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

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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^rd^ 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 1/3rd 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 1/3rd 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 1/3rd 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 1/3rd 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 1/3rd 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 10^{th} 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 $1/3^{rd}$ 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 & $1/3^{rd}$ 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)

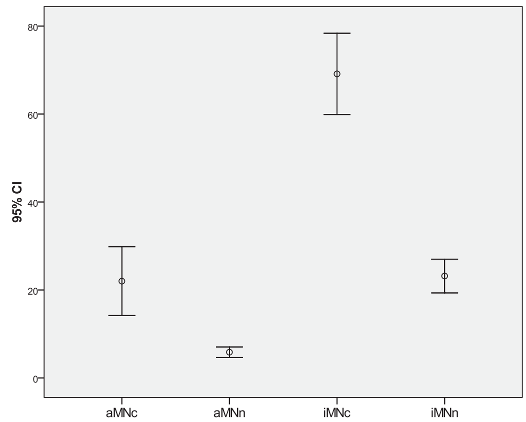

Figure 1: Nasalance (Mean & SD) between the RCLP (c) and Control (n) groups

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

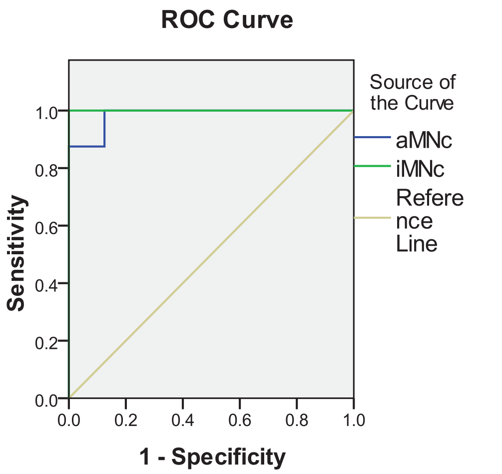

Figure 2: Sensitivity and specificity of mean nasalance scores across stimuli and groups.

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)

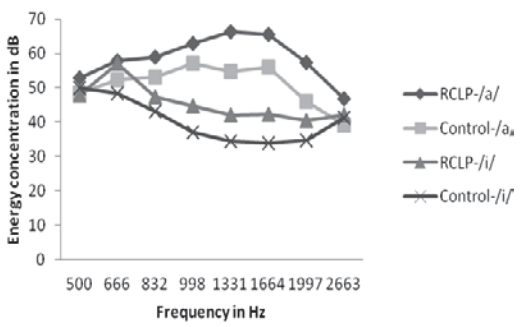

Figure 3: Mean of energy concentration across the frequencies and groups.

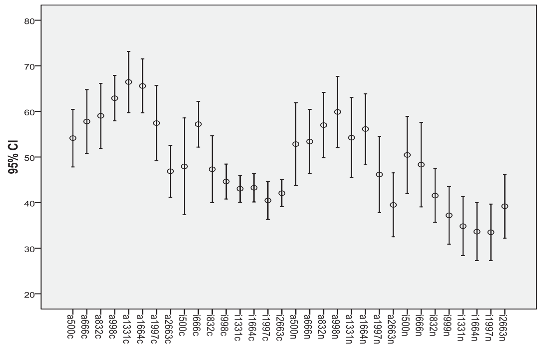

Figure 4: Mean and SD of energy concentration across frequencies and groups (RCLP-c & Control-n).

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

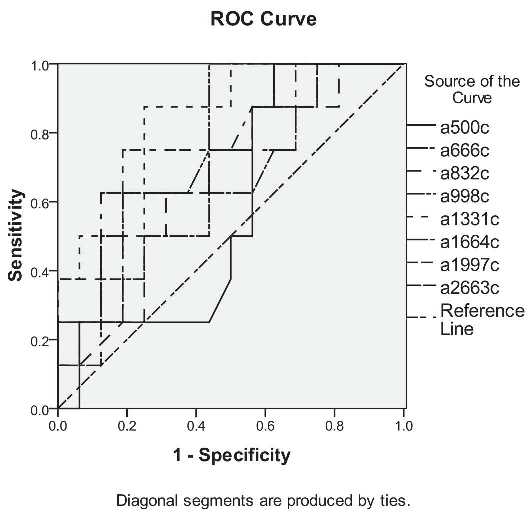

Figure 5: Sensitivity and specificity of frequencies (500Hz to 2663Hz) for /a/ across groups

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

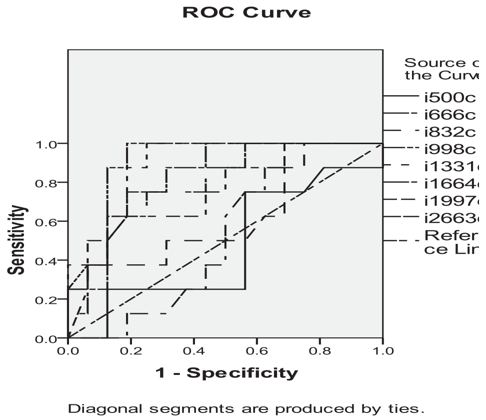

Figure 6: Sensitivity and specificity of frequencies (500Hz to 2663Hz) for /i/ across groups

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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