Research Article

Nasalance in typically developing children and in children with hearing impairment

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Mythri H. M.[a], Deepashree S. R.[a] and M. Pushpavathi[a]

Affiliations

[a]All India Institute of Speech and Hearing, Mysore

Corresponding Author

Dr.M. Pushpavathi
Professor, Dept. of Speech language pathology
All India Institute of Speech and Hearing, Manasagangothri, Mysore-570 006
pushpa19@yahoo.co.in

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Abstract

This study compared the effects of vowels and CV combinations on nasalance scores in children with and without hearing impairment using Nasometer II Model 6400. The effect of voicing on nasalance scores was also analyzed. Fifteen children with normal hearing and fifteen with hearing impairment in the age range of 3 to 7 years participated in the study. The subjects were instructed to repeat isolated vowels (/a/, /i/, /u/) and CV combinations (phonemes /p/, /t/, /k/, /b/, /d/ and /g/ with vowels /a/, /i/ and /u/) at their habitual rate. The mean nasalance value was extracted. Independent samples t-test showed a significant difference in the nasalance values across vowels in both the groups. High nasalance value was seen for high anterior vowel /i/ followed by /a/ and /u/. Both unvoiced and voiced bilabial, dental and velar consonants with /i/ had high nasalance value followed by /u/ and /a/ in the both groups. This is attributed to the valving function of velopharyngeal closure during the articulation of /i/. Children with hearing impairment had significantly higher mean nasalance values when compared to children with normal hearing owing to the lack of auditory feedback, essential to maintain the oral/nasal distribution. The results also showed that voiced consonants had higher nasalance values than their unvoiced counterparts. The outcome of the present study would aid Speech Pathologists in developing appropriate stimuli for assessing velopharyngeal closure for children with hearing impairment.

Introduction

Speech is the key to human communication. To understand the nature and function of speech, it is necessary to know the mechanism involved in the production of speech. During speech or singing, depending on the particular speech sounds to be produced, there is a requirement to open and close the passage way connecting the oropharynx to the nasopharynx. This mechanism leads to nasality or nasal resonance in the speech production. Nasality is one of the important parameters in the perception of normal as well as disordered speech. The concept of “Nasalance” introduced by Fletcher et al. (1978) is the ratio of nasal acoustic energy to the sum of nasal plus oral acoustic energy multiplied by hundred. Study of nasalance permits the speech-language pathologists to authenticate the perceptual assessment and to present a quantitative measure of nasality perceived. Nasalance measures act as a supplement during the speech evaluation of various speech disorders.

Nasality can be assessed by Nasometer II, introduced in 1986. Nasometer employs a noninvasive measurement technique that uses two microphones separated by an acoustic shield to measure the acoustic output from oral and nasal cavities. The instrument calculates a ratio of the acoustic data obtained by the two microphones that are located on the top and bottom of the acoustic shield. Nasalance is expressed by calculating a numeric ratio of nasal acoustic energy to the sum of oral plus nasal acoustic energy and multiplying it by hundred. Hence, the output of the instrument provides the percentage values that reflect the relative amount of nasal energy present in the speech of an individual. Many studies have suggested Nasometer as a clinically useful tool for assessing nasality (Parker & Maw, 1989, Seaver & Dalston, 1990; Dalston et al., 1991a, b, c).

Nasality depends on several factors such as vowel type, length of the stimuli, context of the speech sound and rate of the speech. Nasality can be assessed using short stimuli like vowels, and words loaded with pressure consonants or standard paragraphs like Zoo passage (Fletcher, 1978) and rainbow passage (Fairbanks, 1960) can be used as well.

Data provided by MacKay and Kummer (1994) supported the contention that nasalance values from short stimuli may be markedly influenced by the vowel content. For the Simplified Nasometric Assessment Procedures Test (SNAP Test), the authors provided mean nasalance data for normal subjects using a variety of stimuli. The syllable repetition subtest required the subjects to repeat a CV syllable 6 - 10 times, and data were presented for CV stimuli that varied only with regard to the vowel. The data showed that the nasalance values for the stimuli with high anterior vowel /i/ were strikingly higher than those obtained from the stimuli with low posterior vowel /a/. These authors explained that, the individual consonant environments such as place, manner and voicing exert different influences from one vowel to other, where the voicing produced the maximum effects on perception of nasality. The vowels in the fricative or voiced environments were seen to be more in duration, higher in intensity and lower in fundamental frequency than vowels in plosive or unvoiced environments. The nasality perception increased when the above mentioned acoustic correlates accompanied the phonetic context. The results pointed out that the nasality perception tracked this succession from least to most: (a) unvoiced plosive environments /p, t/, (b) unvoiced fricative /s, f/ and voiced plosive environments /g, d/, and (c) voiced fricative environments /v, z/. On the whole, the tongue height and voicing were found to have the most significant influence on the nasality perception.

In a study by Kerry, Watterson and Terasa (2000) high vowels were associated with significantly higher nasalance values than the low vowels for both sentence and sustained vowels. For the velopharyngeal dysfunction group, nasalance values for high vowel sentences and mixed vowel sentences were significantly higher than for the low vowel sentences. Nasalance values for the sustained vowels were significantly more for the high anterior vowel /i/ than for the other vowel in both normal and children with velopharyngeal dysfunction. Similar results were obtained by Lewis, Wattson and Quint (2000) for nine speech stimuli that included four vowels spoken in isolation and five sentences. The four vowels were /i/, /u/, /a/, and /a/. Out of the five sentences, four were loaded with high front, high back, low front, or low back vowels, and the fifth one had a mixture of vowel types.

The quality of speech in children with hearing impairment is often described as nasalized. Nasalance has been studied in normal as well as children with hearing impairment (McClumpha & Sharon, 1969, Lapine, Stewart, & Tatchell, 1991; Seaver & Dalston, 1990; Dalston et al., 1991a, b, c). There are several studies on nasality in individuals with hearing impairment using perceptual methods (McClumpha & Sharon, 1969), but very few using instrumental methods (Parker & Maw, 1989; Seaver & Dalston, 1990; Dalston et al., 1991a, b, c).

McClumpha and Sharon (1969) compared five profoundly deaf young adults with five normal hearing young adults on eight measures of velopharyngeal dysfunction using cineradiograpic analysis. Films were taken at 30 frames per second during the repetition of consonant-vowel syllables. The authors found a significant difference in velopharyngeal closure between the subjects with hearing impairment and subjects with normal hearing during the task. All the subjects with hearing impairment showed some amount of velopharyngeal opening while producing the repeated syllables. On the contrary, none of the subjects with normal hearing showed any velopharyngeal opening during the production of the same CV syllables repeatedly. Significant differences between the groups were found in velar length, nasopharyngeal depth, and velar thickness. They concluded that the pattern of velopharyngeal closure may be different for speakers with hearing impairment as compared to normals, and the rate of utterance in persons with hearing impairment may also induce the nasality in their speech.

Lapine, Stewart, and Tatchell (1991) assessed 19 children with hearing impairment using Nasometer 6200. Each participant was asked to repeat or read a passage without nasal consonants ("Zoo Passage") without amplification, with amplification and with FM amplification conditions. The analysis of the mean nasalance values in each speaking condition demonstrated that children with hearing impairment had higher nasalance values than the norm. The nasalance values did not vary even after using the amplification systems (hearing aids/ FM systems). It was concluded that motor patterns for the velopharyngeal control are established adequately and the neuromuscular patterns required for speech were sufficiently preserved even without any supplemental amplification.

The same group of authors (Tatchell, Stewart, & Lapine, 1991) measured nasalance in 18 children with hearing impairment under the same three conditions using the Nasometer 6200. The nasalance percentage in each condition was evaluated depending on the participant's age and the severity of hearing loss. The results showed that mean nasalance values for children with hearing impairment did not significantly vary as a function of hearing impairment, age and aided condition. They also suggested that lack of variations between the device-on and device-off conditions could be explained by the invariably maintained neuromuscular control of the velopharyngeal mechanism, even in situations where the auditory feedback loop was compromised. However, there are no studies on measurement of nasalance in children with hearing impairment using different set of stimuli ranging from vowels to paragraphs, even though the nasality can vary depending on the type of stimulus.

The above review indicates limited studies on objective analysis of nasality in children with hearing impairment. This study was taken up due to lack of studies which objectively document the effect of vowels, place of articulation and voicing on nasalance in children with hearing impairment. Since Nasometer is one of the instruments which is used widely to measure the nasalance the present study is an initial attempt to explore the same. The aim of the present study was to compare the mean nasalance values of children with normal hearing and children with hearing impairment for the isolated vowels and oral consonants across different place of articulation in CV context. An attempt was also made to study the effect of voicing on nasalance values across the groups.

Method

Participants: Fifteen typically developing children with normal hearing (7 males, 8 females) and fifteen children with hearing impairment (8 males, 7 females) in the age range of 3 to 7 years (mean age: 5years) participated in the study. Typically developing children underwent audiological and speech language evaluation and they were judged by the investigators to possess age appropriate speech and language skills. All the participants were free from upper respiratory infections during the investigation. All children with hearing impairment had congenital severe to profound hearing loss in both ears. An informed consent was taken from the parents of the children before the data collection.

Table 1: Details of the speech stimuli

Vowels	/a/	/i/	/u/
Bilabial unvoiced consonants	/pa/	/pi/	/pu/
Bilabial voiced consonants	/ba/	/bi/	/bu/
Alveolar unvoiced consonants	/ta/	/ti/	/tu/
Alveolar voiced consonant	/da/	/di/	/du/
Velar unvoiced consonant	/ka/	/ki/	/ku/
Velar voiced consonant	/ga/	/gi/	/gu/

Instrumentation: Nasometer II model 6400 (Kay Elemetrics Corp., Lincoln Park, NJ) along with a lightweight headset made up of a harness which holds a (nasal/oral) separation plate was used. The partition plate was tightly fitted against the area between the upper lip and the nose. The signals were transferred to the computer database where they were analyzed using the Nasometer software. The resultant acoustic values were a ratio of nasal to oral-plus-nasal acoustic energy, which was multiplied by 100, and expressed as "nasalance".

Stimuli: The stimuli consisted of isolated vowels /a/, /i/, /u/ and phonemes /p/, /t/, /k/, /b/, /d/, /g/ in CV combinations with the three vowels. Table 1 shows the list of stimuli used in the study.

Table 2: Nasalance values (in percentage) for vowels across both the groups

Group	/a/		/i/		/u/	
	Mean	SD	Mean	SD	Mean	SD
CNH	8.20	2.57	21.13	9.40	12.80	4.59
CHI	15.87	5.64	32.80	5.65	22.47	3.97

CNH= Children with Normal Hearing,
CHI=Children with Hearing Impairment

Procedure: The Nasometer was set up in a suitable quiet room. The instrument was calibrated prior to the data collection based on the instructions provided in the manual. The participants were seated comfortably and they were assessed & recorded individually. The Nasometer headset was positioned perpendicular to the facial plane and seated firmly against the upper lip. Once the headset was correctly positioned the participants were instructed to sustain vowels (/a/, /i/, /u/) in isolation at their comfortable pitch. For CV combination, they were instructed to repeat/read a CV syllable three times (e.g., pa-pa-pa) at a habitual speed. Average nasalance value for each syllable was computed.

Statistical Analysis: Independent samples t-test was performed to check for the existence of any statistically significant difference between the two groups across the three vowels and CV combinations. Paired sample t-test was used to analyze the effect of voicing feature on nasalance.

Results

Nasalance of isolated vowels across groups: The nasalance value for different vowels for both control group (normal children) and children with hearing impairment was analyzed. Table 2 depicts the mean and standard deviation (SD) for nasalance across the groups.

Increased nasalance values were observed in children with hearing impairment. Figure 1 depicts the mean nasalance values for the three vowels across the two groups. In general, the vowel /i/ had high nasalance value followed by /u/ and /a/ in both the groups. Independent t-test revealed a significant difference ($p<0.05$) between the two groups across all the vowels.

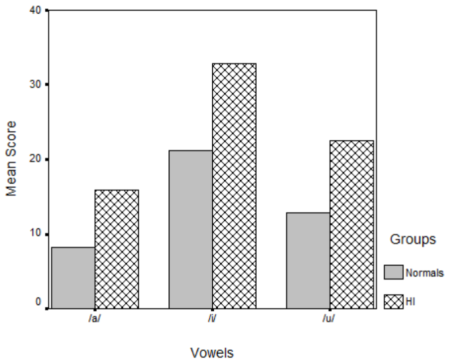

Figure 1: Mean nasalance values for vowels across both the groups.

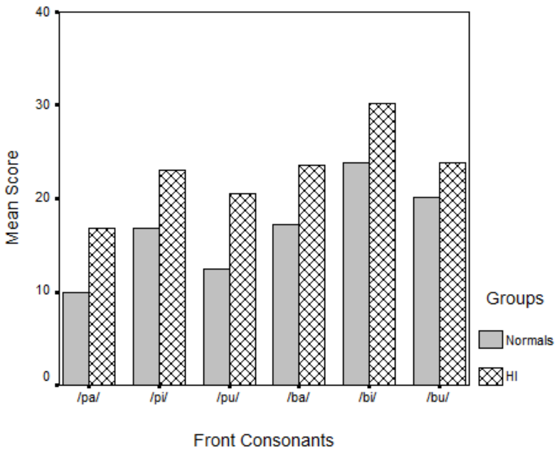

Figure 2: Nasalance values for bilabial consonants.

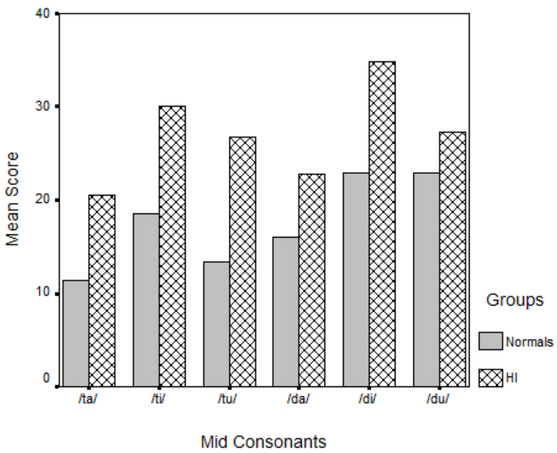

Figure 3: Nasalance values for alveolar consonants.

Effect of vowels on different consonants based on place of articulation (Bilabial, Alveola, Velar) across both the groups: The effect of vowels on different consonants was studied across different place of articulation- bilabial (/p/, /b/), alveolar(/t/, /d/) and velar(/k/, /g/) for both groups. The nasalance value was estimated for all these syllables. Table 3, 4 and 5 depicts the mean and Standard deviation of nasalance values across the groups for the different consonants. As observed with the isolated vowels, the vowel /i/ had higher nasalance value in the context /p/ and /b/ followed by /u/ and /a / in both children with normal hearing and children with hearing impairment respectively. However, the nasality values were significantly higher in children with hearing impairment for all the contexts.

Independent t-test showed a significant difference ($p<0.05$) across the two groups. The nasalance values for bilabial voiced consonants (/ba/, /bi/, /bu/) were significantly higher than those for bilabial unvoiced consonants (/pa/, /pi/, /pu/) as displayed in the figure 2. The values were significantly higher in children with hearing impairment in both the contexts.

The unvoiced alveolar consonant /ti/ had higher mean nasalance values followed by /tu/ and /ta/ in both children with normal hearing and children with hearing impairment. The voiced alveolar consonant /di/ had higher mean nasalance values in both children with normal hearing and children with hearing impairment. However, there was no significant difference between /du/ and /da/. The nasalance values for alveolar voiced consonants (/da/, /di/, /du/) were significantly higher than the nasalance values for alveolar unvoiced consonants (/ta/, /ti/, /tu/). The values were significantly higher in children with hearing impairment. Independent t-test revealed a significant difference ($p<0.05$) across two groups.

The voiced back consonant /gi/ had higher mean nasalance values followed by /gu/ and /ga/ in both children with normal hearing and children with hearing impairment. The unvoiced back consonant /ki/ had higher mean nasalance values in both children with normal hearing and children with hearing impairment. However, there was no significant difference between /ku/ and /ka/. The values were significantly higher in children with hearing impairment. The nasalance values for velar voiced consonants (/ga/, /gi/, /gu/) were significantly higher than the nasalance values for velar unvoiced consonants (/ka/, /ki/, /ku/) in both children with normal hearing and children with hearing impairment respectively. The values were significantly higher in children with hearing impairment. Independent t-test revealed a significant difference (0.05) across two groups.

Effect of voicing feature of oral sounds on nasalance value within groups: Mean nasalance values were compared across the voiced and unvoiced stimuli in CV combination (Table 6). In normal children, the results of the paired sam-

Table 3: The nasalance values of the bilabial consonants with embedded vowels

Group	/pa/	/pi/	/pu/	/ba/	/bi/	/bu/
CNH	9.93(5.47)	16.87(7.16)	12.47(7.09)	17.20(7.18)	23.87(9.53)	20.13(8.59)
CHI	16.80(5.12)	23.07(8.62)	20.47(6.50)	23.60(9.13)	30.20(5.87)	23.87(6.94)

CNH = Children with Normal Hearing, CHI =Children with Hearing Impairment.

Table 4: Nasalance values for the alveolar consonants

Group	/ta/	/ti/	/tu/	/da/	/di/	/du/
CNH	11.40(5.90)	18.53(6.49)	13.40(4.76)	16.00(7.94)	22.93(8.22)	22.87(15.09)
CHI	20.53(4.82)	30.00(6.74)	26.80(12.16)	22.80(7.41)	34.80(8.98)	27.27(10.81)

CHI=Children with Hearing Impairment, CNH= Children with Normal Hearing.

Table 5: Nasalance values for velar consonants

Group	/ka/	/ki/	/ku/	/ga/	/gi/	/gu/
CNH	10.93(3.97)	19.87(6.33)	15.27(6.16)	17.67(9.59)	23.73(8.94)	18.87(9.10)
CHI	21.53(8.63)	34.20(10.32)	21.47(8.74)	27.53(8.77)	35.60(11.40)	32.13(13.03)

CHI=Children with Hearing Impairment, CNH= Children with Normal Hearing.

ple t-test revealed a significant difference ($p<0.05$) between voiced and unvoiced across different places of articulation for all CV combinations. The same was not seen in children with hearing impairment.

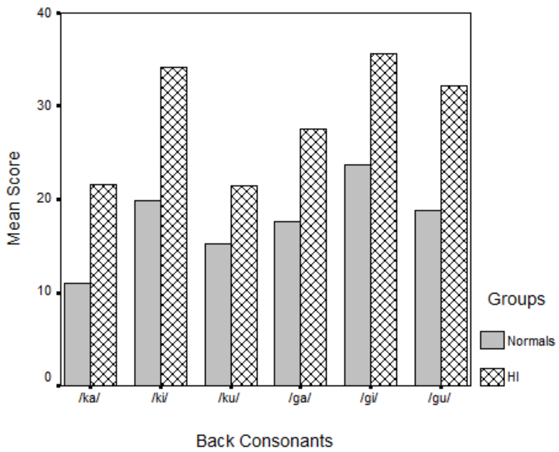

Figure 4: Nasalance values for velar consonants.

Discussion

The present study revealed several points of interest. In general, an increased nasalance value was observed for the vowel /i/ when compared to the other vowels. Nasality was more in children with hearing impairment compared to children with normal hearing. It was also found to be more in voiced context compared to unvoiced context.

First, increased nasalance for the high vowel was seen across both the groups. The results support the findings of Lintz and Sherman (1961), and Kerry, Watterson and Terasa (2000) who reported the increase in nasalance for the high vowel /i/. The increased nasality for the vowel /i/ is due to the valving function of the velopharyngeal closure.

Kendrick (2004) provided a physiological explanation for higher nasalance value in vowel /i/. He suggested a strong effect of horizontal position of the tongue on the nasalance of vowels. Posterior vowels are reported to have lower nasalance values because some of the muscles that pull the body of the tongue posterior also pull the velum down securing a tight closure between two structures. To keep the velum from lowering during vowel production, the muscles that elevate the velum may be more active during posterior vowel production than anterior vowel production to counteract the downward force of the muscle pulling the tongue posterior. The production of the higher vowel requires the positioning of the velum in high position making the tight velopharyngeal closure.

Another finding of interest was the increased nasalance for all the stimuli in children with hearing impairment. This is in consonance with the findings of Fletcher and Daly (1976), Colton and Cookes (1968), Rutherford (1967) reported excessive nasality in the speech of the individuals with hearing impairment. One possible explanation for this could be that the individuals are forced to rely on the auditory feedback to establish and maintain the oral/nasal distinction and children with hearing impairment are known to have limited auditory feedback. Added to this, Rutherford (1967) suggested that the presence of fewer tactile/kinesthetic

Table 6: t-values for voiced and unvoiced consonants

Place of articulation	Voiced-unvoiced contrast	Normal hearing children		Children with hearing impairment	
		t(14)	Sig (2-tailed)	t(14)	Sig (2-tailed)
Bilabial sounds	/pa/-/ba/	5.004	0.000*	3.252	0.006*
	/pi/-/bi/	4.679	0.000*	3.215	0.006*
	/pu/-/bu/	2.885	0.012*	1.500	0.156
Alveolar sounds	/ta/-/da/	2.833	0.013*	0.966	0.336
	/ti/-/di/	2.182	0.047*	1.684	0.114
	/tu/-/du/	2.769	0.015*	0.114	0.911
VelarSounds	/ka/-/ga/	3.718	0.002*	3.562	0.003*
	/ki/-/gi/	2.360	0.033*	0.521	0.0611
	/ku/-/gu/	2.213	0.044*	2.962	0.010*

'*' = p<0.05

sensory receptors in the velum, as compared to the structures found in the anterior portion of oral cavity might also cause higher nasalance in children with hearing impairment.

The improper control of the velum has long been recognized as a source of difficulty in the speech of individuals with hearing impairment (Brehm, 1922). Mc Clumpha (1966) also provided physiological explanations based on cineflourographic observations where he observed that all five normal speakers achieved and maintained the contact of the palate with pharyngeal wall while four of five hearing impaired speakers never achieved closure.

The result of the present study support the findings of Gilbert (1975) who studied the simultaneous nasal and oral airflow in the speech of the hearing impaired children and observed that they were unable to co-ordinate velopharyngeal function with the activity of other speech articulators. In addition, in children with hearing impairment the tongue position is reported to be reduced in vertical range and high variation is reported in high posterior tongue shape.

The present study was also aimed at finding the influence of vowels embedded with different consonants in different place of articulation in voiced and unvoiced distinction. The nasality was found to be more in voiced context compared to unvoiced context. The difference between voiced and unvoiced mainly depends on the coordination of the respiratory and phonatory system and on the auditory feedback.

This study also throws light on the co-articulation phenomenon in the hearing impaired speakers. In spontaneous speech, the speaker has to use the articulators in a precise manner which leads to the proper oral and nasal balance in speech. This requires the speaker to use the " Forward Scanning" in which they position the articulators based on the following sound. Children with hearing impairment do not learn the process of "Forward Scanning". Whitehead and Jones (1978) concluded that the hearing impaired fail to learn to combine phonemes using some of the learned principles of co-articulation and thus may view speech in terms of distinct individual phoneme units rather than as a dynamic co-articulatory action". This would disrupt the normal timing of speech and thus may account in part, for the poor overall speech intelligibility.

The results also indicate that nasality increases as the place of articulation moves backwards. This was clearly seen for the unvoiced consonants and not in their voiced counterparts. The amount of nasality depends on the position of tongue and velum.

In general, there was increased nasalance for all the vowels in voiced context compared to unvoiced sounds. This may be due to vowels in voiced environments were found to be longer in duration, lower in fundamental frequency and greater in intensity than vowels in unvoiced or plosive environments. The perception of nasality increased when these acoustic correlates (i.e. longer duration, lower fundamental frequency, and higher intensity) accompanied the phonetic context.

Conclusions

The degree of velopharyngeal closure is related to the consonant sound being produced; oral consonants require maximum closure while nasal consonants are produced with the valve open. In the production of vowel, the degree of valve closure is influenced by the tongue position required for the vowel, and the consonant produced next to the vowel. Opening and closing the velopharyngeal valve appropriately and consistently during speech is a highly coordinated task. This is reported to be poor in children with hearing impairment. The increased nasality in children with hearing impairment is due to prolonged nasal airflow, delayed velopharyngeal closure and thus increasing the nasalized duration as well.

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