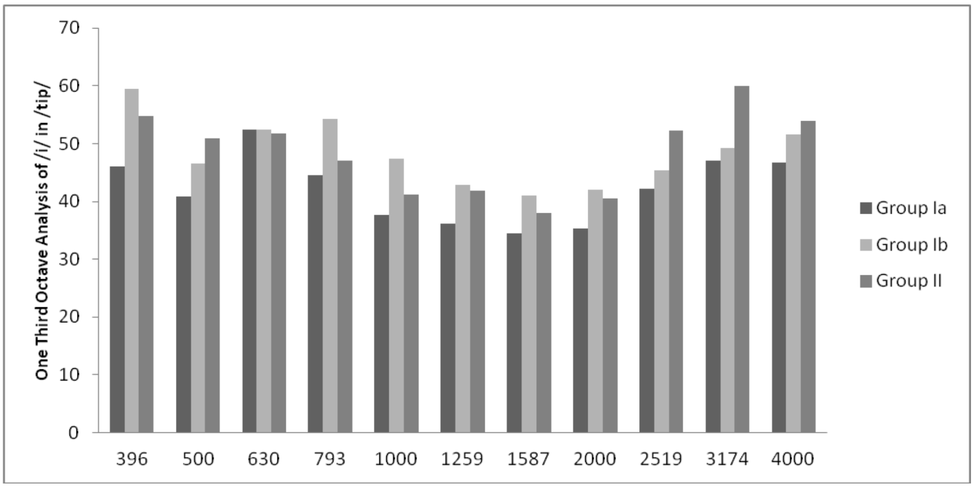


*Figure 22*. One third octave analysis for /i/ in /tip/ in across groups. Group Ia = mild hypernasal, Group Ib = moderate to severe hypernasal, Group II = TDC.

The MANOVA results indicated significant differences in one third octave spectral measures at 396 Hz, 500 Hz, 793 Hz, 1000 Hz, 2519 Hz, and 3174 Hz ($p < 0.05$) across the groups as depicted in table 36.

Table 36

*One third octave analysis of vowel /i/ in /tip/ across the groups*

| MANOVA | Spectral Frequency Analysis (Hz) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 396 | 500 | 630 | 793 | 1000 | 1259 | 1587 | 2000 | 2519 | 3174 | 4000 |
| F(2,73) | 6.37 | 4.68 | .02 | 4.36 | 5.22 | 2.58 | 2.31 | 2.44 | 4.39 | 7.94 | 2.09 |
| *p*-value | .00* | .01* | .98 | .01* | .00* | .08 | .10 | .09 | .01* | .00* | .13 |

*Note.* MANOVA = multivariate analysis, $*p < 0.05$

To find homogeneous subsets of groups, post hoc multiple comparisons was carried out using Duncan's test. The subset indicates set of any two groups. The post hoc analysis revealed significant differences between mild hypernasal with moderate to severe hypernasal and TDC for 396 Hz, and 1587 Hz at $p < 0.05$. The TDC was significantly different from mild hypernasal groups for energy concentrated at 500 Hz and 2519 Hz. The energy concentration at 793 Hz and 1000 Hz was significantly different between mild and moderate to severe hypernasal groups ($p < 0.05$).

***Correlation of one third octave spectra analysis of /i/ in /tIp/ with perceived nasality.***

The table 37 indicates correlation of perceived nasality exhibited by children with RCLP and TDC with one third octave spectra analysis of vowel /i/ in /tip/ across all the frequencies. The correlation coefficients were significant at 0.05 for vowel /i/ in the context of /tIp/ at 793Hz (0.26), 1000Hz (0.29), 2519Hz (-0.32), and 3174Hz (-0.42) ranging from -0.42 to 0.26. The positive and negative significant correlation coefficient indicates that the perception of nasality in the speech can have moderate influence on the measures of one third octave spectral energy.

Table 37

*Correlation of one third octave spectra analysis with perceived nasality for /i/ in /tip/.*

| Stimulus | Frequency (Hz) | SCC | *p*–value |
|---|---|---|---|
| Vowel /i/ in /tip/ | 396 | 0.145 | 0.221 |
| | 500 | -0.150 | 0.205 |
| | 630 | 0.038 | 0.748 |
| | 793 | 0.266 | 0.023* |
| | 1000 | 0.291 | 0.013* |
| | 1259 | 0.050 | 0.674 |
| | 1587 | 0.191 | 0.106 |
| | 2000 | 0.041 | 0.727 |
| | 2519 | -0.329 | 0.005* |
| | 3174 | -0.423 | 0.000* |
| | 4000 | -0.076 | 0.522 |

*Note.* *$p < 0.05$, SCC = Spearman correlation coefficient

***Test-retest reliability measures of one third octave analysis for vowel /i/ in /tip/***

The test - retest reliability for measuring one-third octave spectra analysis for vowel /i/, was performed in 25 % of the entire sample across the groups. Reliability measures were carried out using Cronbach's alpha co-efficient for the above mentioned variables. Table 38 illustrates the Cronbach's alpha co-efficient for one-third octave spectra analysis of vowel /i/ in /tip/ ranging from 0.43 to 0.99 across the groups and stimuli. The test-retest reliability was good across all the frequencies except for 1259 Hz and 3174 Hz in TDC and mild hypernasal group.

Table 38

*Test-retest reliability measures of one third octave spectra analysis for vowel /i/ in /tip/*

| Participants | Spectral Frequencies (Hz) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 396 | 500 | 630 | 793 | 1000 | 1259 | 1587 | 2000 | 2519 | 3174 | 4000 |
| Group Ia | .90 | .83 | .85 | .80 | .91 | .89 | .95 | .91 | .72 | .43 | .88 |
| Group Ib | .79 | .83 | .81 | .85 | .85 | .91 | .79 | .94 | .86 | .81 | .90 |
| Group II | .96 | .94 | .98 | .99 | .84 | .49 | .88 | .94 | .88 | .96 | .95 |

*Note*. Group Ia = mild hypernasal, Group Ib = moderate to severe hypernasal, Group II = TDC.

### 4.3.4 Voice Low Tone to High Tone Ratio Measures

The VLHR measures were evaluated for vowels /a/, /i/, and /i/ in the context of CVC (/pit/ & /tip/) in all the subjects.

***The mean comparison of VLHR of vowels /a/, /i/, and /i/ in /pit/ and /tip/ across the groups***

The VLHR was measured for all the stimuli across the groups. Table 39 and figure 23 depicts the results of mean and SD of VLHR in vowels /a/, /i/, and /i/ in /pit/ and /tip/ with respect to groups. VLHR measures were high for vowel /i/ in isolation and also in the context of /pit/ and /tip/ than vowel /a/. The increased VLHR measures were observed for children with RCLP than TDC across all the stimuli except /i/. The increased VLHR was exhibited by mild hypernasal group followed by moderate to severe hypernasal and TDC for VLHR of /a/ and /i/ in /pit/. Reduced measures of VLHR were indicated in moderate to severe hypernasal group for vowel /i/. Minimal differences were noticed in the measures of VLHR for /i/ and /i/ in /tip/ across all the groups.

Table 39

*Mean and SD of VLHR*

| Participants | Amplitude (dB) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | /a/ | | /i/ | | /pit/ | | /tip/ | |
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| Group Ia | 7.21 | 2.24 | 11.30 | 5.01 | 9.86 | 4.00 | 7.60 | 4.09 |
| Group Ib | 6.13 | 2.50 | 10.16 | 3.68 | 8.25 | 3.37 | 7.65 | 2.86 |
| Group II | 5.44 | 2.98 | 10.65 | 3.35 | 7.52 | 4.10 | 6.77 | 4.02 |

*Note.* Group Ia = mild hypernasal, Group Ib = moderate to severe hypernasal, Group II = TDC, SD = standard deviation.

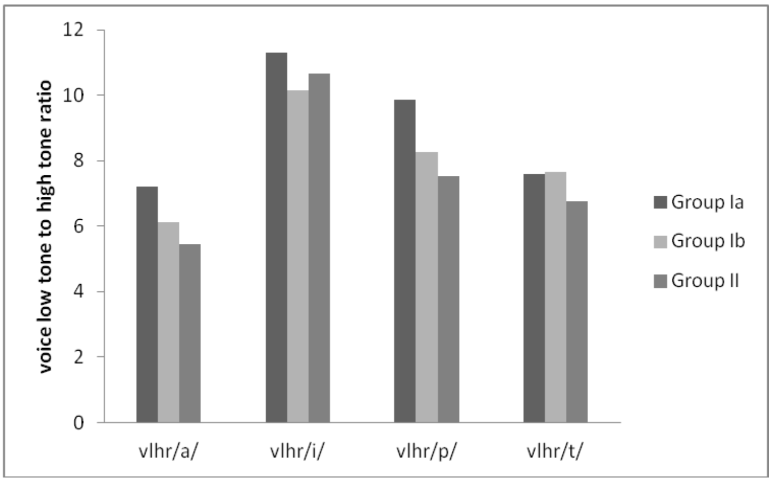


*Figure 23. Mean of VLHR.* Group Ia = mild hypernasal, Group Ib = moderate to severe hypernasal, Group II = TDC.

The MANOVA results indicated no significant differences in VLHR measures for all the stimuli across the groups [/a/ = {F(2,73) = 2.82, $p < 0.06$}, /i/ = {F(2,73) = 0.46, $p < 0.62$}, /pit/ = {F(2,73) = 2.31, $p < 0.10$}, /tip/ = {F(2,73) = 0.44, $p < 0.64$}].

#### *Correlation of VLHR measures with perceived nasality*

The table 40 indicates correlation of perceived nasality exhibited by children with RCLP and TDC with VLHR measures of vowels (/a/, /i/, /i/ in /pit/, /i/ in /tip/). The VLHR measures were not significantly correlated with perceived nasality.

Table 40

*Correlation of VLHR with perceived nasality*

| **Parameters** | **SCC** | ***p* – value** |
|---|---|---|
| **VLHR/a/** | 0.084 | 0.47 |
| **VLHR /i/** | -0.042 | 0.72 |
| **VLHR /i/ in /pit/** | 0.086 | 0.46 |
| **VLHR /i/ in /tip/** | 0.130 | 0.27 |

*Note.* VLHR = Voice low tone to high tone ratio, SCC = Spearman correlation coefficient.

#### *Test-retest reliability measures of VLHR*

The test - retest reliability for measuring VLHR for vowel /a/, /i/, and /i/ in the context of /pit/ and /tip/ was performed for 25 % of the entire sample across the groups. Reliability measures were carried out by Cronbach’s alpha co-efficient for the above mentioned variables. Table 41 illustrates the Cronbach’s alpha co-efficient for

VLHR which ranged from 0.79 to 0.98 across the groups and stimuli. The reliability test result indicated a good reliability across the stimuli.

Table 41

*Test-retest reliability measures of VLHR*

| Participants | Stimuli | | | |
|---|---|---|---|---|
| | /a/ | /i/ | /pit/ | /tip/ |
| Group Ia | 0.879 | 0.927 | 0.917 | 0.902 |
| Group Ib | 0.799 | 0.943 | 0.973 | 0.908 |
| Group II | 0.853 | 0.900 | 0.960 | 0.986 |

*Note*. Group Ia = mild hypernasal, Group Ib = moderate to severe, Group II = TDC.

### 4.3.5 Jitter and Shimmer Measures

The perturbations of the voice were analyzed using jitter and shimmer measures for phonation of vowels /a/ and /i/ for all the subjects.

***Mean of jitter and shimmer vowels /a/ and /i/ across the groups***

The mean and SD of jitter and shimmer measures of vowels across the groups are shown in table 42, figure 24 and figure 25. The results indicated relatively more jitter and shimmer in children with RCLP than TDC. Among the children with RCLP, increased jitter and shimmer measures were exhibited by mild hypernasal group than moderate to severe hypernasal group. With regard to stimuli, jitter and shimmer measures were high for vowel /i/ than /a/.

Table 42

*Mean and SD of jitter (%) and shimmer (dB) for vowels /a/ and /i/*

| Participants | Jitter | | | | Shimmer | | | |
|---|---|---|---|---|---|---|---|---|
| | /a/ | | /i/ | | /a/ | | /i/ | |
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| Group Ia | 0.37 | 0.16 | 0.50 | 0.59 | 8.03 | 3.41 | 7.0 | 4.31 |
| Group Ib | 0.36 | 0.20 | 0.39 | 0.21 | 5.80 | 3.05 | 5.58 | 2.65 |
| Group II | 0.31 | 0.12 | 0.39 | 0.20 | 3.62 | 2.95 | 6.06 | 2.58 |

*Note*. Group Ia = mild hypernasal, Group Ib = moderate to severe, Group II = TDC, SD = standard deviation.

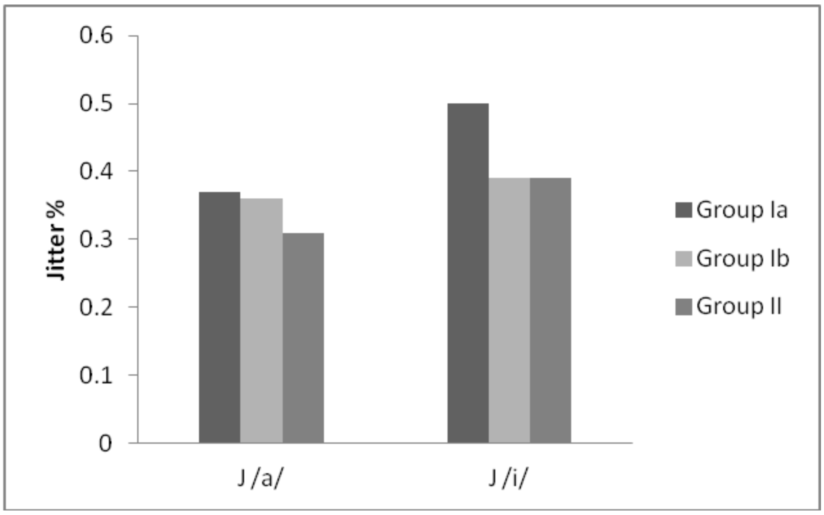

*Figure 24. Mean and SD of jitter (%) for vowels /a/ and /i/.* Group Ia = mild hypernasal, Group Ib = moderate to severe, Group II = TDC.

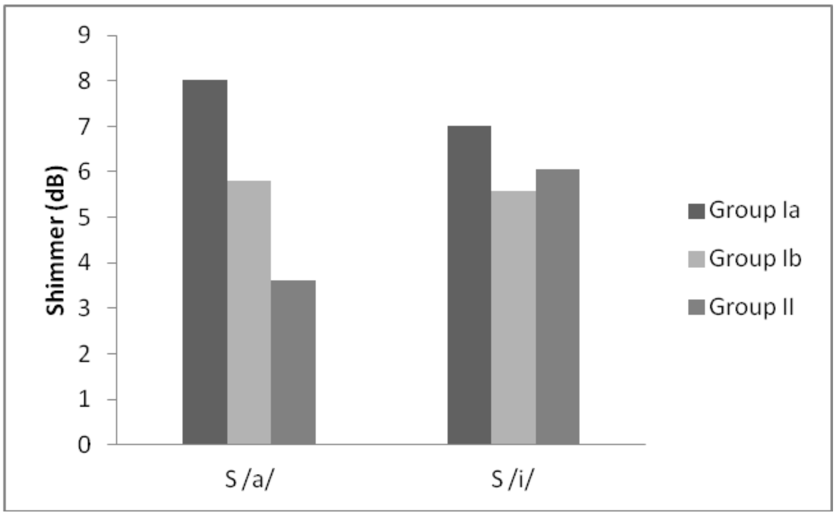

*Figure 25. Mean and SD of shimmer (dB) for vowels /a/ and /i/. Group Ia = mild hypernasal, Group Ib = moderate to severe, Group II = TDC.*

The results of MANOVA indicating highly significant ($p < 0.01$) difference between the groups in measures of shimmer for vowel /a/. There was no significant difference across the groups in measures of jitter for both the vowels [/a/ = {$F(2,73) = 0.99$, $p < 0.37$}, /i/ = {$F(2,73) = 0.59$, $p < 0.55$}]. The measures of shimmer for vowel /a/ was found to be significantly different across the groups [/a/ = {$F(2,73) = 12.04$, $p < 0.01$}, /i/ = {$F(2,73) = 1.19$, $p < 0.31$}].

To find homogeneous subsets of groups, post hoc multiple comparisons was carried out using Duncan’s test. The subset indicates set of any two groups. The post hoc analysis revealed significant differences between each subset of three groups for measures of shimmer for vowel /a/, at $p < 0.05$ level of significance.

***Correlation of jitter and shimmer measures with perceived nasality***

The table 43 indicates correlation of perceived nasality exhibited by children with RCLP and TDC with jitter and shimmer measures for vowels /a/ & /i/. The measures were not significantly correlated with perceived nasality except shimmer measure for vowel /a/. However, the spearman's correlation coefficient was very low (0.259) for shimmer of /a/. This indicates poor correlation of perturbation measures with the perceived nasality.

Table 43

*Correlation of jitter and shimmer measures with perceived nasality*

| **Parameters** | **SCC** | ***p* – value** |
|---|---|---|
| **Jitter/a/** | 0.058 | 0.62 |
| **Jitter /i/** | -0.020 | 0.98 |
| **Shimmer /a/** | 0.259 | 0.02* |
| **Shimmer /i/** | -0.066 | 0.57 |

*Note.* SCC = Spearman correlation coefficient, $*p < 0.05$

***Test-retest reliability measures of Jitter and Shimmer for vowels /a/ and /i/.***

The test - retest reliability for measures of jitter and shimmer for vowels /a/ and /i/ was performed for 25% of the entire sample across the groups. Reliability measures were carried out using Cronbach's alpha co-efficient for the above mentioned variables. Table 44 illustrates the Cronbach's alpha co-efficient for measures of jitter and shimmer for vowels /a/ and /i/ which ranged from 0.68 to 0.95 and 0.68 to 0.98 respectively. The test - retest reliability was good for all the measures except for jitter measures of /a/ in moderate to severe hypernasal and shimmer measures of /i/ in TDC.

Table 44

*Test-retest reliability measures of jitter and shimmer of vowels*

| Participants | Jitter | | Shimmer | |
|---|---|---|---|---|
| | /a/ | /i/ | /a/ | /i/ |
| Group Ia | 0.782 | 0.951 | 0.950 | 0.943 |
| Group Ib | 0.685 | 0.891 | 0.953 | 0.988 |
| Group II | 0.912 | 0.882 | 0.932 | 0.681 |

*Note.* Group Ia = mild hypernasal, Group Ib = moderate to severe hypernasal, Group II = TDC.

### *Discussion*

Spectral analysis was used to explore the acoustic properties of speech in individuals with CLP (Watterson, Hilton, & McFarlane, 1996). In the present study, acoustic analysis of speech using one-third octave spectra analysis, VLHR measures and perturbation measures (jitter % and shimmer %) were investigated across the groups of children with RCLP exhibiting mild hypernasality, moderate to severe hypernasality and TDC. The results indicated significant differences across the groups for few measures of one third octave spectral analysis, shimmer measures for vowel /a/ and there was significant correlation of these measures with perceived nasality, thus first and second hypotheses were rejected. Whereas, there was no significant differences across the groups in the measures of VLHR, jitter, shimmer measures of /i/, and no significant correlation of these measures with perceived nasality thus accepting the first and second hypotheses. The test - retest reliability measures were indicating moderate to good reliability of these acoustic measures.

#### *One third octave spectra analysis and VLHR*

The review of literature indicated that nasalization cannot be measured accurately by using formant analysis alone, specifically in the presence of high fundamental frequency (Kataoka, 1988; Kataoka et al., 1996, 2001). The shape of the entire region of the spectral envelope is important for vowel perception rather than the frequency and amplitude of the spectral peaks (Beddor & Hawkins, 1990). Therefore, 1/3$^{rd}$ octave spectral analysis evaluates overall spectral envelope to have a theoretical advantage in analyzing hypernasal vowels. Hence in the present study, 1/3$^{rd}$ octave spectra analysis was used to evaluate the acoustic characteristics of nasalization. Another advantage of using one third octave spectra analysis is that the 1/3rd octave bandwidth matches with the critical band analyzed by ear for the perception of speech (Pols et al., 1969). Hence, it can be postulated to correlate well with the perceptual analysis of nasalization.

One third octave spectral energy across the frequencies ranging from 100 Hz to 16000 Hz was calculated in the present study. However, study by Kataoka et al. (1996) reported that significant change in spectral amplitude of speech with hypernasality was evident in the frequency bands from 396 Hz to 4000 Hz. Hence, in the present study, evaluation of spectral amplitudes between 396 Hz to 4000 Hz for the final analysis was considered instead of frequency bands from 100 Hz to 16000 Hz. The results of the present study indicated diversifying outcomes across all the stimulus for all the groups. There was no specific trend observed to conclude on the effect of hypernasality in spectral amplitude of vowels (/a/ & /i/) in isolation and /i/ in the CVC context of /pit/ and /tip/. This can be due to the presence of variations in the perception of vowel height in isolation and in phonetic contexts changes with the rising and lowering of nasal vowels at specific frequency bands. The amplitude of the signal depends on the acoustic properties of vowels. Several authors (Fant, 1970; Hawkins & Stevens, 1985; Beddor, 1993; Maeda, 1993) have reported that spectral characteristics vary across vowels in nasalized speech.

Among the vowels, the differences in spectral amplitude across the TDC and children with RCLP were high for /i/ in the context of /pit/, /tip/ followed by isolated vowel /i/ than /a/ especially at mid and high frequencies. The reduced differences in spectral amplitude of vowel /a/ than /i/ across the groups can be attributed to the narrow lingual constriction, which leads to significant perception of nasal sound transmission even at small degree of nasal coupling (Fant, 1970). This can lead to relatively more nasalized production of /i/ in children with RCLP than TDC. The study done by Carignan et al. (2010) reported that mid of the tongue is relatively at higher position during the production of nasalized /i/ than /a/. Hence, the variations in the spectral properties of nasalized vowel /i/ are relatively more than nasalized /a/. The change in spectral characteristics results in a difference in perception of severity of nasality in vowel production. The results of the present study are in accordance with the study by Vogel et al. (2009) who reported similar amplitude for frequency bands of vowel /a/ produced by RCLP and TDC. Another study by Kataoka et al. (1996) evaluated one third octave spectral energies for vowels and reported that vowel /i/ can be considered as the best stimulus for determining nasality. These findings were attributed to the greater velar height during the production of vowel /i/. The high vowel /i/ require less nasal coupling to be perceived as nasal than low vowels such as /a/. Chen (1996) also indicated that the presence of additional peaks are evident in vowel /i/ than /a/. The VP opening of 0.8 $cm^2$ for /a/ may cause extra peak amplitude of 12.1 dB greater for nasal vowel than non nasal vowel /a/. The VP opening of 0.3 $cm^2$ for /i/ leads to 13.5 dB more peak amplitude than non nasalized vowel. The additional peaks are due to large VP opening resulting in shifts in the nasal zero so that moves away from nasal pole causing extra peak above the first formants.

Among the groups, children with moderate to severe hypernasality exhibited lower spectral amplitude at high frequencies followed by mild hypernasality, than TDC. There was an increase in the spectral amplitude around low and mid frequencies and reduced at high frequencies with the increase in the perceived nasality across the stimuli in children with RCLP. This can be attributed to the change in the shape of the vocal tract in relation with the velopharyngeal gap which leads to increased perception of nasality. Generally larger spaces in the vocal tract resonate at lower frequencies, whereas high frequency resonance resulted from smaller places of vocal tract. Hence, the amplitude at lower frequencies gets resonated by the increase in cavity area due to the velopharyngeal opening. Increase in velopharyngeal gap which in turn can lead to increased perception of nasality. The increase in cross sectional area of the velopharyngeal opening can led to broaden first formant and lowering of the overall amplitude. The energy concentrated at particular frequencies is indicated as formants. In the first formant region, a pole zero pair was added and the gap between the pole and zero increases with respect to velopharyngeal gap. In this gap, an additional pole was added indicating spectral prominence with the increased VP gap (Hawkins & Stevens, 1983). The results of this study are in agreement with the findings of Vogel et al. (2009) who reported higher amplitude for /pit/ and /tip/ at frequency bands from 476 Hz to 1200 Hz and 600 Hz to 1511 Hz respectively in hypernasal speakers. They also stated that the significant differences in one third octave spectra analysis were found only across severe hypernasal and TDC.

Bunton and Story (2013) hypothesized that the acoustic properties of nasality in vowels irrespective of the language depends on the prominence of the spectral peak at the vicinity of F1. These conjectures were in accordance with the reports of McDonald and Koepp-Baker (1951) who stated that the variation in acoustic characteristics of speech indicates the shift in the perceived nasality from normal to abnormal. Kataoka et al. (2001) also indicated significant differences in the amplitudes of vowel /i/ between the TDC and children with RCLP. The increase in perceived nasality was attributed to the change in shape of the entire spectral envelope at fundamental frequency or formant frequencies and presence of spectral peak between F1 and F2. The findings of the study done by Miller (1989) showed that the change in at least one of the formant frequency (F0, F1, F2, & Fn) i.e., a spectral peak between F1 and F2 results in change in the relative level of $F_0$ to each formant. This change apparently results in a different perceived severity of hypernasality during vowel production. Hypernasal vowels in general, have broadened peaks and flattened spectra when the spectral peaks are not prominent (House & Stevens, 1956).

The results of the present study also indicated a positive correlation of one third octave spectral analysis with perception of hypernasality across the stimulus at mid frequency regions. This indicates an addition of spectral amplitude at mid frequencies along with the increased perception of nasality. Similarly, additional spectral peaks in the mid frequencies regions were reported by several acoustic studies of nasality (Chen, 1996; Yoshida, et al., 2000 & Kataoka et al., 2001). The additional spectral peaks between F1 and F2 were only noticed in moderate to severe hypernasal group but not in mild hypernasal group. The negative correlation was noticed at high frequency regions indicating the converse relationship of spectral amplitude with the perceived nasality.  This can be due to the dampening of spectral energy at high frequencies. The finding of the present study indicated reduced amplitudes in children with hypernasality was observed at high frequency regions supports the reports of various researchers (House & Stevens, 1956; Hattori, Yamamota, & Fujimura, 1958; Fant, 1970; Kataoka, et al. 2001). These researchers reported that participants with hypernasal speech were exhibiting increased spectral amplitude between first and second formants and decreased between second and third formants.

The spectral change over the duration of the vowel was considered as the coexisting speech characteristics that influenced the percentage of hypernasality perceived. Hence, another acoustic measure based on spectral energy was considered for the investigation is VLHR. The VLHR measures were calculated by dividing the spectrum into a low-frequency power section (LFP) and a high frequency power section (HFP) artificially with the cut-off frequency of 600 Hz. The 600 Hz was used as cut off frequency on the basis of study done by Lee et al. (2009) who reported that VLHR measures calculated at 600Hz significantly correlated with perception of hypernasality. The results of the present study indicating the differences across the groups in VLHR measures were not statistically significant. There was also no significant correlation between VLHR measures with the perceived nasality. The VLHR measures are based on the sum of the amplitudes in the spectrum. The spectral amplitudes can also be attributed to variations in frequency domain characteristics of voice in nasalized speech, such as a reduction in the intensity of the first formant, the presence of extra resonances, and increased bandwidth of formants (Curtis, 1970). The formants can vary with respect to the position of articulators, particularly tongue. (Rong & Kuehn, 2010). The results are in accordance with the findings of Vogel et al. (2009) who also reported no significant differences in the VLHR measures in the children with hypernasality and TDC in the age range of 4 years to 12 years, using cut off frequency 600 Hz.

The review has revealed some contradictory results. The study done on adult population by Lee et al. (2003) reported a significant difference in VLHR measures between hyponasal and nonnasal groups. In another study reported by Lee, Wang, and Fu (2006) in a group of adults with residual fistula, significant differences across the participants with hypernasal and TDC were noticed. The diversity in findings can also be related to methodological variations among the studies. The present study was conducted on children with RCLP and TDC. The above mentioned studies were performed on the children with hyponasality and residual fistula.

The results of the present study also indicated high VLHR measures for vowel /i/ across the CVC contexts (/pit/ & /tip/) and low VLHR measure for vowel /a/ in children with RCLP than TDC. The high vowel /i/ will have F1 less than 600 Hz and F2 frequency will be higher than 600 Hz usually around 2600 Hz. The amplitude of the band centered at 2500Hz was significantly lower in the children with hypernasality using the one third octave spectral analysis for vowel /i/ (Lee et al. 2003). The VLHR will be higher in /i/ than vowel /a/ because, the results of one third octave spectra analysis indicated vowel /a/ as having less spectral energy in low frequencies than mid and high frequencies, the ratio of low to high frequencies will be obviously less. Similar results were also reported by Lee et al. (2008) who reported increased VLHR for vowel /i/ than other high and low back vowels, specifically low VLHR was noticed for vowel /a/. The increased VLHR in RCLP can be attributed to reduced spectral energy at high frequency regions than TDC in the presence of anti formats at high frequency regions in hypernasal speech. The reduced spectral energy between F2 and F3 is also reported by Yoshida et al. (2000) and Vogel et al. (2009). A study done by Lee et al. (2008) indicated decreased high frequency energy (anti-resonance) than low frequencies for nasal voices differentiating significantly from the acoustic characteristics of speech of healthy TDC..

***Jitter and Shimmer Measures***

The individuals with CLP try to compensate the variations in amplitude or spectral disturbances and to prolong the length of utterance during speech. This tend to increase the respiratory effort in order to build adequate intraoral pressure which is most often seen in individuals with VPD, this in turn can lead to vocal abuse altering the vocal fold physiology (Warren et al, 1969). Altered vocal cord vibrations are nothing but perturbations which are defined as cycle to cycle fundamental disturbance measures as jitter and cycle to cycle amplitude variability as shimmer (Teles & Rosinha, 2008). The aperiodicity of the voice is indicated by perturbation measures.

The results of the present study indicated increased jitter and shimmer in children with RCLP than TDC. This can be due to the presence of compensatory mechanism at the level of vocal folds in children with RCLP to compensate for reduced acoustic energy due to acoustic damping in the nasal tract. Hamlet (1973) also reported altered vocal cord vibrations for nasalized vowels. The similar findings were reported by Zajac and Linville, (1989) by examining the perturbations of voice in children with and without VPD. They indicated high jitter and harmonic to noise ratio in children with VPD.

The jitter and shimmer measures were high in mild than moderate to severe hypernasal groups in children with RCLP. However, the differences were not statistically significant except shimmer of vowel /a/. The correlation analysis also indicated no statistical significant correlation of perturbation measures with the perceived nasality except for vowel /a/ in measures of shimmer. There was a poor correlation between shimmer measures of /a/ and perceived nasality. Among vowels /i/ exhibited higher jitter and shimmer measures than /a/ across the groups. The differences can be attributed to the variations in the vocal tract constriction during the production of vowel /a/ and /i/. Depending on the extent of VPD, the abnormalities of velum may lead to hyper-adduction of the vocal folds altering the laryngeal physiology. The disordered laryngeal system leads to alterations in aerodynamic or neuromuscular event due to the imbalanced oronasal coupling in the presence of VPD (Zajac & Linville, 1989). The open velopharyngeal port during speech production can result in changes in the flow rate and transglottal pressures. Hence, individuals with VPD tend to compensate these changes by increasing the glottal resistance and thus would decrease the air flow. These changes help to maintain the subglottic pressure during speech production in individuals with VPD. The efforts to regulate aerodynamic and neuromuscular process in the presence of oronasal imbalance, in turn results in increased perturbations. Similar findings were reported by Van Lierde et al (2003) in individuals with VPD exhibiting increased jitter percentage due to the presence of alterations in the periodicity of vocal fold vibrations. The differences in the studies can be attributed to the methodological variations with respect to the subject selection, cut off frequency and the procedure used for the measurements.

### 4.4. Evaluation of Aerodynamic Parameters

The aerodynamic parameters (nasal emissions, MPD, and laryngeal aerodynamic measures) were evaluated and compared across children with RCLP and TDC.

#### 4.4.1. Measures of Nasal Emissions

The nasal emissions across the groups were measured for vowels /a/, /i/ and for a fricative /s/ using Glatzel mirror test.

***Median and quartile deviations measured for nasal emissions***

Nasal emissions were measured on a 4-point rating scale (ordinal data) for /a/, /i/ and /s/. The appropriate descriptive statistic for ordinal data especially for scaled measures is median. Hence the median for nasal emission ratings across the stimuli is calculated as shown in the table 45. The TDC were not exhibiting nasal emissions indicating median value “0” which was assigned across the stimuli. Children with RCLP were exhibiting mild to moderate nasal emissions indicating score of 1 by mild hypernasal group across the stimuli. The moderate to severe hypernasal group indicated mild to moderate nasal emissions with score of "1" and "1.5" for /a/ and /s/.

Table 45

*Median and quartile deviations for nasal emissions across the groups*

| Participants | /a/ | | /i/ | | /s/ | |
|---|---|---|---|---|---|---|
| | Median | QD | Median | QD | Median | QD |
| Group Ia | 0 | 0.5 | 1 | 0.5 | 1 | 1 |
| Group Ib | 0 | 0.5 | 1.5 | 0.5 | 1 | 0.5 |
| Group II | 0 | 0 | 0 | 0 | 0 | 0 |

*Note.* NE= nasal emission, Group Ia = mild hypernasal RCLP, Group Ib = moderate to severe RCLP, Group II = TDC, QD = quartile deviation.

Nasal emission measures for production of vowel /a/, /i/ and /s/ were rated on four point rating scale and subjected to Kruskal Wallis test to find the significant differences across the groups. The test results indicated significant differences in nasal emission were exhibited by the children across the groups ($p < 0.01$) for all the stimuli

[/a/ - {$\chi^2$ (2,73) = 13.95, $p < 0.01$}, /i/ - {$\chi^2$ (2,73) = 41.11, $p < 0.01$}, /s/ - {$\chi^2$ (2,73) = 33.70, $p < 0.01$}].

The Mann – Whitney U test was performed to find the significant difference between the groups ($p < 0.01$) as depicted in table 46. The test results indicated significant differences in the rating of nasal emission exhibited by the TDC and mild hypernasality. The significant differences were also exhibited between TDC and moderate to severe hypernasal group across the stimuli. The significant difference between the mild and moderate to severe hypernasal group was noticed for vowel /i/.

Table 46

*Results of Mann – Whitney U test across groups*

| Participants | | Nasal Emissions | | |
|---|---|---|---|---|
| | | /a/ | /i/ | /s/ |
| Group Ia * Group II | \|Z\| | 3.00 | 5.03 | 5.28 |
| | *p*-value | 0.00* | 0.00* | 0.00 |
| Group Ib * Group II | \|Z\| | 3.869 | 5.98 | 5.54 |
| | *p*-value | 0.00* | 0.00* | 0.00* |
| Group Ia * Group Ib | \|Z\| | 0.78 | 2.24 | 0.76 |
| | *p*-value | 0.43 | 0.02* | 0.44 |

*Note.* Group Ia = mild hypernasal RCLP, Group Ib = moderate to severe RCLP, Group II = TDC, *$p < 0.05$

### ***Correlation of nasal emissions with perceptual rating of hypernasality***

The table 47 indicates correlation of perceived nasality exhibited by children with RCLP and TDC for nasal emissions present during production of /a/, /i/, and /s/. High correlation coefficient were observed for nasal emission on /i/ (0.73) followed by /s/ (0.63) and /a/ (0.42).

Table 47

*Correlation of aerodynamic measures with perceived nasality*

| Parameters | | NE | |
|---|---|---|---|
| Stimulus | /a/ | /i/ | /s/ |
| SCC | 0.429 | 0.738 | 0.63 |
| *p*-value | 0.00 | 0.00 | 0.00 |

*Note.* NE = Nasal emissions, SCC=Spearman's correlation coefficient

***Test-retest reliability measures of nasal emissions***

The test - retest reliability for measuring nasal emissions was performed for 25 % of the entire speech sample across the groups. The reliability measures were carried out using Cronbach's alpha co-efficient for nasal emission on vowels /a/, /i/ and fricative /s/. Table 48 illustrates the Cronbach's alpha co-efficient for nasal emissions ranging from 0.40 to 1.00 across the groups and stimuli indicating moderate to good test retest reliability. The results indicated, that, nasal emissions on /a/ and /s/ were highly reliable than nasal emissions on vowel /i/.

Table 48

*Test-retest reliability measures of nasal emissions across the groups*

| Participants | /a/ | /i/ | /s/ |
|---|---|---|---|
| Group Ia | 0.72 | 0.62 | 0.84 |
| Group Ib | 0.86 | 0.40 | 0.76 |
| Group II | 1 | 1 | 1 |

*Note.* Group Ia = mild hypernasal RCLP, Group Ib = moderate to severe RCLP, Group II = TDC.

**4.4.2 Maximum Phonation Duration (MPD)**

The prolongation of /a/ and production of /s/ were measured for MPD using stop watch across all the groups.

***MPD for vowels /a/ and /s/ across the groups***

Table 49 indicated increased MPD for vowel /a/ than fricative /s/ across the groups. The reduced MPD measures were observed in children with RCLP than TDC for both /a/ and /s/.

Table 49

*Mean and SD of MPD (seconds)*

| Participants | MPD (seconds) | | | |
|---|---|---|---|---|
| | /a/ | | /s/ | |
| | Mean | SD | Mean | SD |
| Group Ia | 7.16 | 3.21 | 2.55 | 1.42 |
| Group Ib | 7.37 | 4.95 | 2.28 | 1.80 |
| Group II | 8.69 | 3.44 | 4.01 | 2.25 |

*Note.* MPD = Maximum Phonation Duration, SD = standard deviation, Group Ia = mild hypernasal RCLP, Group Ib = moderate to severe hypernasal RCLP, Group II = TDC.

The MANOVA results indicated significant differences in MPD for /s/ ($p < 0.05$) and no significant differences for vowel /a/ [/a/ - {$F(2,73) = 1.115$, $p < 0.33$}, /s/ - {$F(2,73) = 6.23$, $p < 0.03$}]. To find homogeneous subsets of groups, post hoc multiple comparisons were carried out using Duncan's test. The post hoc analysis revealed significant differences between TDC and children with RCLP ($p < 0.05$). There were no significant differences noticed between mild hypernasal and moderate to severe hypernasal groups.

***Correlating the MPD with perceived nasality***

Table 50 indicates correlation of perceived nasality with MPD across the groups. The correlation coefficients were significant across the stimuli ($p < 0.05$). However MPD indicated low negative correlation (-0.28 & -0.39) with perceived nasality.

Table 50

*Correlation of MPD with perceived nasality*

| Parameters | MPD | |
|---|---|---|
| Stimulus | /a/ | /s/ |
| SCC | -0.286 | -0.399 |
| *p*-value | 0.01 | 0.00 |

*Note.* MPD = Maximum phonation duration, SCC = Spearman's correlation coefficient.

***Test-retest reliability measures of MPD for /a/ and /s/***

The test - retest reliability of one-third octave spectral analysis for vowel /a/ and /s/, were performed for 25 % of the entire sample across the groups. Reliability measures were carried out using Cronbach's alpha co-efficient for the above mentioned variables. The Cronbach's alpha co-efficient of MPD for /a/ and /s/ ranged from 0.80 to 0.98 across the groups as depicted in table 51.

Table 51

*Test-retest reliability measures for MPD across groups and stimuli (/a/ & /s/)*

| Participants | Cronbach's alpha coefficient | |
|---|---|---|
| | /a/ | /s/ |
| Group Ia | 0.80 | 0.90 |
| Group Ib | 0.86 | 0.94 |
| Group II | 0.98 | 0.92 |

Note: Group Ia = mild hypernasal RCLP, Group Ib = moderate to severe RCLP, Group II = TDC

### 4.4.3 Laryngeal Aerodynamic Measures

***Laryngeal aerodynamic parameters across the groups***

The mean and SD of laryngeal aerodynamic parameters across the groups are shown in table 52. Increased SGP, MAFR, and decreased LAR were indicated in children with RCLP than TDC. Among children with RCLP, mild hypernasal group exhibited similar SGP, increased MAFR and LAR than moderate to severe hypernasal group. Overall minimal differences were exhibited across the groups.

Table 52

*Mean and SD of SGP, MAFR and LAR*

| Participants | N | SGP | | MAFR | | LAR | |
|---|---|---|---|---|---|---|---|
| | | Mean | SD | Mean | SD | Mean | SD |
| Group Ia | 12 | 10.7 | 2.80 | 335 | 235 | 0.69 | 0.064 |
| Group Ib | 07 | 10.7 | 4.05 | 280 | 147 | 0.44 | 0.021 |
| Group II | 32 | 9.87 | 2.04 | 209 | 176 | 0.88 | 0.072 |

*Note.* N=number of subjects, NE=Nasal emission, Group Ia=mild hypernasal, Group Ib=moderate to severe hypernasal, Group II=TDC, SD=standard deviation, SGP=sub glottal pressure, MAFR=mean airflow rate, LAR=laryngeal airway resistance.

The results of MANOVA indicated no significant differences between the groups for SGP {$F(2,48) = 0.66$, $p < 0.52$}, MAFR {$F(2,48) = 2.07$, $p < 0.13$}, and LAR {$F(2,48) = 1.40$, $p < 0.25$}.

### ***Correlation of laryngeal aerodynamic parameters with perceptual rating of hypernasality***

The table 53 indicates correlation of perceived nasality exhibited by children with RCLP and TDC with laryngeal aerodynamic measures (SGP, MAFR, LAR) across the groups. The correlation coefficients of laryngeal aerodynamic measures except for MAFR were not significant across groups

Table 53

*Correlation of laryngeal aerodynamic measures with perceived nasality*

| Parameters | SGP | MAFR | LAR |
|---|---|---|---|
| Stimulus | | /pa/ | |
| Spearman's Coefficient | 0.145 | 0.287 | -0.252 |
| *p*-value | 0.309 | 0.041* | 0.075 |

*Note*. SGP = Sub glottal pressure, MAFR = Mean airflow rate, LAR = Laryngeal airway resistance, $*p < 0.05$.

### ***Test retest reliability measures of laryngeal aerodynamic parameters***

The test retest reliability measures of LAR, SGP and MAFR were performed on 25% of the entire sample across the groups. Reliability measures were carried out using Cronbach's alpha co-efficient for the above mentioned variables. Table 54 illustrates the Cronbach's alpha co-efficient for measures of LAR, SGP, and MAFR which ranged from 0.76 to 0.93. This indicates a good test retest reliability measure for laryngeal aerodynamic parameters across the groups.

Table 54

*Test retest reliability measures for laryngeal aerodynamic parameters across the groups*

| Participants | SGP | MAFR | LAR |
|---|---|---|---|
| Group Ia | 0.93 | 0.86 | 0.83 |
| Group Ib | 0.76 | 0.81 | 0.92 |
| Group II | 0.79 | 0.82 | 0.84 |

*Note.* Group Ia = mild hypernasal RCLP, Group Ib = moderate to severe RCLP, Group II = TDC, SGP = sub glottal pressure, MAFR = mean airflow rate, LAR = laryngeal airway resistance.

***Discussion***

The aerodynamic analysis of speech included the measures of nasal emissions, MPD, and laryngeal aerodynamic measures. These measures were evaluated across children with RCLP and TDC and correlated with the perceived nasality. The results of the present study indicated significant differences in measures across the groups for nasal emissions, MPD of /s/ correlating with the perceived nasality, thus rejecting the first and second null hypotheses. There was no significant difference across the groups for laryngeal aerodynamic measures, MPD of vowel /a/, and no significant correlation with perceived nasality thus accepting the first and second null hypotheses for only these parameters. The test retest reliability indicated good reliability of these aerodynamic measures.

***Nasal emissions***

The speech of individuals with cleft palate is generally associated with nasal emission (Hess et al, 1960 & Quigley, 1964). Nasal emission is described as the perception of "extra noise" (acoustic energy) in the speech signal (Peterson-Falzone et al, 2001). The source of noise associated with audible nasal emission is the air escaping through a narrow constriction, the nasal passageway. The audible nasal emission ranges from mild to loud and rustling, and it has also been described as nasal turbulence, nasal rustle, nasal snort, or a mixture of other conditions (Mason & Grandstaff, 1971; Kummer et al, 1992; Peterson-Falzone et al, 2001).

In the present study, Glatzel mirror was used to measure nasal emissions. Severity of nasal emissions was calculated based on the amount of condensation on concentric circles of Glatzel mirror. The findings of the present study indicated absence of nasal air emissions during the production of oral sounds in isolation (/a/, /i/, & /s/) for TDC. Among the children with RCLP, severity of the nasal emission varied. They exhibited increased nasal emissions for vowel /i/ followed by /s/ and /a/. A significant increase in nasal emissions for vowel /i/ in children with moderate to severe hypernasal group was noticed when compared to mild hypernasal group. The presence of nasal emissions on oral sounds in individuals with RCLP can be due to the presence of VPD. During the production of oral sounds, the movement of the velum is restricted due to scar or immobility of the muscles leading to the nasal emission. The movement of the velum also depends on the type and severity of the cleft and procedures used for surgical correction of the cleft. Post surgical fibrosis of the velar muscles can lead to VP dysfunction resulting in high nasal airflow. The nasal airflow can be result of stiffness of the velum, or congenital or acquired neuromotor deficits (Dotevall et al., 2001). The previous studies by Zajac et al (1996) and Peterson-Falzone et al (2001) also reported that nasal emissions are commonly associated with the pressure consonants requiring high intra oral air pressure in individuals with CLP exhibiting VPD.

The results of the present study support the findings of Van Lierde et al (2007) who reported the presence of nasal emissions in children with RCLP by using Glatzel mirror. They also concluded that it is an effective method to perform mirror fogging test for differentiating the individuals exhibiting hypernasality from children with normal resonance characteristics. In contrast, Pochat et al., (2012) reported lack of sensitivity of Glatzel method to detect small amounts of air flow through the nose. Van Lierde et al (2007) used Glatzel mirror to visualize the nasal emissions in children with RCLP. They reported significant differences in nasal emissions across children with RCLP and TDC. Pochat et al., (2012) evaluated the nasal patency to study the pre and post results of cosmetic rhinoplasty using Glatzel mirror and through a questionnaire. They reported that mirror fogging test could not detect the patient reported improvement in breathing followed by rhinoplasty based on the condensation on Glatzel mirror.

The results of the present study also indicated increased nasal emissions while producing vowel /i/. The increased nasal emission in production of /i/ can be attributed to the high oral impedance (Bunton & Story, 2012) and complex articulatory pattern during production of /i/ than for /a/ in the vocal tract which leads to airflow through nasal cavity. The findings of Warren et al (1967) indicated that nasal resistance and respiratory effort of individuals with VPD determines pressure and airflow characteristics during the production of plosive sounds but not by only based on orifice size. Nasal emissions also depend on the compensatory strategies developed by individuals with CLP/RCLP. Hence, the differences in the nasal emission within children with mild and moderate to severe hypernasal cannot be attributed only to the size of the VP gap but could also be due to the respiratory airflow and pressure exhibited during speech production. However, the present study did not aimed to quantify the VP gap to comment precisely on the contribution of VP orifice size towards severity of nasal emission during speech production.

The correlation between nasal emissions and perceived nasality indicated high correlation coefficient for /i/ followed by /s/ and modest correlation for vowel /a/. The increased correlation for vowel /i/ can be attributed to the function of velum and articulatory dynamics during production of vowel /i/. Similarly, the production of /s/ requires regulated airflow through oral cavity to sustain the frication during production, however in the presence of VPD, failure to monitor respiratory airflow efficiently lead to nasal emissions. The VPD can vary with the severity of perceived nasality. The low correlation for /a/ can be due to the ease of production and low oral impedance. The results of the present study are in accordance with Subtelny et al (1970), Sapienza et al (1996), Pinborough-Zimmerman et al (1998), Searl and Carpenter (1999) who also reported absence of audible nasal emissions on oral consonants in normal speakers and present in individuals with RCLP with fistulae or velopharyngeal gap. The variations in severity of nasal emission exhibited across the children with RCLPs can be related to the degree of velopharyngeal gap resulting in loss of intraoral air pressure (Warren et al, 1987; Sapienza et al, 1996). The correlation between VP gap and nasal emission decreases as inadequacy of sphincter increases in magnitude. This can be ascribed to the dichotomous effect of VP mechanism on respiratory aspects of speech. The findings of previous literature (Warren et al.,1993 & Lohmander-Agerskov et al., 1996) indicated positive correlation between nasal emission during articulation of nonnasal consonants and insufficient VP closure with perceived nasality. The present study adds to the literature that the Glatzel mirror test can be used to document the severity of nasal emissions which can be correlated with perceptual measures.

### *Maximum Phonation Duration (MPD)*

MPD is defined as the greatest length over which production can be sustained for a voiceless sound (Van Lierde, 2007). MPD was considered as the time participant can sustain a vowel as long as possible (Maier, 2009). The present study indicated reduced MPD values in /a/ and /s/ in children with RCLP than TDC. The decreased MPD in children with RCLP can be due to the inability to sustain the production for longer period in the presence of inadequate velopharyngeal closure. As the MPD depends on the available airflow during the speech production, the velopharyngeal muscular activity contributes to the temporal and dynamic alterations of the nasal airflow in individuals with RCLP. Warren (1986) opined that sustaining the velopharyngeal closure for extended duration during speech production is difficult for individuals with RCLP. This is due to lack of adequate functioning of muscles responsible for velopharyngeal closure. Tait et al. (1980) also reported shorter MPD exhibited by individuals with VPD than TDC due to inadequate use of laryngeal system for efficient air supply during speech production.

The present study also indicated statistically significant difference in MPD across the groups for only /s/. Among the stimuli /a/ and /s/, production of /s/ is more challenging and difficult than /a/ for individuals with RCLP due to the differences in the manner of production. The vowel /a/ requires relatively free passage of airstream without any articulatory constriction to obstruct the airflow. This contrasts with the production of /s/ consonant which requires obstruction of airflow with the tip or blade of the tongue against the alveolar ridge just behind the teeth. The MPD during production of alveolar fricative /s/ will get affected due to lack of adequate constriction to provide frication by managing the airflow dynamics. The possibility for reduced MPD for /s/ can be due to the presence of compensatory articulation in individuals with RCLP. A study by Weinberg & Horii (1975) reported that individuals with RCLP tend to exhibit pharyngealization of /s/. This can be due to continuing the error pattern of articulation post surgically which is developed before surgical correlation of palate. To build-up the pressure for production of consonants in the presence of palatal cleft, individuals with CLP tend to have articulatory constriction at the posterior portion of the vocal tract.

Pereira et al (2009) and Gopi shankar et al (2012) also reported reduced MPD for the production of /s/ in individuals with hypernasality. They hypothesized that lack of adequate air pressure and air flow in the presence of VPD leading to reduced MPD. The air pressure and flow depends on the position and movement of the velum during the speech production. The children with RCLP exhibit lower position and restricted posterior movement of the velum resulting in VP gap. During the production of /s/, air leaks through the VP gap resulting in reduced MPD. Another study by Gnanavel, Satish, and Pushpavathi (2013) also reported reduced phonation duration of /a/ in children with RCLP than age and gender matched TDC. In the present study, the correlation between MPD and perceived nasality for /a/ and /s/ were evaluated using spearmans rank order correlation. The findings indicated significant poor negative correlation for both the stimuli. This refers to an invert relation of MPD with the severity of nasality. However, the poor correlation indicated small differences in MPD across the groups.

***Laryngeal Aerodynamic Parameters***

The voice or speech production requires respiratory and laryngeal system to act in unison. Laryngeal aerodynamic measures capture the differences in phonatory and respiratory systems during voice production. Although they do not give a direct indication of specific muscular or mucosal activity, it reflects relations across the sum of passive and active respiratory and phonatory forces and aerodynamic factors in voice production. The individuals with CLP need to be evaluated for physiological aspects of laryngeal system. Incidence of hoarse voice in individuals with cleft palate is reported to vary from 12% to 43%, which is much higher than the incidence in TDC (Timmons, Wyatt & Murphy, 2001; Hocevar, Jarc, & Kozelj, 2006). The authors assumed that VPD to have compensatory influence on the laryngeal system, thus altering the voice characteristics. Due to the presence of cleft in the palate, the articulatory movements are altered. The manner of articulation is retained, while the place of articulation is shifted posteriorly (Peterson-Falzone, 1986; McWilliams et al., 1990; D'Antonio & Scherer, 1995; LeBlanc, 1996; Whitehill, et al. 2003). Most of the consonants are produced posteriorly which is a feature of cleft type realization. They use more of glottal, pharyngeal and laryngeal articulation which results in edema of the vocal folds.

In the present study it is hypothesized that glottal valving characteristics facilitate understanding the status of velopharyngeal port closure and hence might correlate well with the perceived nasality. Laryngeal aerodynamic parameters such as sub-glottal pressure (SGP), mean airflow rate (MAFR) and laryngeal airway resistance (LAR), etc have been reported to be sensitive in assessing glottal valving characteristics. Therefore, the present study used laryngeal aerodynamic parameters SGP, MAFR, and LAR to evaluate glottal valving characteristics in RCLP and TDC. The results indicated higher SGP, MAFR and reduced LAR in children with RCLP than the TDC. However, these differences were not statistically significant at $p<0.05$. Elevated laryngeal aerodynamic measures in children with RCLPs than TDC can be attributed to poor functioning of velopharyngeal (VP) closure mechanism, leading to greater adductory force on the laryngeal system. These individuals tend to increase the muscular effort on levator veli palatine muscle for adequate VP closure. Kuehn and Moon (1995) also reported increased levator activity during speech production in individuals with VPD than TDC.

The speech of individuals with CLP largely depends on adequacy of the velopharyngeal port closure. If the velum is inconsistently touching the posterior pharyngeal wall, then the VP closure is defined as marginal type (Peterson – Falzone, 2001). The marginal closure of VP valve can lead to hypernasality and nasal air emission, due to lack of ability to maintain sufficient intraoral pressure required for production of normal speech. Navya, Gopikishore, and Pushpavathi (2012) reported a case of submucous cleft palate with insufficient intra oral pressure, which lead to increased subglottal pressure, mean airflow rate and laryngeal airway resistance. The authors reported reduced laryngeal aerodynamic measures with improved intraoral air pressure during speech production after using the prosthesis. Based on the results of their study, authors opined that improved function of velum will have an influence on the laryngeal system. Interestingly, in contrast to the previous study, children with RCLP exhibited lower mean laryngeal airway resistance than the TDC in the present study. Among the RCLP, reduced LAR was observed for moderate to severe hypernasal group than mild hypernasal group. The reduced LAR can be due to high value of oro-nasal airflow or mean airflow rate (MAFR).

LAR is the ratio of SGP and MAFR, as SGP is relatively constant across the groups; increase in MAFR had resulted in lowered LAR. Zajac (1995) and Guyette et al. (2000) opined that increased levels of laryngeal airflow with adequate intraoral air pressure are required to have stable production of speech, leading to reduced LAR. Similar results were reported by Zajac (1995) indicating lower LAR in individuals with marginal VPD than TDC. The results of the present study also supports the findings of Guyette et al (2000) who reported that individuals with cleft palate exhibiting adequate velopharyngeal closure had significantly greater LAR than those individuals with severe VPD. They concluded that individuals with CLP could achieve marginal VP by increasing respiratory effort with high subglottal pressure which increases the LAR as the pressure is directly proportional to LAR. In cases with severe VPD, even with increased SGP achieving adequate VP closure is difficult. The lower SGP levels exhibited by moderate to severe hypernasal group can lead to increased airflow to maintain constant intra oral air pressure for speech production. Thus the increased airflow rate might have reduced the laryngeal airway resistance during speech production.

In the present study, the differences in laryngeal aerodynamic measures among children with RCLP were not statistically significant. The subglottal pressures were same among children with RCLP and the MAFR was high in mild hypernasal group than moderate to severe hypernasal group. The MAFR was found to be lower in mild hypernasal group than moderate to severe hypernasal group. The finding of the present study was in accordance with the results of the study by Guyette, Sanchez, & Smith, (2000). They reported that individuals with CLP use higher laryngeal airway resistance, transglottal pressure and reduced airflow to achieve complete closure of the velopharyngeal valve. They attributed the results to the compensatory effects of laryngeal system to overcome the potential air leak due to VPD. The laryngeal and respiratory systems involved in precise control and maintenance of pressure and airflow while speaking (Lewis et al., 1993). Rampp and Counihan (1970) reported large amount of energy absorption due to improper oronasal coupling as a result of

VPD. To compensate for the loss of energy, an individual with RCLP try to generate greater acoustic energy at laryngeal level.

Velopharyngeal closure can also be achieved with increased respiratory effort and consequently an increase in intra-oral air pressure. These strategies aid to compensate for the inadequate velopharyngeal closure by providing a streamlined system of regulation and control to stabilize the air pressure during speech production (Warren, 1986). In the presence of VPD, larynx plays a significant role in regulating expiratory flow and aerodynamic events of speech.

The relation between laryngeal aerodynamic measures and perceived nasality were evaluated using spearman’s rank order correlation. The results indicated significant low correlation for MAFR and no significant correlations for SGP and LAR. The low correlation indicates minimal differences in MAFR measures across the groups. A Study by Brustello et al (2010) reported no statistically significant differences in laryngeal airway resistance between individuals with VPD relation with the perceived severity of nasality. As laryngeal airway resistance is the ratio of subglottic pressure to the mean airflow rate, the marginal differences in mean airflow rate and subglottal pressure across the groups may result in no significant variations in laryngeal resistance. Hence, the reduced differences in SGP, MAFR, and LAR across the groups exhibit poor relation with perceived nasality.

### 4.5 Construction of Nasality Severity Index (NSI)

To construct the NSI discriminant analysis was performed. With predictive discriminant analysis (Huberty, 1994), two linear combinations of quantitative predictors were created which are called discriminant functions. Predictive discriminant analysis can provide a model, which can be used to predict the group membership of future samples. This indicates using the model to predict group membership well beyond the particular cases in the present sample (Meyers et al. 2006).

#### 4.5.1 Discriminant function analysis for constructing NSI

In the present study, the discriminant analysis was used to determine whether all the 61 independent variables predict the groups (TDC, mild hypernasal, moderate to severe hypernasal groups). Out of these 61 measures, 59 are based on acoustic measures (7 nasalance values, 4 perturbation measures, 4 VLHR measures, & 44 measures of 1/3$^{rd}$ octave analysis) and two are based on aerodynamic (2 MPD measures) aspects of speech.

Wilk's lambda was used to test the significant differences between the groups on the individual predictor variables. The F test of Wilk's lambda in table 55 indicates the variables which are statistically significant-that is, which variables contribute a significant amount of prediction to help differentiate the groups. Those predictors failing to demonstrate statistically significant differences between the groups could be considered for deletion from the model. If the groups do not differ on individual variables, then it is unlikely the groups will differ on the discriminant function (Meyers et al. 2006). Finally 27 variables with significant Wilk's lambda are considered for final equation. All these 27 are based on acoustic measures of speech. Among these 6 are based on nasalance values and 21 are based on one third octave spectral analysis.

Table 55

*Tests of equality of group means*

| Predictors | Wilk's Lambda | F(2,73) | Sig. |
|---|---|---|---|
| a1000 Hz | .902 | 3.823 | .027 |
| a1587 Hz | .904 | 3.713 | .029 |
| i1000 Hz | .885 | 4.563 | .014 |
| i1259 Hz | .868 | 5.337 | .007 |
| i1587 Hz | .916 | 3.203 | .047 |
| i3174 Hz | .872 | 5.125 | .008 |
| P396 Hz | .880 | 4.767 | .011 |
| P500 Hz | .890 | 4.343 | .017 |
| P793 Hz | .911 | 3.432 | .038 |
| P1000 Hz | .890 | 4.334 | .017 |
| P1259 Hz | .869 | 5.277 | .007 |
| P1587 Hz | .897 | 4.015 | .022 |
| P2000 Hz | .858 | 5.811 | .005 |
| P2519 Hz | .838 | 6.787 | .002 |
| P3174 Hz | .787 | 9.469 | .000 |
| P4000 Hz | .904 | 3.725 | .029 |
| T396 Hz | .846 | 6.371 | .003 |
| T500 Hz | .882 | 4.684 | .012 |
| T793 Hz | .889 | 4.364 | .016 |
| T1000 Hz | .870 | 5.228 | .008 |
| T2519 Hz | .888 | 4.397 | .016 |
| M_Nasl /a/ | .543 | 29.501 | .000 |
| M_Nasl /i/ | .414 | 49.550 | .000 |
| M_O | .379 | 57.373 | .000 |
| M_N | .894 | 4.161 | .020 |
| M_ON | .753 | 11.472 | .000 |
| M_NR | .273 | 93.037 | .000 |

*Note.* M_Nasl /a/ = mean of nasalance value for /a/, M_Nasl /i/ = mean of nasalance value for /i/, M_O = mean of oral sentences, M_N = mean of nasal sentences, M_ON = mean of oronasal sentences, M_NR = mean of nasalance ratio for sentences.

Table 56 depicts the within – groups correlations (structure matrix) between the predictors and the discriminant functions as well as the standardized weights assigned to the independent variables. The standardized discriminant function coefficients indicate the relative importance of the independent variables in predicting the dependent. These coefficients allow for comparing the variables measured on different scales (Green & Salkind, 2008). The strength of relationship is assessed by magnitude of the standardized coefficients for the predictor variables in the function and the correlation coefficients (coefficients in the structure matrix) between the predictor variables and the function within a group (Green & Salkind, 2008).

Table 56

*Structure Matrix*

| Predictors | SCDF | | CCDF | |
|---|---|---|---|---|
| | DF1 | DF2 | DF1 | DF2 |
| a1000 Hz | -.104 | -.262 | -.093 | .222* |
| a1587 Hz | .181 | .286 | -.072 | .256* |
| i1000 Hz | .813 | .110 | .120 | .190* |
| i1259 Hz | -.180 | 1.623 | .095 | .292* |
| i1587 Hz | -.463 | -1.176 | .087 | .199* |
| i3174 Hz | -.162 | -1.145 | -.139 | .150* |
| P396 Hz | .840 | -.260 | .006 | .347* |
| P500 Hz | .247 | -.139 | -.071 | .286* |
| P793 Hz | .239 | -.361 | .022 | .290* |
| P1000 Hz | -.385 | .301 | .059 | .301* |
| P1259 Hz | -1.154 | .666 | .095 | .292* |
| P1587 Hz | .506 | -1.699 | -.018 | .316* |
| P2000 Hz | .484 | 1.198 | -.087 | .325* |
| P2519 Hz | -.371 | .269 | -.131 | .278* |
| P3174 Hz | -.578 | -.154 | -.176 | .263* |
| P4000 Hz | .420 | .600 | -.072 | .256* |
| T396 Hz | -.219 | .721 | .012 | .401* |
| T500 Hz | .230 | .211 | -.099 | .253* |
| T793 Hz | -.134 | -.062 | .072 | .286* |
| T1000 Hz | .300 | .442 | .061 | .334* |
| T2519 Hz | -.144 | -.404 | -.123 | .168* |
| M_Nasla | .330 | -.009 | .368* | -.014 |
| M_Nasli | .425 | -.886 | .476* | -.037 |
| M_O | .837 | 1.375 | .508* | .163 |

| | | | | |
|---|---|---|---|---|
| M_N | -.583 | -1.453 | .081 | .262* |
| M_ON | -.076 | 1.184 | .169 | .365* |
| M_NR | .358 | -.840 | .652* | -.053 |

*Note*. SCDF= standardized coefficients discriminant function, CCDF=correlation coefficient discriminant function, M_Nasl /a/ = mean of nasalance value for /a/, M_Nasl /i/ = mean of nasalance value for /i/, M_O = mean of oral sentences, M_N = mean of nasal sentences, M_ON = mean of oronasal sentences, M_NR = mean of nasalance ratio for sentences. *Largest absolute correlation between each variable and any discriminate function

The canonical discriminant function coefficients in table 57 are used in the formula for making the classifications and predicting the group membership for new cases. A predicted score can be calculated from the weighted combination of the independent variables. Similarly, in a discriminant function analysis, one can calculate a discriminant score (designated as Di) from the weighted combination of the independent variables. For each participant, multiply the score on each predictor by its discriminant unstandardized coefficient and the constant has to be added. The result of this computation yields the discriminant score. The equation for the discriminant score is as follows: Di = a + b1X1 + b2X2 + ….. + bnXn. In this equation, Di is the predicted score on the criterion variable, the Xs are the predictor variables in the equation, “a” is the constant, and “bs” is the unstandardized coefficients associated with the prediction (Meyers et al. 2006). The equation for DF1 and DF2 can be formed as follows and indicated as nasality severity index {NSI (1) & NSI (2)}.

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) - 0.18(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 overall Wilk's lambda was significant, $\lambda=0.065$; $\chi^2$ (54, N=73)=155.84, $p<0.001$, indicating that overall the predictors differentiated among the three groups based on perceived nasality. In addition the residual Wilk's Lambda was significant $\lambda=0.470$; $\chi^2$(26, N=73)=43.03, $p < 0.019$. This second function NSI (2) indicated that the predictors differentiated significantly among the three groups based on perceived nasality after partialling out the effects of the first discriminant function NSI (1). Thus both the functions are significant, and these can be chosen to discriminate the groups. The percentage of variance in NSI (1) and NSI (2) are accounted for 84.7% and 15.3 % respectively.

Table 57

*Canonical Discriminant Function Coefficients*

| | Function | |
|---|---|---|
| | 1 | 2 |
| a1000 Hz | -.011 | -.026 |
| a1587 Hz | .018 | .029 |
| i1000 Hz | .078 | .010 |
| i1259 Hz | -.017 | .151 |
| i1587 Hz | -.044 | -.111 |
| i3174 Hz | -.015 | -.106 |
| P396 Hz | .064 | -.020 |
| P500 Hz | .021 | -.012 |
| P793 Hz | .020 | -.030 |
| P1000 Hz | -.038 | .030 |
| P1259 Hz | -.122 | .070 |
| P1587 Hz | .052 | -.176 |
| P2000 Hz | .045 | .112 |
| P2519 Hz | -.028 | .020 |
| P3174 Hz | -.049 | -.013 |
| P4000 Hz | .035 | .049 |
| T396 Hz | -.017 | .055 |
| T500 Hz | .020 | .018 |
| T793 Hz | -.011 | -.005 |
| T1000 Hz | .029 | .043 |

| | | |
|---|---|---|
| T2519 Hz | -.012 | -.033 |
| M_Nasla | .039 | -.001 |
| M_Nasli | .027 | -.056 |
| M_O | .090 | .147 |
| M_N | -.073 | -.182 |
| M_ON | -.010 | .162 |
| M_NR | 2.957 | -6.935 |
| (Constant) | -3.108 | 1.461 |

*Note.* The above mentioned are unstandardized coefficients. M_Nasl /a/ = mean of nasalance value for /a/, M_Nasl /i/ = mean of nasalance value for /i/, M_O = mean of oral sentences, M_N = mean of nasal sentences, M_ON = mean of oronasal sentences, M_NR = mean of nasalance ratio for sentences.

The weights in the discriminant function are derived through the maximum likelihood method. This is an iterative process that starts with an initial arbitrary “guesstimate” of the weights and then determines the direction and magnitude of the coefficients to minimize the number of classification errors. The maximum likelihood technique ultimately assigns a case to a group from a specific discriminant cutoff score. The cutoff score is the one that results in the fewest classification errors. For the unequal group sizes the cutoff score is calculated from the weighted means of the centroids (Meyers et al. 2006). The figure 26 depicts the group centroids for control, mild, and moderate to severe hypernasal groups as -3.19, 1.03, and 2.46 respectively on NSI (1). The centroids based on NSI (2) are 0.32, -1.46, and 1.05 for control, mild and moderate to severe groups respectively. The cutoff score of NSI (1) to differentiate TDC and hypernasal groups is -1.21 based on the weighted average of TDC and mild hypernasal group. The increase in the values of NSI (1) is indicating the increased severity of perceived nasality with as the centriod of children with moderate to severe hypernasal group is 2.46. Thus index score below -1.21 indicates TDC and above indicates hypernasal groups. The mild hypernasal is differentiated from moderate hypernasal group when the index score based on NSI (2) is below -0.18 based on the weighted average of centroids indicated by mild and moderate to severe hypernasal groups.

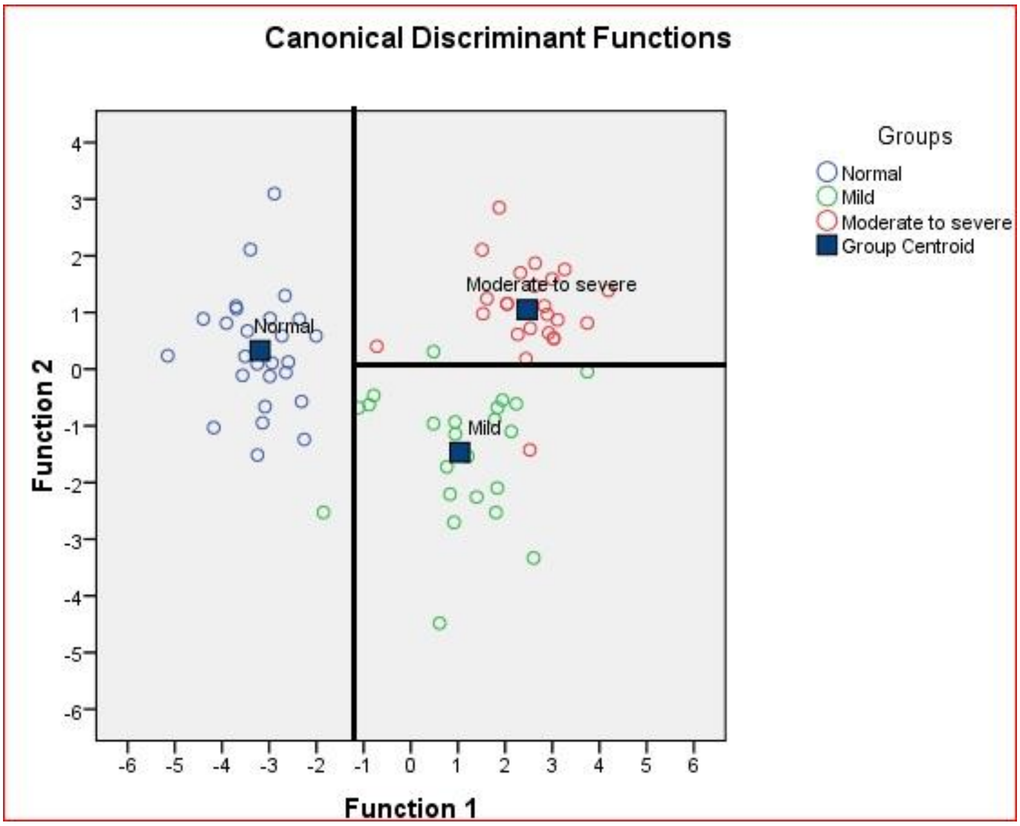


*Figure 26.* Grouping of participants based on NSI (1 & 2). Normal = typically developing children, Mild = children with mild hypernasality, moderate to severe = children with moderate to severe hypernasality, Function 1 = NSI (1), Function 2 = NSI (2).

The discriminant analysis tried to predict group membership and classified correctly 96% of participants of the study. Specific to individual groups, 100%, 95.7%, and 91.7% were correctly classified in control, mild hypernasal and moderate to severe hypernasal groups. Finally to assess how well the classification procedure would predict in a new sample, the study estimated the percent of participants classified by leave one out technique based on Kappa index. The Kappa index has correctly classified 80.82% of the participants from the original data included to construct the index. Specific to individual groups, 100%, 52.2%, and 87.5% were correctly classified in to control, mild hypernasal and moderate to severe hypernasal groups.

### 4.5.2 Validation of the NSI (1 & 2)

To validate the above, fifteen new participants five in each group were considered and verified the index. NSI (1) and NSI (2) were measured for all the new participants. The figure 27 depicts the new participants considered for validation of index were superimposed on the participants included in the construction of NSI. The participants correctly classified are 100%, 60% and 80% in TDC, mild hypernasal and moderate to severe hypernasal groups respectively.

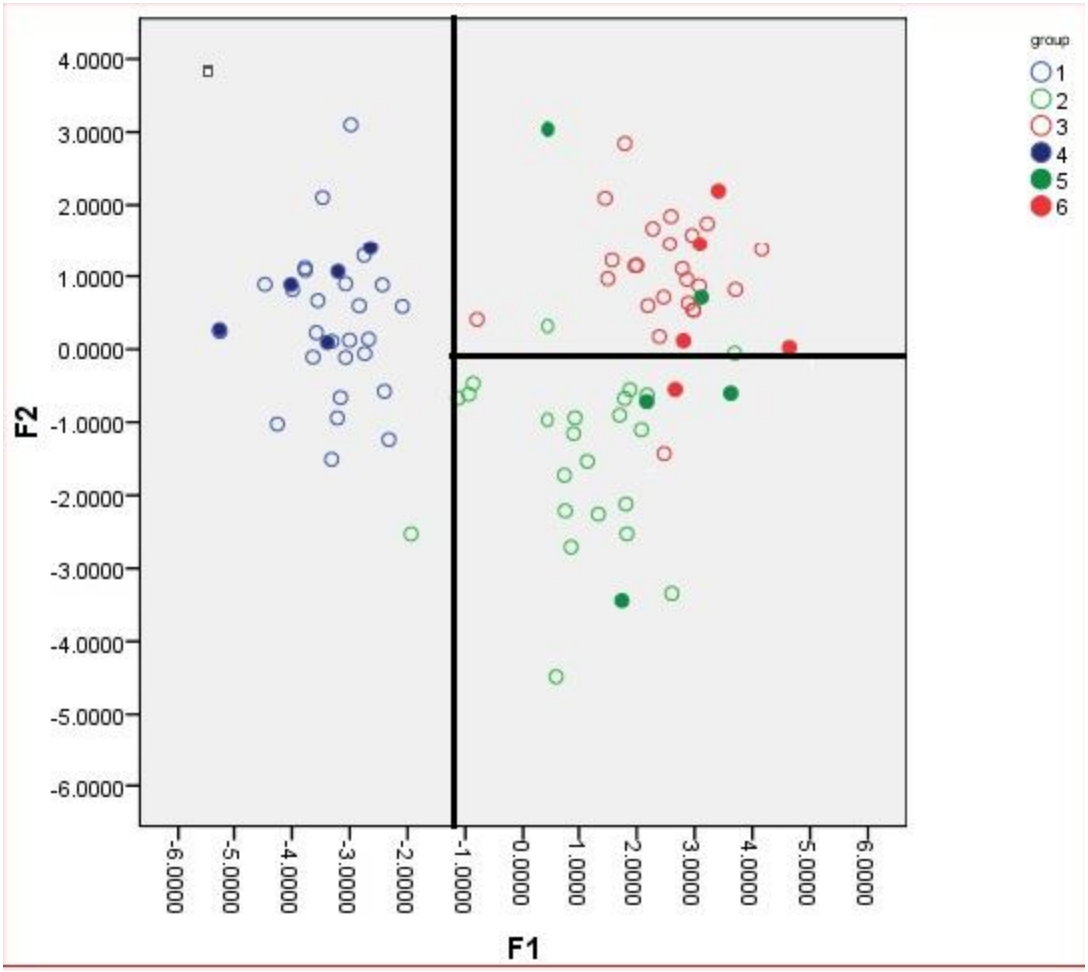


*Figure 27.* Validation of NSI (1 & 2), 1 = normal (TDC), 2 = mild hypernasal, 3 = moderate to severe hypernasal, 4 = five normals (TDC), 5 = five mild hypernasal, 6 = five moderate to severe hypernasal, Function 1 = NSI (1), Function 2 = NSI (2).

### 4.5.3 Stepwise discriminant function analysis for constructing NSI

Construction of nasality severity index is based on the values of 27 variables, which can be derived from two parameters used in the analysis of speech with hypernasality. To simplify the equation for clinical purpose the stepwise discriminant analysis was used which can reduce the number of variables in the construction of equation. The equation is formed by linear combination of variables which are discriminating the independent variables and exhibiting significant and low Wilk's Lambda values.

Hence, step wise discriminant analysis was run through all the 67 variables to find the potential variables contributing for discriminating the groups. The step wise discriminant analysis derive discriminant functions based on only 5 variables. All these five are acoustic measures based on nasalance and one third octave spectral analysis. The thrid discriminant function (DF3) accounted for 86.9 % of the total variability among groups [Wilk's Lambda $\lambda$=0.155; $\chi^2(10)$=126.65; $p$<0.001], fourth discriminant function (DF4) for remaining 13.1% [Wilk's Lambda $\lambda$=0.668; $\chi^2(4)$=27.4; $p$<0.01] variability. The DF3 was observed to be highly significant in discriminating the groups than DF4. As the canonical correlation of discriminant function 3 and 4 with the groups is 0.876 and 0.576 respectively. Table 58 indicates standardized coefficients with large absolute values correspond to variables with greater discriminating ability. Table 59 depicts the Wilk's lambda values along with the significance values. The structure matrix obtained from the discriminant function analysis provides the information on correlation of each variable with each canonical discriminant function 3 and 4 as shown in table 60. The unstandardized canonical discriminant function coefficients depicted in table 61 were used to construct the actual prediction equation which can be used to classify new cases.

Table 58

*Standardized Canonical Discriminant Function Coefficients*

| | Function | |
|---|---|---|
| | DF3 | DF4 |
| M_Nasli | .381 | .571 |
| M_ON | -.187 | -.940 |
| M_NDS | -.344 | .685 |
| M_NRS | .576 | .441 |
| T396 | .229 | -.733 |

Table 59

*Wilk's Lambda values*

| | Wilk's Lambda | F(2, 73) | Sig. |
|---|---|---|---|
| M_Nasli | .414 | 49.550 | .000 |
| M_ON | .753 | 11.472 | .000 |
| M_NDS | .323 | 73.480 | .000 |
| M_NRS | .273 | 93.037 | .000 |
| T396 | .846 | 6.371 | .003 |

Table 60

*Structure Matrix of variables obtained using step wise discriminant analysis*

| | Function | |
|---|---|---|
| | DF3 | DF4 |
| M_NRS | .916* | .060 |
| M_NDS[a] | -.689* | .205 |
| M_Nasli | .669* | .046 |
| M_O[a] | .656* | .289 |
| Ji[a] | .255* | .012 |
| a396[a] | -.253* | .221 |
| Sa[a] | .239* | -.161 |
| Vlhrp | -.202* | -.114 |
| M_Nasla | .199* | .103 |
| T630 | -.182* | .096 |
| Ja | .173* | -.055 |
| Vlhri | .142* | -.110 |
| Si | .059* | -.048 |

| | | |
|---|---|---|
| i500 | -.055* | .026 |
| T396[a] | .003 | .670* |
| M_ON[a] | .224 | .645* |
| a1587[a] | -.040 | .587* |
| P396[a] | -.119 | .546* |
| T793[a] | .064 | .524* |
| M_N[a] | .120 | .513* |
| P1259[a] | .133 | .503* |
| a2000[a] | -.066 | .491* |
| T1587[a] | -.023 | .485* |
| a1000[a] | -.147 | .485* |
| i3174[a] | -.098 | .479* |
| T1259[a] | -.017 | .466* |
| P1587[a] | .031 | .460* |
| P793[a] | -.063 | .459* |
| a1259 | -.145 | .453* |
| a3174 | -.180 | .442* |
| i630[a] | .034 | .438* |
| T1000[a] | .095 | .426* |
| T2000[a] | -.083 | .410* |
| a2519[a] | -.124 | .409* |
| i2519[a] | -.076 | .408* |
| P2000[a] | .016 | .392* |
| i1259[a] | -.014 | .390* |
| i4000[a] | -.104 | .386* |
| a630[a] | -.040 | .386* |
| a4000[a] | -.236 | .383* |
| T4000[a] | .030 | .378* |
| i1587[a] | .043 | .378* |
| P3174[a] | .016 | .370* |
| T3174[a] | .002 | .368* |
| T2519[a] | -.012 | .360* |
| P1000[a] | .095 | .358* |
| P2519[a] | .070 | .353* |
| i2000[a] | .009 | .343* |
| P500[a] | -.187 | .323* |
| P4000[a] | .061 | .321* |
| i793[a] | -.151 | .316* |
| i1000[a] | -.084 | .304* |
| a793[a] | -.117 | .297* |

| | | |
|---|---|---|
| T500[a] | -.221 | .282* |
| i396[a] | -.223 | .265* |
| MPDs[a] | -.121 | -.242* |
| a500[a] | .033 | .211* |
| vlhra[a] | .123 | -.202* |
| MPDa[a] | -.074 | -.190* |
| vlhrt[a] | -.049 | -.115* |
| P630[a] | .019 | .094* |

Note. *$p < 0.05$

Table 61

*Canonical Discriminant Function Coefficients*

| | Function | |
|---|---|---|
| | DF3 | DF4 |
| M_Nasli | .024 | .036 |
| M_ON | -.026 | -.128 |
| M_NDS | -.047 | .093 |
| M_NRS | 4.753 | 3.645 |
| T396 | .018 | -.056 |
| (Constant) | -2.397 | 3.637 |

***Functions at centroids***

The equations of DF3 and DF4 are based on canonical discriminant scores that can be formulated and indicated as nasality severity index {NSI (3) & NSI (4)}. Table 62 indicates centroids of the mean discriminant scores for each group. The centroids are significant in determining the cutting point for classifying cases. As the groups are unequal, the optimal cutting point to classify the groups was based on the weighted average of the centroids of the groups. The NSI (3) is indicating positive values for normals and moving towards negative value indicates increasing severity of hypernasality. If the NSI (3) (weighted average of TDC and mild hypernasal) value is more than -0.85 it indicates hypernasal group and participants exhibiting less than -0.85 are considered as TDC. If the NSI (4) (weighted average of mild and moderate to severe hypernasal groups) value is less than 1.29 indicates moderate to severe hypernasal group and exceeding this indicates mild hypernasal group. The percentage of variance of NSI (3) and NSI (4) are 86.9% and 13.1 % respectively. The figure 28 depicts the combined group plot for canonical discriminant function coefficients derived based on step wise discriminant 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).

Table 62

*Functions at Group Centroids*

| | Function | |
|---|---|---|
| Groups | 1 | 2 |
| Normal | -2.336 | -.202 |
| Mild | .798 | .969 |
| Moderate to severe | 1.765 | -.710 |

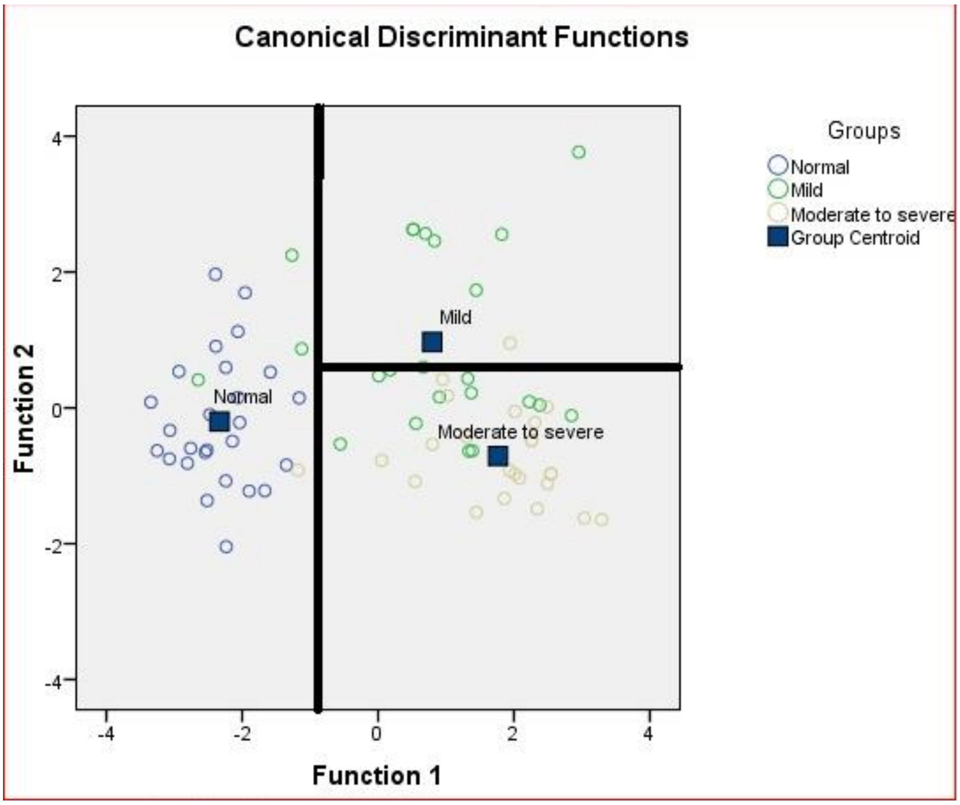


*Figure 28*. Grouping of participants based on NSI (3 & 4), Function 1 = NSI (3), Function 2 = NSI (4)

### 4.5.4 Validation of NSI (3 & 4)

Based on these coefficients the validity was evaluated by including 15 participants five participants in each group. The participants included for validity evaluation were grouped and plotted to verify with the index and found overlapping with the model developed as shown in figure 29.

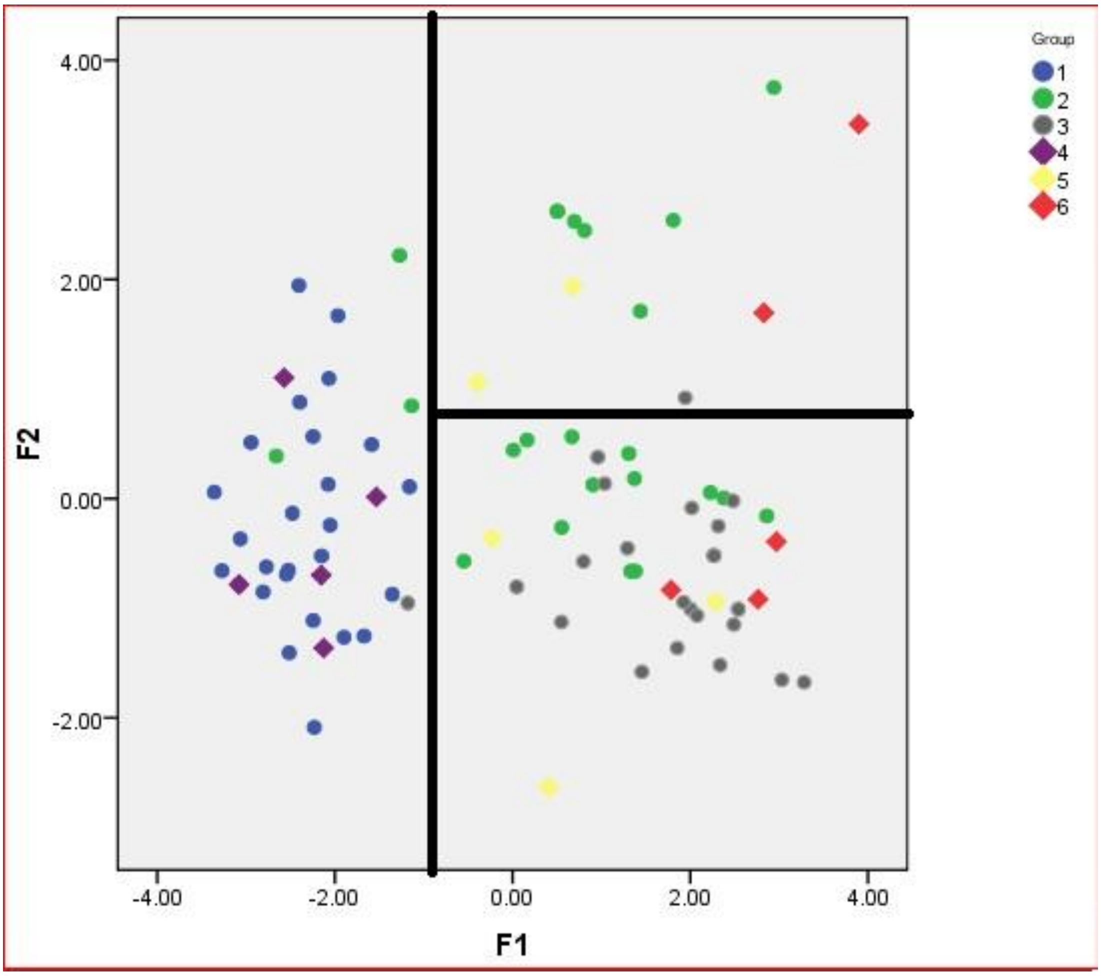


*Figure 29.* Validity of NSI (3 & 4). F1 = NSI (3), F2 = NSI (4), 1 = normal, 2 = mild, 3 = moderate to severe, 4 = five normals, 5 = five mild, 6 = five moderate to severe.

NSI(3) and NSI (4) coefficients are used to construct the actual prediction equation which can be used to classify new cases to verify the validity of the equation. Table 55 shows correct prediction of group membership based on discriminant function indicating 100%, 65.2%, and 83.5% for the normal, mild and moderate to severe hypernasal groups. The below table 63 provides an overall overview about the ability to classify the groups based on discriminant functions obtained using discriminant analysis NSI (1 & 2) and stepwise discriminant function NSI (3 & 4).

Table 63

*Discriminant functions NSI (1 & 2) and NSI (3 & 4) predicting group membership*

| Classification Results | | | | | | |
|---|---|---|---|---|---|---|
| | | | Predicted Group Membership | | | |
| | | Groups | Normal | Mild | Moderate to severe | Total |
| NSI(1 & 2) | Count | Normal | 26 | 0 | 0 | 26 |
| | | Mild | 0 | 22 | 1 | 23 |
| | | Moderate to severe | 1 | 1 | 22 | 24 |
| | % | Normal | 100.0 | .0 | .0 | 100.0 |
| | | Mild | 0 | 95.7 | 4.3 | 100.0 |
| | | Moderate to severe | 4.2 | 4.2 | 91.7 | 100.0 |
| NSI(3 & 4) | Count | Normal | 26 | 0 | 0 | 26 |
| | | Mild | 3 | 15 | 5 | 23 |
| | | Moderate to severe | 1 | 3 | 20 | 24 |
| | % | Normal | 100.0 | .0 | .0 | 100.0 |
| | | Mild | 13.0 | 65.2 | 21.7 | 100.0 |
| | | Moderate to severe | 4.2 | 12.5 | 83.3 | 100.0 |

***Discussion***

The obtained different parameters of acoustic and aerodynamic data was subjected to discriminant analysis to understand the relative significance of each of the parameters in grouping the participants based on perceived nasality. Based on discriminant analysis, an equation consisting specific weighted combination of the obtained parameters was constructed. The construction of equation initially included variables based on mean and derived nasalance measures, one third octave spectra analysis, voice low tone to high tone ratio, perturbation measures (jitter & shimmer) and aerodynamic measure (MPD of /a/ & /s/). However, based on the parameters contributing significantly for distinguishing the groups, only nasalance based measures and one third octave spectra analysis measures were included for the final equation to calculate the index. The nasalance based measures included in the analysis were having modest to good correlation with the discriminant function 1 (NSI 1) and one third octave spectra analysis is indicating poor to modest correlation with discriminant function 2 (NSI 2) in differentiating the groups. If the NSI (1) value is more than -0.85 it indicates hypernasal group and participants exhibiting less than -0.85 are considered as TDC. If the NSI (2) value is less than 1.29 indicates moderate to severe hypernasal group and exceeding this indicates mild hypernasal group. These NSI (1) and NSI (2) are providing different centroids to differentiate across the groups, thus the third hypothesis is rejected.

The markedly higher weightage for nasalance based measures in the discriminant function compared to the other acoustic and aerodynamic parameters indicates the strong association of nasalance based measures with the variation in degrees of perceived nasality. This high correlation of nasalance based measures with the discriminant function may be because nasalance is the objective measure of nasality derived from the ratio of nasal to nasal-plus-oral acoustic energy during speech. Further, the perturbation measures and MPD are predominantly influenced by laryngeal and respiratory systems, and the parameters 1/3$^{rd}$ octave analysis and voice low tone high tone ratio are predominantly influenced by the articulatory system. Even though the nasalance based measures are influenced by these sub systems of speech production, their influence could be minimal on the nasal resonance.

The nasality is the predominant speech characteristic in the speech of individuals with repaired CLP due to VPD. Further, with increase in severity of VPD, the temporal differences in oronasal balance increases, which in turn lead to perception of hypernasality (Jones, 2000). This could be the reason for nasalance values to have significant weightage in the discriminant function. The previous studies have indicated good relationship of nasalance values, such as 0.82 (Dalston et al. 1991a) and 0.74 (Sweeney et al. 2008) with the perceived nasality. Similarly, the studies based on the sensitivity and specificity of nasalance values in differentiating individuals with CLP and normals were evaluated. Dalston et al (1991a) reported the sensitivity and specificity measures of nasality using Nasometer as 0.38 and 0.92 respectively. Dalston et al (1991b) reported relatively high scores of sensitivity (78%) and specificity (79%) with a cutoff score of 32%. The relation between perceptual and nasalance scores was reported to be having modest correlation (r = 0.49) with 0.42 and 0.73 sensitivity and specificity were reported (Watterson et al. 1993). In a recent study, Sweeney et al (2008) reported high sensitivity (0.87 to 0.88) and specificity (0.78 to 0.95) than previous studies (Dalston et al., 1991a, 1991b; Dalston et al., 1992).

However, results of the current study indicated that the ability to distinguish across the groups is markedly higher with a combined weighted index consisting of nasalance and 1/3$^{rd}$ octave analysis than the nasalance alone. The index constructed with the nasalance measures and one third octave spectra analysis indicated that 96% of the participants were predicted correctly. Specific to groups 100%, 95.7%, and 91.7% correct prediction of group membership across control, mild and moderate to severe groups respectively. The sensitivity of the index indicates the percentage of participants who are correctly identified as having hypernasality based on perceptual evaluation. The specificity indicates participants who are correctly identified as having normal resonance. The sensitivity and specificity of the index are based on nasalance measures and one third octave spectra analysis is 96% and 100% respectively. The high level of accuracy in discriminating the individuals with hypernasality from controls is due to the combined effect of six nasalance based measures and twenty one one third octave spectra diagnostic measures at various frequency bands.

The final equation consists of totally twenty seven variables as shown below. The group centroids for control, mild, and moderate to severe hypernasal groups were noted as -3.19, 1.03, and 2.46 on NSI (1) respectively. The centroids based on NSI (2) are 0.32, -1.46, and 1.05 for control, mild and moderate to severe groups respectively. Based on this equation the cutoff score of NSI (1) to differentiate TDC and hypernasal groups is -1.21. This indicates the index score below -1.21 indicates TDC and above indicates hypernasal groups. The mild hypernasal is differentiated from moderate hypernasal group when the index score based on NSI (2) is below -0.18. The percentage of variance in NSI (1) and NSI (2) are accounted for 84.7% and 15.3 % respectively. The discriminant analysis tried to predict group membership and classified correctly 96% of participants of the study. Specific to individual groups, 100%, 95.7%, and 91.7% were correctly classified in control, mild hypernasal and moderate to severe hypernasal groups. Hence, these equations can be used for research and clinical purpose to obtained diagnostic measures in children with CLP.

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)-0.18(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.

However, these equations can be effectively used in clinical scenario if the number of variables to formulate the equation is reduced, as it may take more time in measuring 27 variables and deriving the index. Henceforth, stepwise discriminant analysis was performed including all the acoustic and aerodynamic variables to reduce the number of variables contributing significantly for grouping the participants. Based on this method the equation was formulated using only five variables as shown below.

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).

Out of these five variables, four are based on nasalance measures and one is based on one third octave spectra analysis. The NSI (3) is indicating positive values for TDC and moving towards negative value indicates increasing severity of hypernasality. If the NSI (3) value is more than -0.85 it indicates hypernasal group and participants exhibiting less than -0.85 are considered as TDC. If the NSI (4) value is less than 1.29 indicates moderate to severe hypernasal group and exceeding this indicates mild hypernasal group. The percentage of variance of NSI (3) and NSI (4) are 86.9% and 13.1 % respectively. The sensitivity and specificity of the equation in differentiating the groups is 75% and 100%. Specific to groups 100%, 65.2%, and 83.5% correct prediction of group membership across control, mild and moderate to severe groups respectively.

# CHAPTER V

## SUMMARY AND CONCLUSION

The cleft lip and palate is a congenital condition as a result of disruption in tissue planes in the formation of oral and nasal cavities. The most common characteristics of speech of CLP are hypernasality, audible nasal emission, weak pressure consonants, and compensatory articulatory patterns leading to reduction in speech intelligibility. The assessment requires subjective and objective measures and to find the correlation of the same. There are many perceptual protocols available for assessment and documentation of the speech of cleft palate. To have consensus in the measures of evaluation across the centers Henningsson et al (2007) developed universally standardized four point perceptual rating scale to evaluate different parameters of speech. Also there are many objectives methods such as aerodynamic, acoustic investigation which provide insight to physiological aspects of VP closure. Hence, there is a need for a comprehensive measure that describes perception of hypernasality. The comprehensive measures should reflect the multidimensional nature of hypernasal resonance characteristics including subjective and objective methods and it must be robust.

The present study was aimed at developing a nasality severity index based on an integration of perceptual, aerodynamic and acoustic measurements that reflects the overall severity of perceived nasality in children with RCLP. The children with RCLP were classified based on the standardized four point rating scale developed by Henningsson et al (2008) by three experienced SLP's. The stimuli used were spontaneous speech, oral sentences, nasal sentences, and oronasal sentences. Based on perceived nasality, group Ia included 33 children with RCLP exhibiting mild hypernasality and group Ib included 34 children with RCLP exhibiting moderate to severe hypernasality. Group II included 35 age and gender matched TDC. All these children were subjected to various objective measures of speech. The different parameters of acoustic and aerodynamic measures in children with RCLP were compared with TDC to propose and validate NSI for children in Kannada language.

The objective measures include analysis of various acoustic and aerodynamic parameters. The acoustic measures include estimation of nasalance, one third octave spectral analysis, VLHR, jitter and shimmer. The nasality was measured using Nasometer for phonation of vowels (/a/ & /i/), oral, nasal and oronasal sentences were investigated across the children. The results indicated increase in nasalance values in children with RCLP across the stimuli than TDC. Among the stimuli used nasal sentences exhibited higher nasalance values followed by oronasal sentences, vowel /i/, oral sentences, and vowel /a/. The increased nasalance in RCLP were due to the lack of adequate velopharyngeal closure as a result of muscle fibrosis and stiffness of levator veli palatine. The increased nasalance of /i/ over /a/ can be due to increased oral resistance during the production of /i/ in the oral cavity. The increased nasalance values in nasal and oronasal sentences can be due to the lower position of the velum during the production of nasal consonants exhibiting nasal resonance. The nasalance distance was high in control group followed by children with mild and moderate to severe hypernasal group and contrasting results were noticed for nasalance ratio. Hence, the variations in nasalance distance and ratio across the groups may be attributed to the increased differences between the mean nasalance values of oral and nasal sentences in control group followed by hypernasal groups.

The current study was also aimed to investigate and compare other acoustic measures such as one third octave spectra analysis, VLHR, jitter and shimmer across groups. The one third octave spectra analysis evaluates the distribution of spectral energy across the frequency bands. All the groups exhibited similar spectral energy levels at low frequencies. The spectral amplitude of vowel /i/ exhibited additional spectral peaks at mid frequencies only for moderate to severe hypernasal groups. The reduced spectral amplitudes were exhibited at high frequency region for hypernasal groups than control group. This may be due to the velopharyngeal gap exhibited by the children with nasality lead to dampening of the F1, increased bandwidth of F, additional spectral peaks at mid frequencies, and antiformants lead to dampening of energy at high frequency region in children with RCLP than TDC. The correlation coefficient indicates reduction in the spectral energy with the increase in perceived nasality. Relatively reduced energy at high frequencies than at low frequencies indicated increased VLHR in children with RCLP than TDC. However, these differences were not statistically significant. There was no significant correlation between the measures of VLHR with the perceived nasality. Another acoustic measure evaluated was jitter and shimmer measures of vowels /a/ & /i/, which are more in children with RCLP than TDC. However, statistically significant differences across the groups were noted for shimmer measures of vowel /a/. The variations in perturbations can be attributed to the imbalanced resonatory system which will have an effect on the phonatory system, resulting changes in the vocal fold movements.

Another objective of the study was to investigate and compare the aerodynamic measures such as nasal emissions, MPD, sub-glottal pressure, mean airflow rate, laryngeal airway resistance across the groups. The nasal emissions were evaluated by mirror fogging test using Glatzel mirror for phonation of vowel /a/, /i/, and /s/ for 5 sec. The results indicated increase in the nasal emissions as the severity of perceived nasality is increases. The increase in velopharyngeal gap results in increased nasal airflow during speech production. Another parameter MPD was investigated across all the groups. The results indicated reduced MPD to produce /a/ and /s/ in hypernasal group than control groups. However, significant differences in MPD were only observed for production of /s/ across the groups. This may be attributed to difficulty faced by children with RCLP due to inadequate control over the release of air through the oral cavity than TDC. The excessive nasal airflow due to velopharyngeal dysfunction results in inadequate air pressure to sustain phonation or speech.

The laryngeal aerodynamic parameters (SGP, MAFR, LAR) were investigated by instructing the participant to repeat nine CV syllables /papapapapapapapapa/ into the mask with syllable production rate 2.0–3.5 per second. The results indicated children with RCLP exhibiting increased sub glottal pressure (SGP), mean airflow rate (MAFR) and reduced laryngeal airway resistance (LAR) than TDC. However these differences were not statistically significant. The variations in laryngeal aerodynamics can be attributed as a compensatory mechanism utilized by children with RCLP to have stable speech production in the presence of VPD by increasing MAFR and SGP. In general the acoustic and aerodynamic parameters indicate difference across the children with RCLP and TDC.

## 5.1 Construction and validation of nasality severity index

The discriminant analysis was used to evaluate the relative importance of these parameters to construct the equation. The equation consists of specific weighted combination of the variables included in the study. On subjecting these variables to discriminant analysis, the results indicate Wilk's Lambda value for the variables. Then nasality severity index is derived by including variables exhibiting significant Wilk's Lambda value ($p < 0.05$). The equation included 27 variables based on one third octave spectral analysis and nasalance measures. There were two discrimination functions such as NSI (1) and NSI (2). If the cutoff score based on NSI (1) was below -1.21 indicates controls group and above is hypernasal group. Based on equation derived from NSI (2) mild hypernasal group were indicated with score below -0.18 and above this are considered as moderate to severe hypernasal group. The percentage of predicted group member ship was 100 %, 95.7 %, and 91.7 % for normal, mild and moderate to severe hypernasal groups respectively. This can be used for research purpose in the area of cleft lip and palate

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.

To check the validity of the index fifteen children with RCLP and TDC five in each group were included and verified the group membership by calculating the NSI. The results indicated 100%, 60% and 80% correct identification of the predicted group membership on control, mild and moderate to severe hypernasal groups. To formulate an index with less number of variables to ease of use of index so that this can be used clinically on daily basis. Another statistical method called as step wise discriminant analysis was used. The equation included 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).

Based on functions derived using this method, if the NSI (3) value is more than -0.85 it indicates hypernasal group and participants exhibiting less than -0.85 are considered as TDC. If the NSI (4) value is less than 1.29 indicates moderate to severe hypernasal group and exceeding this indicates mild hypernasal group. Among NSI (3) and NSI (4), the groups are significantly differentiated for 86.9% based on NSI (3) and 13.1 % based on NSI (4). The validity of the index indicated 100%, 40% and 60% correct identification of the predicted group membership on TDC, mild hypernasal and moderate to severe hypernasal groups.

**5.2 Implications of the study**

- The study helped in exploring the acoustic, aerodynamic and perceptual correlates of resonance in Kannada speaking children with repaired cleft lip and palate.
- NSI is a refined objective assessment protocol for a more precise objective assessment of VPD and corresponding well with the subjective perceptual evaluation of nasality.

- NSI assist for an ease of communication between the multidisciplinary professionals involved in clinical and research activities related to rehabilitating the individuals with CLP population.

**5.3 Limitations and Future Recommendations**

- The present study included limited number of participants which restricts the generalization of the findings.

- The stimulus included in the study is based on Kannada language, which restricts the application NSI to only Kannada speaking children.

- The study could be replicated involving adults with repaired cleft lip and palate as the present study involved only children in the age range of four to twelve years.

- The index formulated is based on the data collected from individuals with repaired cleft lip and palate. Hence the results cannot be generalized while assessing individuals with unrepaired cleft lip and palate.

- Further research can be conducted by adding few more diagnostic variables like tongue anchored test, cepstral analysis of cleft speech etc and evaluate the potential variables for analysis and condense the equation to less number of variables.

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## APPENDIX A

| Details of the participants included in the study | | | | |
|---|---|---|---|---|
| S.No. | Age (years) | Sex | Socio economic status | Groups based on hypernasality |
| 1. | 4 | Female | Lower | Normal |
| 2. | 6 | Female | Lower | Normal |
| 3. | 8 | Female | Lower | Normal |
| 4. | 8 | Female | Lower | Normal |
| 5. | 10 | Female | Lower | Normal |
| 6. | 12 | Female | Lower | Normal |
| 7. | 12 | Female | Lower | Normal |
| 8. | 12 | Female | Lower | Normal |
| 9. | 6 | Male | Lower | Normal |
| 10. | 7 | Male | Lower | Normal |
| 11. | 8 | Male | Lower | Normal |
| 12. | 8 | Male | Lower | Normal |
| 13. | 10 | Male | Lower | Normal |
| 14. | 10 | Male | Lower | Normal |
| 15. | 12 | Male | Lower | Normal |
| 16. | 6 | Female | Middle | Normal |
| 17. | 8 | Female | Middle | Normal |
| 18. | 10 | Female | Middle | Normal |
| 19. | 10 | Female | Middle | Normal |
| 20. | 11 | Female | Middle | Normal |
| 21. | 11 | Female | Middle | Normal |
| 22. | 11 | Female | Middle | Normal |
| 23. | 11 | Female | Middle | Normal |
| 24. | 11 | Female | Middle | Normal |
| 25. | 6 | Male | Middle | Normal |
| 26. | 7 | Male | Middle | Normal |
| 27. | 8 | Male | Middle | Normal |
| 28. | 8 | Male | Middle | Normal |
| 29. | 9 | Male | Middle | Normal |
| 30. | 10 | Male | Middle | Normal |
| 31. | 10 | Male | Middle | Normal |
| 32. | 11 | Male | Middle | Normal |
| 33. | 11 | Male | Middle | Normal |
| 34. | 12 | Male | Middle | Normal |
| 35. | 12 | Male | Middle | Normal |
| 36. | 4 | Female | Lower | Mild |
| 37. | 5 | Female | Lower | Mild |
| 38. | 5 | Female | Lower | Mild |
| 39. | 6 | Female | Lower | Mild |

| | | | | |
|---|---|---|---|---|
| 40. | 8 | Female | Lower | Mild |
| 41. | 9 | Female | Lower | Mild |
| 42. | 9 | Female | Lower | Mild |
| 43. | 10 | Female | Lower | Mild |
| 44. | 12 | Female | Lower | Mild |
| 45. | 12 | Female | Lower | Mild |
| 46. | 5 | Male | Lower | Mild |
| 47. | 7 | Male | Lower | Mild |
| 48. | 7 | Male | Lower | Mild |
| 49. | 8 | Male | Lower | Mild |
| 50. | 9 | Male | Lower | Mild |
| 51. | 10 | Male | Lower | Mild |
| 52. | 11 | Male | Lower | Mild |
| 53. | 11 | Male | Lower | Mild |
| 54. | 7 | Female | Middle | Mild |
| 55. | 8 | Female | Middle | Mild |
| 56. | 11 | Female | Middle | Mild |
| 57. | 11 | Female | Middle | Mild |
| 58. | 11 | Female | Middle | Mild |
| 59. | 12 | Female | Middle | Mild |
| 60. | 5 | Male | Middle | Mild |
| 61. | 6 | Male | Middle | Mild |
| 62. | 8 | Male | Middle | Mild |
| 63. | 9 | Male | Middle | Mild |
| 64. | 9 | Male | Middle | Mild |
| 65. | 10 | Male | Middle | Mild |
| 66. | 10 | Male | Middle | Mild |
| 67. | 12 | Male | Middle | Mild |
| 68. | 12 | Male | Middle | Mild |
| 69. | 5 | Female | Lower | Moderate |
| 70. | 8 | Female | Lower | Moderate |
| 71. | 8 | Female | Lower | Moderate |
| 72. | 11 | Female | Lower | Moderate |
| 73. | 12 | Female | Lower | Moderate |
| 74. | 4 | Male | Lower | Moderate |
| 75. | 6 | Male | Lower | Moderate |
| 76. | 8 | Male | Lower | Moderate |
| 77. | 10 | Male | Lower | Moderate |
| 78. | 10 | Male | Lower | Moderate |
| 79. | 11 | Male | Lower | Moderate |
| 80. | 11 | Male | Lower | Moderate |
| 81. | 6 | Female | Middle | Moderate |
| 82. | 7 | Female | Middle | Moderate |

| | | | | |
|---|---|---|---|---|
| 83. | 7 | Female | Middle | Moderate |
| 84. | 8 | Female | Middle | Moderate |
| 85. | 9 | Female | Middle | Moderate |
| 86. | 10 | Female | Middle | Moderate |
| 87. | 10 | Female | Middle | Moderate |
| 88. | 12 | Female | Middle | Moderate |
| 89. | 8 | Male | Middle | Moderate |
| 90. | 11 | Male | Middle | Moderate |
| 91. | 11 | Male | Middle | Moderate |
| 92. | 8 | Female | Lower | Severe |
| 93. | 11 | Female | Lower | Severe |
| 94. | 12 | Female | Lower | Severe |
| 95. | 12 | Female | Lower | Severe |
| 96. | 8 | Male | Lower | Severe |
| 97. | 12 | Male | Lower | Severe |
| 98. | 5 | Female | Middle | Severe |
| 99. | 12 | Female | Middle | Severe |
| 100. | 10 | Male | Middle | Severe |
| 101. | 11 | Male | Middle | Severe |
| 102. | 12 | Male | Middle | Severe |

# APPENDIX B

## Stimuli Used in the Data Collection

### ORAL SENTENCES

| S.No. | Kannada | IPA |
|---|---|---|
| 1 | ಕಾಗೆ ಕಾಲು ಕಪ್ಪು. | Ka:gɛ ka:lu kappu |
| 2 | ಗೀತ ಬೇಗ ಹೋಗು. | gi̪t̪a bɛga ho:gu |
| 3 | ದನ ದಾರಿ ತಪ್ಪಿತು. | d̪ʌna d̪a:ri t̪appit̪u |
| 4 | ಅಪ್ಪ ಪಟ ತಾ. | appa paṭa t̪a |
| 5 | ಬಾಲು ತಬಲ ಬಾರಿಸು | ba:lu t̪ʌbalʌ ba:risu |

### NASAL SENTENCES

| S.No. | Kannada | IPA |
|---|---|---|
| 1 | ಮನು ಆನೆಯನ್ನು ನೋಡಿದ. | mʌnu a: nƐjannu no:d̥id̪a |
| 2 | ನವೀನ ಮನೆಯಿಂದ ಬಂದನು. | nʌvi:na mʌnƐjind̪a band̪ʌnu |
| 3 | ನಾನು ಆನೆಯನ್ನು ನೋಡಿದೆ. | na:nu a: nƐjannu no:did̪ɛ |
| 4 | ಮಂಗ ಮನೆಯ ಮೇಲಿದೆ. | maŋga manɛja me:lid̪e |
| 5 | ಮಾಮ ಮಂಡ್ಯದಿಂದ ಬಂದರು. | ma:ma mʌnd̥ja:d̪ind̪a band̪ʌru |

### ORONASAL SENTENCES

| S.No. | Kannada | IPA |
|---|---|---|
| 1 | ವಿನಯ ನಿದ್ದೆ ಮಾಡಿದನು | vinʌja nid̪ɛ ma:did̪ʌnu |
| 2 | ಅನಿಲ್ ಮನೆಗೆ ಹೋದನು | anil mʌnegɛ ho:d̪ʌnu |
| 3 | ರಾಮ ಊಟ ಮಾಡಿಧನು | ra:ma u:ṭa ma:did̪ʌnu |
| 4 | ನಿತಿನ್ ಆನೆ ನೋಡಿದನು | nit̪in a:nɛ no:d̥id̪anu |
| 5 | ಅಪನು ಮನೆಗೆ ಹೋದನು | apʌnu mʌnɛgɛ ho:d̪ʌnu |

**APPENDIX C**

# All India Institute of Speech and Hearing, Manasagangothri, Mysore – 570006

**Doctoral Thesis on**
Construction of Nasality Severity Index

**Information to the individuals**

I, Navya. A. have undertaken the research study related to the diagnostic factors of children with repaired cleft lip and palate attending to the U-SOFA. The thesis entitled "Construction of Nasality Severity Index" under the guidance of Dr. Pushpavathi. M., Professor, Department of Speech Language Pathology, AIISH, Mysore -06. I request you to participate in the study. Your co-operation in the study will go a long way in helping us in refining the diagnostic protocols for children with cleft lip and palate. This is for your information that as a part of this study to evaluate the speech of children with repaired cleft lip and palate we need to record audio/video speech samples.

**Informed Consent**

I have been informed about the aims, objectives and the procedure for the study. The possible risks - benefits of myself participation as human subject in the study are clearly understood by me. I understand that I have a right to refuse participation or withdraw my consent at any time. I have the freedom to write to head of the institute, in case of any violation of these provisions without the danger of my being denied any rights to secure the clinical services at this institute. I am interested in participating in the study and hereby give my written consent for the same.

I, ____________________, the undersigned, give my consent to be participant of this investigation/study/program. I have no objection in permitting my child /grandchild to participate in this program. I have no objection in myself / my son/daughter/wife/family members to be photographed/ videotaped/ shown to public / used for official communication in journal/ magazines/ newsletter and research purposes.

(AGREE/DISAGREE)

Place:

Date: Signature of Parents/Guardian

# APPENDIX D

## ಅಖಿಲ ಭಾರತ ವಾಕ್ ಶ್ರವಣ ಸಂಸ್ಥೆ, ನೈಮಿಷಂ ಆವರಣ, ಮಾನಸಗಂಗೋತ್ರಿ, ಮೈಸೂರು – ೫೭೦೦೦೬

**ವಿಷಯ: ಡಾಕ್ಟರೇಟ್ ಪದವಿ ಪೂರ್ವ ಸಂಶೋಧನೆ**

**ಸಂಶೋಧನೆಯ ವಿಷಯ: ಅನುನಾಸಿಕತೆಯ ತೀವ್ರತೆಯನ್ನು ಅಳೆಯುವ ಸೂಚ್ಯಂಕದ ನಿರ್ಮಾಣ**

ಡಾಕ್ಟರೇಟ್ ಪದವಿ ಪೂರ್ವ ಸಂಶೋಧನಾ ವಿದ್ಯಾರ್ಥಿಯಾದ ನಾನು- ಶ್ರೀಮತಿ ನವ್ಯ. ಎ, ಈ ಮೇಲ್ಕಂಡ ವಿಷಯದಲ್ಲಿ ಸಂಶೋಧನೆ ಮಾಡಬೇಕೆಂದಿದ್ದೇನೆ. ಈ ಸಂಶೋಧನೆಯನ್ನು ಡಾ|| ಎಂ. ಪುಷ್ಪಾವತಿ , ಪ್ರಾಧ್ಯಾಪಕರು (ವಾಕ್ ಮತ್ತು ಭಾಷಾ ರೋಗಲಕ್ಷಣಗಳ ವಿಭಾಗ) ಅವರ ನೇತೃತ್ವದಲ್ಲಿ ಮಾಡುತ್ತಿದ್ದೇನೆ. ಈ ಸಂಶೋಧನೆಯಲ್ಲಿ ತಾವು ಭಾಗವಹಿಸಬೇಕೆಂದು ಕೋರಿಕೊಳ್ಳುತ್ತೇನೆ. ಸಂಶೋಧನೆಗೆ ಬೇಕಾದ ಮಾಹಿತಿಗಳನ್ನು ಧ್ವನಿ ಮತ್ತು ವಿಡಿಯೋ ಚಿತ್ರೀಕರಣದ (ಆಡಿಯೋ ಮತ್ತು ವೀಡಿಯೊ ರೆಕಾರ್ಡಿಂಗ್) ಮೂಲಕ ಸಂಗ್ರಹಿಸಲಾಗುತ್ತದೆ. ಈ ಕಾರ್ಯಕ್ಕೆ ಸಂಶೋಧನೆಯಲ್ಲಿ ಭಾಗವಹಿಸುವ ಮಕ್ಕಳ ಜೊತೆ ಸುಮಾರು ಒಂದು ಗಂಟೆಯ ಸಂದರ್ಶನದ ಅವಶ್ಯಕತೆ ಇದೆ. ಈ ಮಾಹಿತಿಗಳನ್ನೆಲ್ಲಾ ಗೌಪ್ಯವಾಗಿ (Confidential) ಇಡಲಾಗುತ್ತದೆ ಎಂದು ಭರವಸೆ ನೀಡುತ್ತೇನೆ. ಈ ಸಂಶೋಧನೆಯಿಂದ ನಮಗೆ ಸೀಳು ಅಂಗುಳ ಇರುವ ಮಕ್ಕಳ ಮಾತಿನ ನ್ಯೂನತೆಗಳನ್ನು ಪತ್ತೆಹಚ್ಚಬಹುದು. ಇದಲ್ಲದೆ ಇಂತಹ ಮಕ್ಕಳ ಪುನರ್ವಸತಿ/ ತರಬೇತಿಯನ್ನು ಬೇಕಾದ ರೀತಿಯಲ್ಲಿ ಅಳವಡಿಸಿಕೊಳ್ಳುವ ಬಗ್ಗೆ ಮಾಹಿತಿ ದೊರೆಯುತ್ತದೆ. ಆದ್ದರಿಂದ ಈ ಸಂಶೋಧನೆಯಿಂದ ಸೀಳು ಅಂಗುಳ ಇರುವ ಮಕ್ಕಳಿಗೆ ಬಹಳ ಉಪಯೋಗವಾಗುತ್ತದೆ. ಇದಕ್ಕಾಗಿ ಸಹಕರಿಸಬೇಕಾಗಿ ವಿನಂತಿ.

**ಸಮ್ಮತಿ ಪತ್ರ**

ಈ ಸಂಶೋಧನೆಯ ಬಗ್ಗೆ ಅಂದರೆ, ಅದರ ಗುರಿ ಹಾಗು ಮಾಹಿತಿ ಸಂಗ್ರಹಿಸುವ ವಿಧಾನದ ಬಗ್ಗೆ ನನಗೆ ಪೂರ್ಣ ತಿಳುವಿಕೆ ಲಭಿಸಿದೆ. ಈ ಸಂಶೋಧನೆಯಲ್ಲಿ ಭಾಗವಹಿಸುವಾಗ ಉಂಟಾಗುವ ಅಡತಡೆ / ತೊಂದರೆಗಳ ಬಗ್ಗೆಯೂ ನನಗೆ ಅರಿವಿಕೆ / ಅರ್ಥವಾಗಿದೆ. ಈ ಸಂಶೋಧನೆಯಲ್ಲಿ ನನ್ನ ಮಗು / ಮೊಮ್ಮಗು ಭಾಗವಹಿಸುವುದನ್ನು ಯಾವಾಗ ಬೇಕಾದರೂ ನಿರಾಕರಿಸುವ ಸಂಪೂರ್ಣ ಹಕ್ಕನು ನಾನು ಪಡೆದಿರುತ್ತೇನೆ. ಈ ಮೇಲ್ಕಂಡ ಸಂಶೋಧನೆಯಲ್ಲಿ ಹೇಳಿರುವಂತಹ ಕಾರ್ಯಗಳಲ್ಲಿ/ ವಿಧಾನಗಳಲ್ಲಿ ಏನಾದರೂ ನಿಯಮದ ಉಲಂಘನೆಯಾದಲ್ಲಿ ಚೇರ್ಮೆನ್ (AEC Chairman) ರನ್ನು ಸಂಪರ್ಕಿಸುವ ಸ್ವಾತಂತ್ರ್ಯಾ ನನಗಿದೆ. ಇದರಿಂದಾಗಿ ಮೇಲ್ಕಂಡ ಸಂಸ್ಥೆಯವರು ನನಗೆ ಅಲ್ಲಿ ಸಿಗುವಂತಹ ಚಿಕಿತ್ಸಾ ಸೌಲಭ್ಯಗಳನ್ನು ನಿರಾಕರಿಸಲು ಸಾಧ್ಯವಿಲ್ಲ. ನನಗೆ ಈ ಸಂಶೋಧನೆಯಲ್ಲಿ ಭಾಗವಹಿಸಲು ಸಮ್ಮತಿ ಇದೆ. ಈ ಸಮ್ಮತಿಯನ್ನು ಬರವಣಿಗೆಯಲ್ಲಿ ಕೊಡುತ್ತಿದ್ದೇನೆ.

ನಾನು ______________________________ , ನನ್ನ ಮಗು / ಮೊಮ್ಮಗು ಈ ಮೇಲ್ಕಂಡ ಕಾರ್ಯಕ್ರಮದಲ್ಲಿ/ ಸಂಶೋಧನೆಯಲ್ಲಿ ಭಾಗವಹಿಸಲು ಸಂಪೂರ್ಣ ಸಮ್ಮತಿ ನೀಡುತ್ತೇನೆ. ಈ ಕೆಳಕಂಡಂತೆ ಸಹಿ ಹಾಕಿರುತ್ತೇನೆ.

ವ್ಯಕ್ತಿಯ ಸಹಿ — ಸಂಶೋಧಕರ ಸಹಿ

(ಹೆಸರು ಮತ್ತು ವಿಳಾಸ) — ದಿನಾಂಕ:

______________________________

## APPENDIX F

## PUBLICATIONS AS A PART OF THESIS WORK

| S.No | Publication Details | ISSN Number |
|---|---|---|
| 1 | 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 All India Institute of Speech and Hearing, 32,* 36-44. | 0973 - 662X |
| 2 | Navya, A., & Pushpavathi, M. (2014). Derived nasalance measures of nasality for sentences in children with repaired cleft lip and palate. *Language in India, 14(8)*, 125-138. | 1930 - 2940 |

# ONE THIRD OCTAVE ANALYSIS: A DIAGNOSTIC TOOL TO MEASURE NASALITY IN CONJUNCTION WITH NASALANCE IN CHILDREN WITH REPAIRED CLEFT LIP AND PALATE

**[1]Navya, A., & [2]Pushpavathi, M.**

**Abstract**

*Hypernasality is the most predominant feature perceived in speech of individuals with cleft lip and palate. Instrumental assessment of speech can provide additional information along with the perceptual evaluation of speech for accuracy in diagnosis in individuals with cleft lip and palate (CLP). The widely used objective assessment of nasality is measuring nasalance using Nasometer. However, the spectral analysis of nasality in speech can provide complementary information along with nasalance measures. Hence, the present study is aimed to measure nasalance values and one third octave spectral peaks and their ability to differentiate children with repaired cleft lip and palate (RCLP) from control group. The study included eight children with RCLP age ranging from six to ten years. The control group included sixteen typically developing age and gender matched children. Vowel /a/ and /i/ was selected as stimuli. Nasalance was measured using Nasometer and 1/3<sup>rd</sup> octave spectral analysis was measured using a specially designed MATLAB programme. Statistical analysis was performed using SPSS 17 software. To differentiate the groups with the cutoff values, sensitivity and specificity of the variables was derived using receiver operating curves (ROC). The results showed high sensitivity and specificity of the nasalance values with the cutoff of 8.8% for /a/ and 31.6% for /i/. The frequency region between 998Hz and 2663 Hz provided high sensitivity and specificity for differentiating groups using 1/3$^{rd}$ octave spectra analysis. Further studies are required to generalize the results of one third octave spectra analysis.*

**Keywords:** *Nasalance, 1/3$^{rd}$ octave analysis, Repaired cleft lip and palate.*

Hypernasality and nasal emission are the evident perceptual characteristics of the individuals with cleft lip and palate due to unoperated cleft/fistula. (Mc Williams, 1958; Morris, 1962, 1968). This is due to velopharyngeal inadequacy leading to nasal escape of air through nasal cavity. Perceptual rating scales were used to distinguish speech of individuals with CLP (Weinberg & Shanks, 1971). The reliability of perceptual judgments in population with cleft is becoming more confronting due to versatile nature of the voice. The perception of speech depends on alterations in pitch, loudness and resonance. There are different perceptual rating scales available for assessing the speech of cleft lip and palate. The various centers use different rating scales and this is leading to difficulty in comparing the speech outcomes across the centers (Vogel, Ibrahim, Reilly, & Kilpatrick, 2009). This led to the need of developing a protocol to measure the outcome which can be used across centers. (Henningsson, Kuehn, Sell, Sweeney, Trost-Cardamone, & Whitehill, 2007). But, due to the differences in linguistic structure of the language, the adaptability of this tool was limited (Hutters & Henningsson, 2004).

The perceptual evaluation is considered as the gold standard method for evaluating nasality. The development of a comprehensive assessment tool can improve the accuracy of an investigation in clinical population along with perceptual measures. The data obtained using these instrumental measures can allow the clinicians to right away use the formerly obtained data without any apprehension for reduced test-retest reliability. This has led to the development of several quantitative measures of nasality. The most commonly used quantitative measure of perceptual nasality is nasalance derived using Nasometer (Kay PENTAX, Lincoln Park, NJ). The nasalance score is the ratio of acoustic output of the oral and nasal cavities that are measured using Nasometer (Dalston, Warren, & Dalston, 1991). Nasometer is provided with a headset having a baffle plate separating the nasal and oral cavities. This plate aids in improving the accuracy of the data analysis by limiting the integration of signals from the oral and nasal cavities. The previous studies have shown good correlation of the perception of nasality with the Nasometer scores (Sweeney & Sell, 2008; Hardin, Van Demark, Morris, & Payne, 1992). Along with the nasalance measures using Nasometer, several other methods based on the speech physiology have developed together with the Horii Oral-Nasal Coupling Index, ratio of oral breath pressure (Vogel, Ibrahim, Reilly, & Kilpatrick, 2009), sonography (Dillenschneider, Zaleski, & Greiner, 1973). Each one of these measures is supplement to the perceptual measures for the

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accurate diagnosis. However, the use of these objective measures is often limited due to lack of published data on the sensitivity and specificity of these research designs. Along with the recognition for imaging studies (nasoendoscopy & videofluroscopy) that provides information on the structure and function of velopharyngeal value (Vogel et. al, 2009) the user friendly commercially available instruments like the Nasometer reduces the need of other objective measures.

The analysis of spectral peak amplitudes of the speech signal provides information on the perceived nasality in speech of individuals exhibiting velopharyngeal dysfunction (Forner, 1983; Philips & Kent, 1984; Ericsson, 1987). However, some limitations of these measures need to be recognized before implementing the technique. Extensive user expertise and laborious analysis regimes are required in most of the acoustic techniques. The rigorous evaluation is not done to find the appropriateness of the selected stimulus (Watterson, Lewis & Foley-Homan, 1999; Vogel, Ibrahim, Reilly, & Kilpatrick,).

The literature has shown reduced amplitudes of the first formant frequencies (F1) in assessing speech of individuals with RCLP using acoustic analysis (Kent, Liss, & Philips, 1989; Fant, 1970; Dickson, 1962; House & Stevens, 1956; Smith, 1951). The loudness of speech influences the variations in amplitude of F1 between the individuals with CLP. Hence, Kataoka (1988) studied amplitude and frequency of the first formant at $1/3^{rd}$ octave intervals to normalize the spectral envelope. The selection of this particular bandwidth over a broad frequency range depends on its similarity with the critical bandwidth utilized by our ear to analyze speech (Pols, Vander Kamp, & Plomp, 1969).

Another study by Kataoka, Michi, Okabe, Miura, and Yoshida (1996) was conducted assuming that high correlation between the nasality and nasalance measures can be obtained using $1/3^{rd}$ octave analysis. Individuals with hypernasal resonance and normal resonance were analyzed for power level at formant frequencies. The results had shown increased amplitudes for F1 and F2, reduced amplitudes between F2 and F3. Perceptual analysis was correlated with these measures using multiple regression analysis and the results revealed a high correlation between the difference in power levels and perception of hypernasality at formant frequencies.

Following these the researchers were interested to investigate the relation between variations in the spectrum leading to the inconsistent responses or unreliable judgments from the judges. Hence Kataoka, Zajac, Mayo, and Lutz (2001) investigated the variations in listeners perception of vowel /i/ based on the acoustic and perceptual factors of speech. The study included 22 children with CLP and 6 non CLP. These speech samples divided into two groups based on 10 listeners ratings; 1) the group (n=14) that received variable ratings among listeners or inconsistent ratings from each listener (i.e., unreliable ratings) and 2) the group (n=14) that received similar ratings among listeners and consistent ratings from each listener (i.e., reliable ratings). These two groups were subjected for perceptual evaluation (3 experienced judges in first group, 7 speech pathology graduate students in another group) using 5-point equal appearing interval scale for voice quality and hypernasality. The frequencies ranging from 250 Hz to 8 kHz were subjected to the $1/3^{rd}$ octave spectra analysis. The results indicated reliable and consistent ratings in perceptual evaluation indicating significant spectral change (greater than 20 dB in the spectral component of Fn between $F_1$ and $F_2$) in majority of the subjects. Hence they concluded in the speech of CLP the first segment should be perceived as more hypernasal followed by the middle and the last segments. The deviated spectral change and voice quality can influence severity of the perceived hypernasality.

To explore further the application of 1/3rd octave spectra analysis in evaluating nasality Kataoka, Warren, Zajac, Mayo, and Lutz (2001) studied quantification of perceived hypernasality in children with cleft palate. Thirty two children with cleft palate and five children without cleft palate included in the study and vowel /i/ was considered to obtain one-third octave spectrum. All these 37 speech samples were rated severity of hypernasality by four experienced listeners using a six-point equal–appearing interval scale. On comparing the groups, increased spectral amplitudes between $F_1$ and $F_2$ and decreased spectral amplitudes in the region of $F_2$ indicated characteristics of hypernasality for cleft group. High correlation (r=0.84) between the amplitudes of $1/3^{rd}$ octave bands (1k, 1.6k, & 2.5 kHz) and the perceptual ratings was revealed using multiple regression analysis. The study concluded that the appropriate measure for quantification of hypernasality can be done by measuring the amplitude of the three 1/3-octave bands using the isolated vowel /i/.

The nasality in speech of children with CLP is evaluated predominantly using perceptual judgments. However, the easy-to-use objective techniques can contribute significantly for the effective empirical and clinical practice. One such tool is $1/3^{rd}$ octave spectra analysis. Another objective measure which is extensively used is nasalance using Nasometer. Any diagnostic tool need to have high sensitivity and specificity while using for differential diagnosis. Hence the goal of the present study is to measure the mean nasalance values and variations in the one third octave spectral peaks (energy concentration) in the spectrum of speech in children with repaired cleft lip and palate (RCLP) and control subjects.

*Objectives of the study:* The objectives of the present study are as follows.

1. To evaluate the following acoustic parameters in children with RCLP with age and gender matched typically developing children (Control group).
   a. Nasalance value for vowels - /a/ and /i/
   b. Spectral amplitude (energy concentration) at 1/3rd octave spectrum for vowels /a/ and /i/.
2. To investigate the sensitivity and specificity of nasalance and 1/3rd octave spectral analysis for vowels /a/ and /i/ to differentiate between children with RCLP with age and gender matched typically developing children (Control group).

## Method

The present study considered twenty four children between six to ten years. The eight children with RCLP (experimental group) are attending diagnostic and therapeutic services at All India Institute of Speech and Hearing. Sixteen age and gender matched typically developing Kannada speaking children passing the WHO checklist to screen for disability detection (Singhi, Kumar, Malhi, & Kumar, 2007) with no history of diseases related to ear, nose and throat were included as control group. All the children were subjected to hearing screening before including in to the study. All the care takers/ parents of the participants provided the informed consent. The following inclusion and exclusion criteria were considered for selecting the children in to the Group I.

Inclusion criteria for Group I (Children with repaired cleft lip and palate):

1 The children with repaired cleft palate, cleft lip and palate, and repaired soft palate in the age range of 6 to 10 years with normal cognitive abilities and neuromotor dysfunction

2 Children with no residual hard or soft palate fistulae and non-syndromic clefts.

3 Children with hearing thresholds below 20 dB in the poorer ear

Exclusion Criteria:

1 Children with unrepaired cleft palate, cleft lip and palate, facial clefts, submucous palate, presence of fistulae in soft / hard palate associated with secondary pharyngeal surgeries and syndromes.

2 Children with neuromotor dysfunction, cognitive deficiency, and history of ear, throat and nose pathologies.

3 Children with associated problems like cerebral palsy, dysarthria and apraxia.

*Instrumentation:* Nasalance Measures were derived using Nasometer *(Model 6400 II, Kay Pentax, New Jersey*). The one third octave spectra analysis was extracted using *MATLAB.7 version software.*

**Procedure**

*Nasalance measure for vowel /a/ and /i/:* Nasalance values were obtained using Nasometer (*Model 6400 II,* Kay Pentax). The children were instructed to sit comfortably in upright position and the headgear of nasometer is placed and adjusted. The children were demonstrated to repeat/ phonate at comfortable pitch and loudness level.

Calibration of the Nasometer II was done every day prior to the data collection as per the instructions provided by the manufacturer. Before the recording session the phonation of the stimulus was demonstrated. To make up the child more comfortable with the recording procedure the phonation for the first time was considered as practice trail. The phonation of the consecutive speech samples were recorded with an interval of 1-2 minutes. Every recording was saved for further analysis. The selection of the stimulus for analysis was performed by dragging the cursors from onset to the offset of the part of the selected stimulus. Each stimulus was recorded separately and mean nasalance values were obtained. The average of mean nasalance values of three trails of the phonated stimulus was calculated.

*One-third (1/3rd) octave spectra analysis for vowel /a/ and /i/:* Computerized Speech Lab (CSL) 4500 was used to record the stimuli /a: / and /i: /. The steady state of 50 msec portion of the vowel was selected for analysis using *Praat 5.3.17* version software. The computer loaded with was used to perform One third octave analysis of the selected stimulus was performed using *MATLAB.7 version software* in the computer. The mean of the amplitudes (dB) were calculated for every 1/3rd of an octave frequency bands (100–16,000 Hz) for the stimulus /a:/ and /i:/. The speech sample was analyzed over 23 one-third octave bands (over a frequency range of

100–16,000 Hz) to match the ANSI standard (ANSI S1.11-1986) using a digital filter. A 10th order Butterworth band pass filter with attenuation of 60 dB/Octave was used. By adding and considering mean of components over 1/3rd octave intervals with center frequencies ranging from 100 Hz to 16,000Hz average long-term RMS value were obtained. The procedure involved writing the *MATLAB.7 version* software and analyzing the mean amplitudes of one third octave filters between 100 Hz to 16,000Hz. Each stimulus was recorded and analyzed separately.

*Statistical Analysis :* SPSS 18 was used for statistical analysis and at $p < .05$ was considered as significant levels. For vowels /a/ and /i/ eventhough the 1/3rd octave spectra mean amplitudes (dB) were measured between 100 Hz to 16,000Hz statistical analysis was limited to frequency bands (476 Hz and 3089 Hz). These are the frequency bands that had high sensitivity to hypernasality as mentioned in the literature (Kataoka et. al, 2001; Lee, Yang, & Kuo, 2003). Further, the chance of Type II error can be reduced by limiting the analysis to those frequency bands proved to be more sensitive. The normality check was performed for all the data included in the study using Kolmogorov-Smirnov Test. The histograms were plotted across each stimulus and group prior conducting the statistical analysis. Normality was observed on majority of the data sets considered. As the diagnostic measures should have high sensitivity and specificity (i.e., low false negative and false positive rates) to widely use across the clinical population ROC curves were estimated. In order to arrive at optimum values, Receiver-Operating Characteristics (ROC) curves (Swets & Pickett, 1982; Begg, 1987) were used for the variables (nasalance & 1/3rd octave spectral analysis). The cutoffs values were derived from these ROC curves and used to differentiate between the groups of children with RCLP and control subjects with optimum sensitivity and specificity.

### Results and Discussion

The present study is aimed to analyze the nasality interms of nasalance scores and one third octave spectra analysis in children with RCLP and control group.

*a) Nasalance Values:* Means of nasalance values were calculated for the stimuli (/a/ and /i/) out of three trails. The mean values for the stimuli and standard deviations for the groups are reported in Table 1 and Figure 1. In general, the increased nasalance value was observed in children with RCLP and vowel /i/ had higher nasalance values compared to /a/ in both groups. Statistically significance difference (p<0.05) was observed between the groups. The results supports the finding of the are previous studies (Watterson et al., 1996; Sweeney & Sell, 2008) who reported high nasalance values in individuals with cleft lip and palate when the correlation was investigated.

*Table 1: Nasalance (Mean & SD) between the RCLP (c) and Control (n) groups.*

| | Normals(%) Mean (SD) | RCLP(%) Mean (SD) |
|---|---|---|
| Nasalance - /a/ | 5.00 (1.70) | 22.00 (9.33) |
| Nasalance - /i/ | 22.56 (5.88) | 65.38 (19.53) |

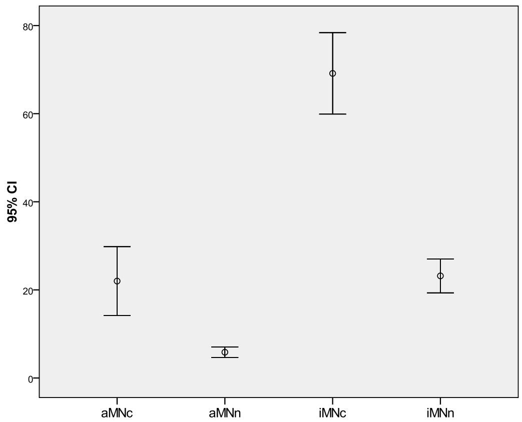


*Figure 1: Nasalance (Mean & SD) between the RCLP (c) and Control (n) groups*

The correlation coefficient was reported from 0.70 to 0.82 (Dalston et al. 1991), and 0.69 to 0.74 (Sweeney & Sell, 2008). The increased nasalance scores reported in subjects with RCLP in the present study and across the studies may be due to incomplete closure of velopharyngeal port leading to the flow of air through the nasal cavity reducing the oral airflow. Another finding of the present study is increased nasalance for vowel /i/ than /a/ which is an expected finding based on the literature (Lewis, Watterson, & Quint, 2000; Gopi Sankar & Pushpavathi, 2008). This finding can be related to the articulatory dynamics while producing the vowels. The open vowel (/a/) demonstrates less resistance to airflow out of the mouth results in maximum transmission through the oral cavity. In case of high vowels (/i/ & /u/) relatively more resistance to airflow is imposed resulting in reduced airflow through oral cavity. The physiological point of view the production of high vowels (/i/) requires greater degree of velopharyngeal closure than the production of low vowel (/a/) in normals (Moll, 1960).

Table 2 represents the maximum area of the variable under the reference curve. The area covered under the reference curve provides the ability of the variable to differentiate the RCLP and control groups. If the variable covers greater area under the reference (ROC) line the ability to differentiate the groups with high sensitivity and specificity will be more. The nasalance scores for both the vowels are under the curve, eventhough the difference between the vowels is negligible the area covered by /i/ (1.00) is more than /a/ (0.98). This represents the nasalance scores of both the vowels are valid measures for discriminating the groups. Figure 2 depicts the groups difference using nasalance values of /a/ with a sensitivity of 0.87 specificity of 0.93 and cutoff point was 8.8% and for /i/ sensitivity was 1.00 specificity was 0.93 and cutoff point was 31.6%. On the basis of the cutoffs identified using ROC curves, the nasalance measures of the vowels /a/ and /i/ differentiated across groups. The results showed significant difference in the nasalance values across the groups. The above results are in accordance with earlier study by Sweeney and Sell (2008) found sensitivity ranged from 0.83 to 0.88 and specificity ranged from 0.78 to 0.95.

*Table 2: Area under the ROC curve based on nasalance scores across stimuli and groups.*

| Variable | Area under the ROC curve for /a/ | | |
|---|---|---|---|
| | Area | Std. Error | Asymp Sig. |
| /a/ MN | .984 | .020 | .000 |
| /i/ MN | 1.000 | .000 | .000 |

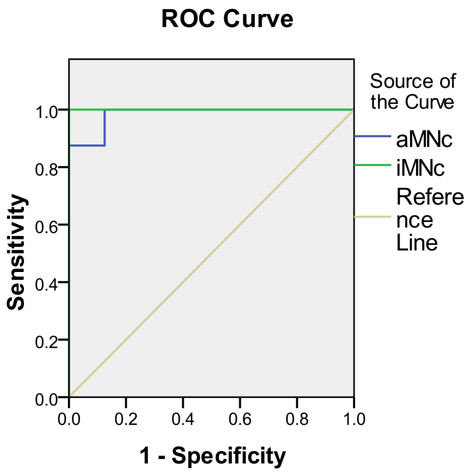


*Figure 2: Sensitivity and specificity of mean nasalance scores across stimuli and groups.*

*b) 1/3rd octave spectra analysis* :A summary of 1/3rd octave spectra mean amplitudes (dB) and standard deviations of children with RCLP and control subjects for stimuli (/a/ & /i/) are in Table 3 and Figure 3 and 4. According to data derived from one-third octave spectra analysis, significant differences in mean scores across the groups are evident in the Figure 3. In the present study energy concentration over the one third octave spectrum for vowel /a/ and /i/ were more in RCLP than normal. These findings strengthen the results of the study by Kataoka (2001) who stated that different spectral profiles were demonstrated by speakers with hypernasality than compared with controls.

*Table 3: Mean and standard deviations of energy concentration across groups.*

| Frequency(Hz) | 500 | 666 | 832 | 998 | 1331 | 1664 | 1997 | 2663 |
|---|---|---|---|---|---|---|---|---|
| RCLP-/a/ | 52.89 (10.12) | 57.79 (8.36) | 59.0 (8.54) | 62.89 (5.96) | 66.45 (8.03) | 65.58 (7.07) | 57.43 (9.84) | 46.87 (6.79) |
| Control-/a/ | 48.44 (12.17) | 52.29 (8.04) | 53.08 (9.81) | 57.02 (9.43) | 54.86 (9.33) | 56.01 (9.81) | 45.99 (11.4) | 39.28 (8.21) |
| RCLP-/i/ | 47.93 (12.70) | 57.2 (6.01) | 47.31 (8.77) | 44.62 (4.58) | 42.16 (5.31) | 42.37 (5.39) | 40.47 (4.99) | 42.06 (3.55) |
| Control-/i/ | 49.88 (12.89) | 48.42 (8.39) | 43.1 (7.91) | 36.96 (6.40) | 34.49 (6.25) | 33.93 (5.99) | 34.66 (6.51) | 41.23 (8.54) |

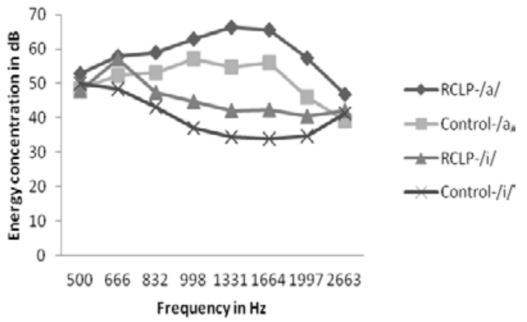


*Figure 3: Mean of energy concentration across the frequencies and groups.*

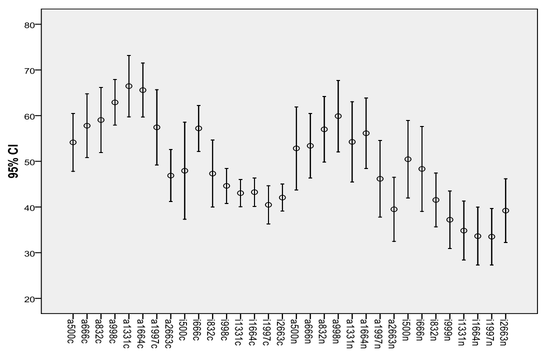


*Figure 4: Mean and SD of energy concentration across frequencies and groups (RCLP-c & Control-n).*

Table 4 depicts significant differences in energy concentration of vowel /a/ in 1331Hz, 1664 Hz, 1997 Hz, and 2663 Hz frequencies, where as for /i/ in 998 Hz, 1331Hz, 1664 Hz and 1997 Hz frequencies between the groups as shown in Table 5. However, significant differences in spectral peaks were observed in the mid frequencies between 1331 Hz to 2663 Hz for vowel /a/ and between the 997 Hz to 1997 Hz For /i/.

Another finding of the present study is significant differences in spectral peak amplitudes for /a/ and /i/ were observed above 1331 Hz and 998Hz respectively. This indicates the change in the spectral amplitudes below 1331Hz for vowel /a/ were not significant. However, for vowel /i/ the increase in amplitude was noticed at the frequencies below 1 KHz itself exhibiting significant differences between the groups. This could be due to coupling of the nasal tract to the main vocal tract introduces pole-zero pairs in the transfer function. Whereas low vowel /a/ is nasalized, the amplitude of F1 decreased because the first nasal zero appears in the frequency region of F1. When high vowels such as /i/ and /u/ are nasalized, however, the first nasal zero appears in a higher frequency region than F1. Therefore, the amplitude of F1 is not attenuated. (Kataoka, et al., 2001). The findings of Kataoka et al (2001) reported similar results indicating highest spectral peak amplitudes at 1, 1.6, and 2 KHz for vowel /a/ in the moderate to severe hypernasal group than the normal resonance group. For vowel /i/ characterized by increased amplitude level at F1 and between F1 and F2, decreased amplitude in the levels of F2 and F3 region in children with cleft lip and palate (House & Stevens, 1956; Fant, 1970).

*Table 4: Significance values of the frequencies differentiating the groups across the vowels*

| Frequency (Hz)- /a/ & /i/ | Sig. value (P<0.05)-a | Sig. value (P<0.05)-i |
|---|---|---|
| 500 | .384 | .729 |
| 666 | .133 | .015 |
| 832 | .158 | .248 |
| 998 | .186 | .007 |
| 1331 | .007 | .011 |
| 1664 | .023 | .003 |
| 1997 | .024 | .038 |
| 2663 | .035 | .798 |

As mentioned earlier the area covered by the variable indicates the ability to differentiate the groups. Table 5 represents the maximum area covered by the target frequencies are 1331 Hz, followed by 1664Hz, 1997Hz and 2663Hz for /a/. Figure 5 represents the cutoffs frequencies differentiating the groups with high sensitivity 0.87 to 0.75 and 0.75 to 0.56 specificity with cut off 61.58dB at 1331Hz and 43.75dB at 2663Hz are identified using ROC curves.

Table 6 represents the maximum area covered by the target frequencies of /i/ under the ROC curve are 1664Hz followed by 1331Hz, 988Hz, and 1997Hz. Figure 6 represents the cutoffs frequencies differentiating the groups with high sensitivity 87% to 62% and 87% to 81% specificity with cut off 40.16dB at 1664Hz and 39.75dB at 1997Hz.

*Table 5: Area under the ROC curve based on energy concentration distributed across frequencies for vowel /a/.*

| Freq (Hz) | Area under the ROC curve for /a/ | | |
|---|---|---|---|
| | Area | Std. Error | Asym Sig. |
| 500 | .574 | .122 | .561 |
| 666 | .680 | .117 | .159 |
| 832 | .656 | .117 | .221 |
| 998 | .629 | .121 | .312 |
| 1331 | .836 | .084 | .008 |
| 1664 | .785 | .094 | .025 |
| 1997 | .773 | .105 | .032 |
| 2663 | .754 | .105 | .047 |

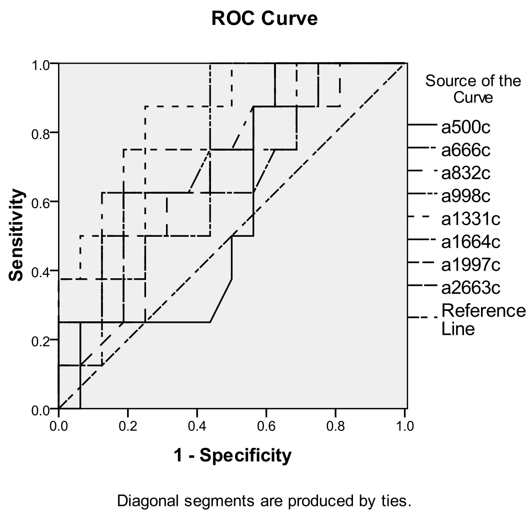


*Figure 5: Sensitivity and specificity of frequencies (500Hz to 2663Hz) for /a/ across groups*

To strengthen the objective evaluation of nasality along with the nasalance measures, spectral analysis of speech was carried out by the earlier researchers. In the present study, energy concentration over the one third octave spectrum for vowel /a/ and /i/ were more in CLP than normals. In case of vowel /a/ various acoustic studies have shown similar pattern of additional spectral peaks.

*Table 6: Area under the ROC curve based on energy concentration distribution for various frequencies for vowel /i/.*

| Freq (Hz) | Area under the ROC curve for /i/ | | |
|---|---|---|---|
| | Area | Std. Error | Asymp Sig. |
| 500 | .465 | .129 | .783 |
| 666 | .813 | .088 | .014 |
| 832 | .613 | .129 | .375 |
| 998 | .816 | .089 | .013 |
| 1331 | .891 | .066 | .002 |
| 1664 | .910 | .061 | .001 |
| 1997 | .754 | .107 | .047 |
| 2663 | .523 | .117 | .854 |

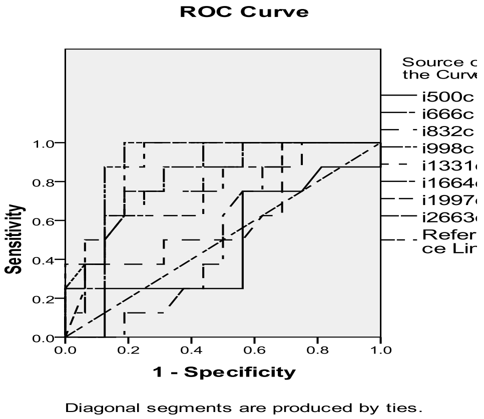


*Figure 6: Sensitivity and specificity of frequencies (500Hz to 2663Hz) for /i/ across groups*

However, reduced amplitude between F2 and F3 is also reported in majority of the studies (Yoshida et al., 2000; Vogel, Ibrahim, Reilly, & Kilpatrick, 2009). Kataoka et al (2001) reported difference in amplitude of isolated vowels across experiment and control groups. The spectral change over the duration of the vowel was considered as the coexisting speech characteristics that influenced the percentage of hypernasality perceived. Miller (1989) reported that the influence of spectral changes such as logarithmic shifts in frequency and intensity on perception is insufficient. However, shifts in the relative position of spectral peaks have a significant influence on vowel perception. Strange (1989) stated that dynamic properties of vowels could be represented by the spectra at three different points of time at one glide (the initial), off glide, and the nucleus, which contain formant values most closely approximating the steady state part of vowels. Bakkum et al (1995) applied whole spectrum analysis to represent these dynamic properties of vowels (1/3rd octave) using the averaged 1/3rd octave spectrum over a time window.

According to Miller's (1989) the change in atleast one of the formant frequency (F0, F1, F2, & Fn) i.e., a spectral peak between F1 and F2 results in changing the relative level of $F_0$ to each formant. This change apparently results in a different perceived severity of hypernasality during vowel production. Hypernasal vowels in general, have broad peaks and flattened spectra when the spectral peaks are not prominent. The shape of the entire region of the spectral envelope is important for vowel perception rather than the frequency and amplitude of the spectral peaks (Beddor & Hawkins, 1990). Therefore, 1/3rd octave spectral analysis evaluates overall spectral envelope may have a theoretical advantage in analyzing hypernasal vowels. Furthermore, the static properties of the vowel spectra have been examined by formant analysis, where as 1/3rd octave analysis can utilize both static and dynamic approaches. This is the initial study focused on exploring the application of ROC curves in differentiating the RCLP from the control groups based on one third octave analyses. Hence to generalize the results related to the specificity and sensitivity of 1/3rd octave analysis to differentiate the groups, further research needs to be carried out.

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# Derived Nasalance Measures of Nasality for Sentences in Children with Repaired Cleft Lip and Palate

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**Abstract**

***Context***: Hypernasality is dominant characteristic of speech exhibited by individuals with cleft lip and palate. Hypernasality can be assessed by subjective and objective methods, Nasometer is one of the instrument widely used as a diagnostic and therapeutic tool to estimate nasality. Nasometer provides nasalance values and other two new derived nasalance measures.

***Aim***: The aim of the present study is to explore the use of derived nasalance measures in differentiating the children with repaired cleft lip and palate (RCLP) with respect to severity and also from control group.

***Settings and design***: Institutional setup and standard group's comparison design.

***Methods and material***: The study considered ninety children equally divided into three groups. Group Ia included children with repaired cleft lip and palate (RCLP) exhibiting mild hypernasal and group Ib included children with RCLP exhibiting moderate to severe hypernasal, and group II is typically developing age and gender matched children. The children with RCLP were divided into groups based on perceptual evaluation of hypernasality using a standardized four point rating scale. Nasometer II was used to measure the nasalance values, nasalance distance and ratio for oral and nasal sentences.

***Statistical analysis***: SPSS, Descriptive statistics and Multivariate analysis (MANOVA) were used to analyze the data.

***Results*****:** Increased nasalance value was seen in children with moderate to hypernasal than mild hypernasal and control group. The derived nasalance measures (nasalance distance and nasalance ratio) calculated from mean nasalance were significantly differentiating the children with RCLP based on severity and from the typically developing children.

***Conclusions*****:** The new nasalance measures can be used potentially in clinical scenario and may be explored across the various methodological conditions to further evaluate the efficacy of these measures.

***Key-words*****:** Nasalance distance, Nasalance ratio, Hypernasality.

## Introduction

Nasality is one of the important parameters of resonance aspects related to speech production and perception. The varying shape of the vocal tract results in change of resonance characteristics of speech. Individuals with cleft of the lip or palate (CLP) have disorders in speech dominantly exhibiting hypernasality. They exhibit articulation, resonance and voice disorders leading to unintelligible speech. Among these hypernasality resonance disorder is frequently seen.  Nasality is assessed through perceptual or instrumental method.

The speech of individuals with repaired cleft lip and palate and/ or velopharyngeal dysfunction can be evaluated primarily using perceptual evaluation (McWilliams, et al. 1990, Sell, et al. 1990). There is diversity across evaluations procedures in terms of reporting parameters and guidelines for usage, speech sampling procedures. The perceptual rating scales usually vary from four to nine points or even eleven points (Whitehill 2002). Most widely used is the ordinal scale with 5 categories (normal nasality, mild, moderate, severe and very severe hypernasality/ nasal emission). To build a consensus in evaluating, reporting and exchanging the information among the professions and for ease of communication Henningsson et al. (2007) developed a universally standardized speech protocol for reporting speech outcomes in individuals with CLP. However, the differences in inter and intra judge reliabilities are high and there found to be significant variations in the use of methodological procedures of using various test and rating scales to measure the speech and language abilities. Hence, subjective assessment procedures can be a supplement along with the objective measures.

The measure of nasalance using Nasometer is one to the most popular objective diagnostic measure of nasality for individual with CLP. Nasometer is developed by Kay Elemetrics (Pine Brook, NJ) based on the work done by Fletcher (1970, 1972, & 1978). Extensive studies have been reported using Nasometer Model No. 6200 and 6400 (Seaver, Dalston, Leeper, & Adams, 1991; Watterson, Lewis, & Brancamp, 2005). Various studies have focused on developing the normative data across the languages (Haapanen, 1991; Van Doorn & Purcell, 1998; Jayakumar & Pushpavathi, 2005; Devi & Pushpavathi, 2009). Studies have also focused in documenting nasalance values in clinical populations i.e., individuals with CLP or deformity of nose and compared with the perceptual studies (Keuning, Wieneke, Van Wijngaarden, and Dejonckere, 2002).

A study done by Hardin et al (1992) on cleft and non flap cleft subjects correlated the nasalance scores with the perceptual judgments of perceived nasality. Pharyngeal flap surgery was received by 29 of the 51 subjects with cleft palate. The efficiency, sensitivity and specificity of Nasometer as a screening instrument was evaluated using predictive analysis method. Nasal sentences for assessing hyponasality and zoo passage for assessing hypernasality were used as stimulus. The results indicated a good correlation and high sensitivity (0.87) and specificity (0.93) for non flap subjects, than subjects with cleft undergone pharyngeal flap surgery. Hence, the author concluded that efficiency was poorer in individuals who underwent flap surgery.

Another study by Keuning, Wieneke, Van Wijngaarden, and Dejonckere (2002) correlated between the nasalance score and the perceptual rating of several aspects of speech in speakers with velopharyngeal dysfunction (VPD) by six experienced speech-language pathologists. The overall grade of severity, hypernasality, audible nasal emission, misarticulations, and intelligibility were rated on visual analog scales. Speech samples with a normal distribution of phonemes (11.67% of the consonants are nasal) called as normal text - NT and those free of nasal consonants (denasal text- DT) comparable to zoo passage were used for 43 individuals with VPD as stimulus for measuring nasalance. Mean nasalance scores were computed for the speech samples. Results revealed that the correlation coefficients between mean nasalance and perceptual rating of hypernasality ranged among judges from 0.31 to 0.56 for nasal text speech samples and 0.36 to 0.60 for denasal text speech samples.

Sweeney and Sell (2008) conducted a study to explore the correlation between acoustic measurements and perceptual assessment while using controlled speech stimuli. The Temple Street Scale was developed which is based on perceptual evaluation to describe perceived nasality. The study included 50 children with nasality were evaluated using Nasometer to derive nasalance values and perceptual evaluation was performed using Temple Street Scale. The relationship between the perceptual ratings and the Nasometry results were evaluated using correlation analysis, test sensitivity, specificity and overall efficiency. The findings of the study indicated correlation coefficients for perceived nasality and nasalance ranged from 0.69 to 0.74. The sensitivity and specificity of nasalance values ranged from 0.83 to 0.88 and from 0.78 to 0.95 respectively. Its efficiency was between 0.82 and 0.92. The study concluded that the existence of strong relationship studies related to correlation of speech based on nasalance value with perceptual judgments of nasality. This is due to the considerable variation in the magnitude of mean nasalance values of speakers with perceptually normal nasal resonance. This indicates the range of nasality used in speech by normal individuals can vary considerably. Hence it is difficult for judges to determine the limit for normal nasalance just based on perceptual evaluation.

To overcome this limitation, Bressmann, Sader, Whitehill, Awan, Zeilhofer, and Horch (2000) evaluated two measures which are derived from mean nasalance values. Those are nasalance distance (difference between maximum and minimum nasalance) and nasalance ratio (ratio of minimum nasalance to maximum nasalance). The study included 133 individuals with cleft lip and palate exhibiting hypernasality. Nasal view system was used to perform the oral and nasal acoustic measurements. The modified Heidelberg Rhinophonia Assessment Form was used to calculate nasalance distance and nasalance ratio for five non-nasal and three nasal sentences. Optimum cut-offs were derived from Receiver-Operating characteristics. Results revealed that, for the sentence stimuli sensitivity and specificity ranged from 64.4% to 89.6% and from 91.2% to 94.1% respectively. The study concluded that these two new measurements which are valuable in routine clinical examinations can becomes supplements for the nasalance mean value. Hence the present study is aimed to investigate the new derived nasalance measures using the standardized Kannada oral and nasal sentences in Kannada speaking children with repaired cleft lip and palate.

**Objectives of the Study**

1. To group the children with RCLP exhibiting hypernasality based on perceptual evaluation.
2. To investigate the mean and derived nasalance values (Nasalance Distance - ND and Nasalance Ratio – NR) for oral and nasal sentences in children with RCLP and control group.

**Method**

**Participants:** The present study considered ninety children (42 boys & 48 girls) as participants who were divided into three groups. Group I consisted of sixty children with 27 boys and 33 girls with RCLP age ranging from four to twelve years. Only children with repaired cleft lip and palate or cleft palate not exhibiting any associated syndromes, without any ear infections and neurological issues were considered for the study. The control group consisted of thirty age and gender matched typically developing children. All the children included in the study had passed hearing screening, exhibited normal cognitive abilities without any neuromotor dysfunction. The parents and care takers of the participants were requested to provide informed consent.

Table 1

*Details of the subjects participated in the study.*

| **Participants** | **Mean Age** | **Gender** | | **Severity of nasality** |
|---|---|---|---|---|
| | | **M** | **F** | |
| Group Ia | 8.2 | 14 | 16 | Mild hypernasal |
| Group Ib | 9.1 | 13 | 17 | Moderate to severe hypernasal |
| Group II | 8.7 | 16 | 14 | Normal nasality. |

Group Ia = mild hypernasal, Group Ib = moderate to severe hypernasal, Group II = control group, M = Male, F = Female.

**Materials**: The stimuli used for perceptual analysis consists of spontaneous speech (on self-introduction, school, leisure activities and picture description). The stimuli used for nasalance measures were standardized oral and nasal sentences.

**Procedure**: The spontaneous speech of children was video recorded in sound treated room by placing the handycam at a distance of 2 feet in front of the child. The recorded speech was subjected to perceptual analysis of hypernasality by three experienced judges (qualified speech language pathologist). The standardized four point rating scale was used by the judges to rate the severity of nasality perceived. The scale is defined as 0 = within normal limits (WNL), 1 = mild, 2 = moderate, 3 = severe. Three reference samples were used prior to the actual perception task to provide familiarity to the judges. These reference samples represented examples of scale points 0, 1, 2, 3 that ranged from normal nasal resonance at 0 to severe hypernasal at 3. The reference samples were selected from the 10 samples based on the 3 experienced listeners' agreement before the perceptual experiment. Written instructions regarding the description given for each rating scale by Henningsson et al. (2007) was provided and reviewed vocally at the beginning of the task.

The calibration of the Nasometer II was carried out by adjusting the headgear according to the instructions provided by the manufacture every day prior to the data collection. Each subject was instructed to repeat the standardized five oral and nasal sentences of six to ten syllable length in Kannada. The standardized Kannada oral sentences (Jayakumar & Pushpavathi, 2005) were selected, where the oral sentences loaded with 90 % oral pressure consonants and nasal sentences with 85% of nasal consonants along with the vowels. Each stimulus was recorded and saved separately for further analysis. The subject was instructed to phonate /a/ and trail one was taken as practice trail, to let the subject get adapted to the procedure. The subject was instructed to repeat the sample with an interval of 2-3 minutes. The phonation of the child was recorded and saved for further evaluation. The analysis was performed by pointing the cursors on the screen from onset to the offset of the stimulus end. The average of the mean nasalance of two trials out of three was calculated. Sentences were recorded only once, as the variability was high in case of production of phonemes and the reliability of nasalance value was reported to be more if the length of the stimulus is around six syllables (Watterson, Lewis, Foley-Homan, 1999) and mean nasalance value was noted.

After obtaining the nasalance values for the five oral and five nasal sentences separately, the mean of the nasalance values for both sets of sentences were considered. The two measures of ND and NR were derived from these mean values using the following formulas: ND (sentences) = Mean nasalance of nasal sentences – Mean nasalance of oral sentences and NR (sentences) = Mean nasalance of oral sentences / Mean nasalance of nasal sentences (Bressmann, et al., 2000).

**Instrumentation:** For perceptual evaluation the speech of children is video recorded using *Sony handycam with 60 optical zoom, bearing Model no. DCR-SR88.* The standardized four point rating scale developed by Henningsson, Kuehn, Sell, Sweeny, Trost-Cardamone, Whitehill (2007) is used for perceived nasality rating by three experienced speech language pathologists. The nasalance measures were obtained using Nasometer (Model 6400 II, Kay Pentax, and New Jersey) in speech lab.

**Statistical Analysis**

The mean and standard deviation (SD) were calculated and multivariate analysis was performed using SPSS software to obtain the significance level of the variables in differentiating the groups. Cronbach's Alpha test was administered to measure inter judge reliability of perceived hypernasality between three judges on four point rating scale. Receiver operating curves were used to obtain the sensitivity and specificity of the mean and derived nasalance measures.

**Results**

a) *Perceptual evaluation of hypernasality to group the subjects.*

The study included sixty children with RCLP, exhibiting varying degrees of nasality in their speech. The recorded spontaneous speech of these children was subjected to perceptual evaluation of hypernasality by three experienced judges using standardized four point rating scale. The scale is defined as 0 = within normal limits (WNL), 1 = mild, 2 = moderate, 3 = severe (Henningsson, 2007). All these children were grouped on the basis of severity of nasality exhibited in spontaneous speech. Perceptual evaluation revealed, thirty mild, nineteen with moderate and eleven with severe hypernasality. The children with mild hypernasal were considered as Group Ia and children together with moderate and severe were considered as Group Ib and typically developing children were considered as Group II. Twenty percent of the sample was considered for inter and intra judge reliability of the ratings. The interjudge reliability is 0.83 and intra judge reliability is 0.86 for the perceived hypernasality by three judges indicated high Cronbach's Alpha coefficient.

*b) Nasalance measures for oral and nasal sentences.*

The nasalance was measured using standardized oral and nasal sentences across the groups. The mean and derived nasalance values for various stimulus is shown below. Table 2 and Figure 1 Illustrates the results for mean nasalance values of oral sentences, nasal sentences, nasalance distance and nasalance ratio with respect to three groups. Children with RCLP exhibited increased nasalance values across the stimuli compared than typically developing children. The difference between the groups was high for oral sentences than nasal sentences. Among the children with RCLP, group Ia (mild hypernasal) exhibited low mean nasalance values than group Ib (moderate-severe hypernasal). The nasalance distance was high for typically developing children (control group) than compared to children with RCLP. Among the groups the nasalance distance was reduced for moderate to severe hypernasal group than mild hypernasal group. The group with moderate to severe hypernasal exhibited increased nasalance ratio than the mild hypernasal group and control group as indicated in Figure 1.

Table 2

*The mean and derived nasalance values for oral and nasal sentences across the groups.*

| Parameters | Oral sentences Mean (±SD) | Nasal sentences Mean (±SD) | Nasalance Distance Mean (±SD) | Nasalance Ratio Mean (±SD) |
|---|---|---|---|---|
| Group Ia | 32.79 (9.7) | 52.71 (9.31) | 18.5 (8.98) | 0.63 (0.15) |
| Group Ib | 42.92 (10.9) | 55.62 (9.38) | 11.8 (7.21) | 0.76 (0.10) |
| Group II | 15.25 (5.2) | 50.96 (6.26) | 35.8 (4.43) | 0.30 (0.081) |

*Notes.*

Group Ia = mild hypernasal, Group Ib = moderate to severe hypernasal, Group II = control group, SD= standard deviation.

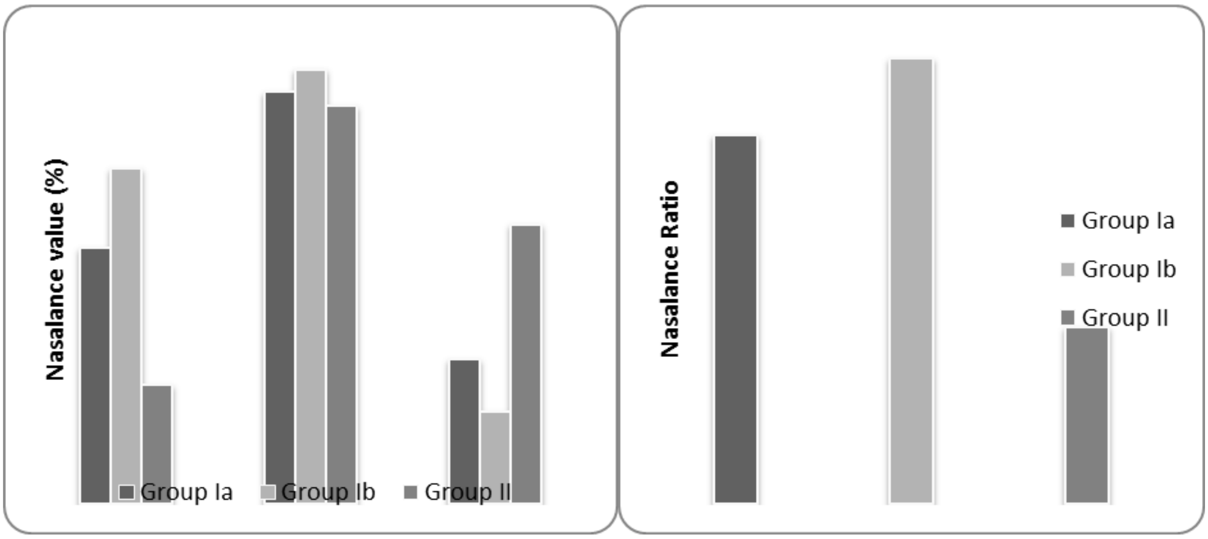


Figure 1: *The mean and derived nasalance values for oral and nasal sentences across the groups.*

Group Ia = mild hypernasal, Group Ib = moderate to severe hypernasal, Group II = control group, OS = oral sentences, NS = nasal sentences, ND = nasalance distance, NR = nasalance ratio.

MANOVA was used to find the differences in mean and derived nasalance measures between the three groups (mild hypernasal, moderate to severe hypernasal and normal) as shown in table 3. The significance values for oral sentences [F(2,87) = 72.8, $p < 0.001$] nasal sentences [F(2.87) = 2.33, $p < 0.10$], nasalance distance [F(2,87) = 90.99, $p < 0.001$], nasalance ratio [F(2,87) = 116.38, $p < 0.001$]. The results of MANOVA indicated highly significant (P<0.01) difference between the groups for oral sentences, nasalance distance and nasalance ratio. The MANOVA indicated no significant difference across the groups for mean nasalance values of nasal sentences at $p > 0.05$ level of significance.

Table 3

Mean and derived nasalance values differentiating the groups using MANOVA.

| Parameters | Oral | Nasal | Nasalance | Nasalance |
|---|---|---|---|---|

| | sentences | sentences | Distance | Ratio |
|---|---|---|---|---|
| F (2,87) | 72.8 | 2.33 | 90.99 | 116.38 |
| Significance (*p*-value) | 0.00 | 0.10 | 0.00 | 0.00 |

Post hoc multiple comparison using Duncan's test revealed significant differences between the three groups for mean nasalance values of oral sentences, derived nasalance measures (nasalance distance and nasalance ratio) at $p < 0.05$ level of significance. For nasal sentences, normal and moderate to severe groups were significantly different at $p < 0.05$ level of significance.

**Discussion**

The present study is aimed to evaluate, mean nasalance measures and derived nasalance measures for standardized oral and nasal sentences in Kannada to differentiate children with repaired cleft lip and palate from typically developing children. The perceptual evaluation of severity of hypernasality was conducted using a four point standardized rating scale developed by Henningsson et al (2007) resulted in differentiating the ninety children in to three groups; thirty children with mild hypernasal as Group Ia), nineteen with moderate and eleven with severe hypernasality together as group Ib. The interjudge reliability of perceptual rating among the judges resulted in Cronbach's alpha coefficient of 0.83. This indicates a high reliability among the judges in rating the samples. Even though hypernasality is one of the difficult variables to judge reliably because of the large number of variables influencing the internal standard of hypernasality, the high reliability in the present study was possible because of the experienced listeners and prior training to the listeners was provided using reference samples.

The results of the study support Laczi et al. (2005) who stated that expertise listeners in rating hypernasality were highly reliable than inexperienced listeners. The length of the stimulus (sentences used in present study) is one of the important factors effecting the reliability of the hypernasality ratings, as found by Counihan and Cullinan (1970). The reliability for nasality ratings was higher for sentences followed by single words and isolated vowels. Watterson (1999) on comparison of nasalance scores with the length of the stimuli, they found that longer the stimulus, the stronger the correlation with the perceived nasality. The results of the study also agrees with by Redenbaugh and Reich (1985) who reported good intrasubject reliability for perceived hypernasality on equal appearing interval ratings for forward played sentences, reliability coefficient of 0.89 and backward played sentences, a coefficient of 0.96 was found.

Nasometry measures are useful in supplementing the perceptual ratings of hypernasality by speech language pathologists. Higher nasalance values were exhibited by group I (mild and moderate to severe hypernasal groups) for oral and nasal sentences than by group II (normal children). The increased nasalance values in children with repaired cleft lip and palate can be attributed to the oral – nasal imbalance due to velopharyngeal impairment. The measurement of oral – nasal acoustic balance (which in essence represents the physical measurement of nasality) has shown that the amplitude of oral nasal balance increases with greater velopharyngeal impairment (Jones, 2000).

The nasalance distance is significantly more for group II (35.8) i.e., typically developing children than group Ia (18.5) followed by group Ib (11.5). As the nasalance distance is the difference of mean nasalance values of oral and nasal sentences, the mild hypernasal and moderate hypernasal groups exhibited high mean values for oral sentences as the perceived nasality is increasing. This inturn reduces the difference between mean values for oral and nasal sentences than the typically developing children. The results are in accordance with the study by Bressmann et al., (2000) indicating high values of nasalance distance for normal resonance (27.31) followed by borderline hypernasality (23.41) and marked hypernasality (17.09). The inverse pattern was observed for values of nasalance ratio (NR) i.e., the NR value was less for group II (0.30) followed by group Ia (0.63) and group Ib (0.76). As nasalance ratio is the division of mean nasalance values for oral and nasal sentences, increased value in the numerator for children with RCLP lead to high nasalance ratio than typically developing children. Similar results were indicated by Bressman, et al. (2000) for nasalance ratio of normal resonance group (0.49), followed by group with borderline hypernasality (0.57) and group with marked hypernasality (0.69).

## Conclusion

The study concludes that the derived nasalance measures (nasalance distance and nasalance ratio) calculated from the mean nasalance values of oral and nasal sentences are also significantly differentiating the children with repaired cleft lip and palate based on severity and from the typically developing children. Hence these measures can be used in the clinical scenario to evaluate the children with cleft lip and palate.

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