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Automatic speech processing software – New sensitive tool for the assessment of nasality: A preliminary study

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ABSTRACT

Introduction: Automatic speech processing (ASP) software is a nasality assessment tool. ASP studies focusing on investigating sentences to find nasality and correlating ASP scores with other objective assessment scores measuring nasality are scarce. Hence, the present study aimed at comparing the nasalance values of the ASP software with the nasometer in typically developing children (TDC) and children with repaired cleft palate (RCP) across different stimuli. **Methods:** Participants included 30 Kannada speaking TDC and 10 children with RCP (9–12 years). Speech stimuli (oral, nasal, and oronasal sentences) were recorded and the values were obtained from the ASP software as well as the nasometer. The following statistical tests were applied: mixed ANOVA, repeated measures ANOVA, paired samples *t*-test, independent samples *t*-test and Pearson's correlation. **Results:** Like nasometer, the nasalance values of ASP software were high for the nasal sentences followed by the oronasal sentences and the oral sentences, for both the populations. Higher nasalance values were found for children with RCP than for TDC across all the stimuli. Significant differences were found in nasalance values between the instruments in oral and oronasal sentences in TDC and nasal sentences and oronasal sentences in RCP. The nasalance values across the stimuli between nasometer and ASP software in both the groups showed no significant correlations. **Conclusions:** ASP software was successful in identifying nasalance in TDC and children with RCP. However, a major issue needs to be addressed concerning the dynamic range of the software and it has to be validated on a large number of populations.

Key words: Automatic speech processing software, cleft lip and palate, hypernasality, nasometer, repaired cleft palate

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INTRODUCTION

Hypernasality is the abnormal coupling of oral and nasal cavities which results in excessive nasality on vowels and vocalic consonants.[1] Along with articulation errors and nasal air emission, hypernasality is one of the major speech errors affecting the intelligibility of speech in children with cleft palate.[2] Assessment of hypernasality can be done subjectively as well as objectively.

Several test materials and protocols are developed to perceptually assess hypernasality in children with cleft palate.[3-8] However, this method carries inherent limitations, hence, subjective assessments are augmented by objective assessments to overcome these limitations. Instruments universally used for the measurement of nasality are nasometer, nasal view, and nasal visualization system. Among these, nasometer (Kay Elemetrics, USA) is the widely used objective assessment tool for the measurement of nasality for both clinical and research purposes.[9] It measures the nasalance values by separately measuring the nasal sound pressure level and oral sound pressure level, i.e., "nasalance = nasal energy/(nasal energy + oral energy) ×100."[10] However, nasalance varies across various factors such as language, age, gender, cleft palate, and stimuli.[1,11]

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Over decades, nasometry studies have shown higher nasalance values for individuals with a history of the cleft palate than noncleft individuals.[12,13] Across the stimuli, studies have revealed higher nasalance values for nasal stimuli, followed by oronasal and oral stimuli in noncleft individuals.[14-17] Furthermore, the same trend was followed across the stimuli, in individuals with cleft lip and palate (CLP).[12,13] Although nasometer has good sensitivity and specificity, there are some limitations which include expensive, inability to record the original signals for further analysis, nonportability, sanitization after each use, time-consuming test procedures, refusal to wear headgear by children, and the requirement of skilled transducer placement.[2,18,19]

To overcome the limitations, speech processing-based techniques have been recently proposed to analyze nasality in the cleft palate population. These methods analyze the acoustic characteristics of nasalization from speech signals and provide values. Many studies have been conducted using speech processing techniques in the assessment of nasality in noncleft individuals as well as in the cleft palate population.[20,21] The authors have investigated automatic detection of nasality in noncleft and clinical populations using acoustic analysis and the results showed a good accuracy level in detecting nasality in vowels[22] and syllables/words.[23,24] Most of the automatic speech processing (ASP) studies are done on vowels and words, but studies have rarely used sentences.[25] Furthermore, very few studies correlated nasality assessing ASP tools with perceptual or objective assessment tool assessments to check the reliability.[26-28]

It is clear that the automatic evaluation using the ASP software is a valuable means for research and clinical purpose to quantify nasality in children with CLP, but there are no commercially made instruments available using the ASP system. Hence, to overcome the limitations of the presently available objective assessment tools, ASP software was developed by speech scientists.[29] It is diagnostic computer software that works on the principle of ASP. In this system, the acoustic models for the nasals and oral sounds are developed. The likelihood scores computed for the nasal class are used as acoustic correlates of hypernasality. It is intended to use for the assessment of the severity of hypernasality in children with a history of cleft palate in the age range of 6–12 years. Scoring will be provided in the form of continuous numbers from “0” to “100.” However, the reliability of the software needs to be checked.

With the increasing incidence of cleft palate population in India (1.09–1.4 in 1000 live births),[30,31] which is scattered over a wide region, it demands the need to have an objective assessment tool that is portable, aiding the SLP to reach clients in remote areas. In addition, it is relatively cost-effective when compared to nasometer, nasal view, and NVS. This software is compatible with most of the “windows” versions and can be easily installed on any laptop or computer. This software requires a simple dynamic microphone connected to the computer/laptop for recording and can be operated by speech professionals and other qualified professionals as well. Whereas, other available instruments require separate hardware and software of their own. It is also equipped with headgear with a sound separator plate, which small children refuse to wear.[19]

Furthermore, very few ASP studies have focused on investigating the use of sentences to measure nasality. Objective evaluation of hypernasality using sentences in individuals with CLP is important as the listener reliability for the perceptual rating of nasality is higher for sentences than for words and isolated vowels.[32] Comparison of nasalance values of the ASP software and nasometer helps in checking the effectiveness of the ASP software in identifying the nasalance. Furthermore, as a result of this preliminary study, we get to know the drawbacks of the ASP software, if any, enabling us to improvise the software accordingly. ASP software can be used across various medical and rehabilitation centers if proven effective. This will help in reaching a greater number of children with a history of CLP in turn helping in the early identification, diagnosis, and management of children with CLP. Hence, the present study aims at comparing the nasalance values of the ASP software and nasalance values of the nasometer in typically developing children (TDC) and children with repaired cleft palate (RCP) across different stimuli. The objectives are (1) comparison of nasalance values across the stimuli using nasometer and ASP software in TDC, (2) comparison of nasalance values across the stimuli using nasometer and ASP software in children with RCP, (3) comparison of nasalance values across the stimuli between the groups (TDC vs. RCP) in both nasometer and ASP software, (4) comparison of nasalance values between the instruments (nasometer and ASP software) across the stimuli in both the groups, and (5) correlation of nasalance values across the stimuli between nasometer and ASP software in both the groups.

METHODS

Participants

Participants included 30 TDC and 10 nonsyndromic children with RCP (cleft palate alone – 7, CLP – 3) between 9 and 12 years of age. All the participants had Kannada as their native language. All the TDC were screened by the investigator, whereas all the children with RCP were tested by ENT, plastic surgeon, clinical psychologist, orthodontist, and SLP (investigator) at the "Unit for Structural Oro-Facial Anomalies" at the investigator's institute to rule out children with associated problems such as hearing loss, intellectual disability, language disorder, and nasal pathologies. Furthermore, the investigator perceptually screened all the children with RCP, and only those who had hypernasality were considered for this study. All the children with RCP had moderate-to-severe hypernasality. All the ethical guidelines were followed and written consent was taken from parents/caregivers of children with RCP and TDC.[33] Participants' details are provided in Table 1.

Research design

The study involved comparing the nasalance values of children with RCP and TDC. Hence, the standard group comparison was employed.

Materials

The speech stimuli included five oral sentences, five nasal sentences, and five oronasal sentences [Appendix 1].[14] Oral sentences are loaded with high-pressure oral consonants, nasal sentences with nasal consonants, and oronasal sentences with both oral and nasal consonants.

Procedure

The present study included two objective test procedures. Both the test procedures were modeled by the investigator to each participant and were asked to follow the same. The test procedures are as follows:

Nasometry

Before recording, the nasometer (Model 6450, PENTAX Medical) was calibrated according to the manufacturer's instructions. Each participant was comfortably seated on a chair and the nasometer headgear was firmly placed against the upper lip perpendicular to the facial plane, as shown in Figure 1.

Participants were instructed to carefully listen to the stimuli and repeat once clearly, in their comfortable pitch and loudness. The responses were recorded using the nasometer application and saved in "nsp" format for further analysis. In this application, the cursors on the screen were set from onset to the offset of the stimulus and the nasalance values were noted, as shown in Figure 2.

Automatic speech processing software

Each participant was comfortably seated on a chair in a sound-treated room. The participants were instructed to listen carefully and repeat the stimulus once after the investigator, in their comfortable pitch and loudness. The responses were audio recorded by placing a super-cardioid vocal dynamic microphone (Mipro MM-107) at 4 cm[34] away from the child's mouth using ASP software on a computer. The recorded speech samples were saved in "wav" format on the computer. For proof, the entire procedure was recorded using a Sony digital video camera recorder, as shown in Figure 3.

The saved speech samples were analyzed by the investigator within the ASP software. The speech sample was loaded and the required stimulus was segmented on the screen from onset to the offset of the signal and the nasalance values were computed [as shown in Figure 4]. From the segmented speech signal, Mel-frequency cepstral coefficients (MFCCs)

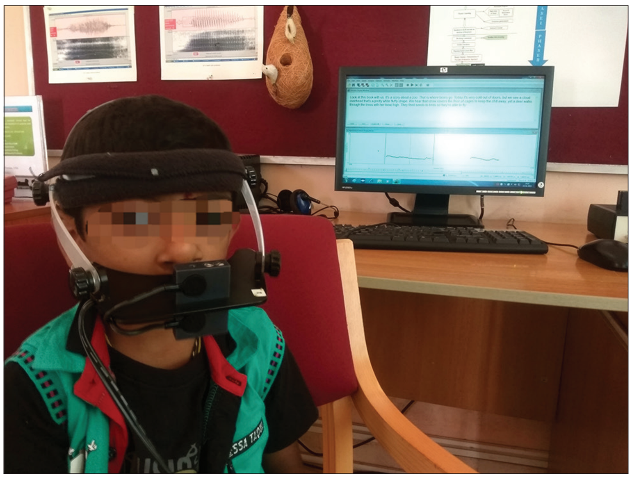

Figure 1: A child seated for the recording of speech samples in the nasometer

Table 1: Participants' details in typically developing children and repaired cleft palate

	Age (years)						Total
	9-10		10-11		11-12		
	Male	Female	Male	Female	Male	Female	
TDC	5	5	5	5	5	5	30
RCP			10				10
Total							40

TDC: Typically developing children, RCP: Repaired cleft palate

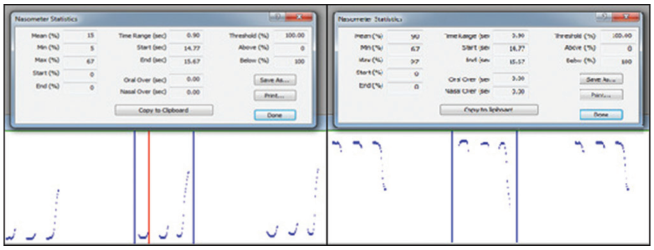

Figure 2: Stimulus selection and extraction of nasalance values for an oral stimulus (left) and a nasal stimulus (right)

are computed. The MFCC features are given as input to the Gaussian mixture model (GMM)-based oral and nasal classifier. The posterior probability scores computed for the nasal class are used for the nasality score computation. In this work, the pretrained GMM model from an ASP study is used.[35]

Children were effectively reinforced for their cooperation and response during the assessment procedure. All the ASP software values and nasometry values were carefully entered into an Excel sheet.

Statistical analysis

Obtained data were subjected to statistical analysis using IBM Statistical Package of the Social Sciences Software for Windows (Version 20. Armonk, New York: IBM Corp). Shapiro–Wilk test of normality revealed normal distribution (P > 0.05) of the data. Mixed ANOVA was done with the "stimulus type" and "instrument type" as within-subject factors and the "participant group" (TDC vs. RCP) as a between-subject factor. Repeated measures ANOVA was done with the "stimulus type" and "instrument type" as within-subject factors. Paired samples t-test was used to compare the nasalance values between the stimuli. Independent samples t-test was used to compare the nasalance values between TDC and RCP, across all the stimuli. Pearson's correlation was carried out to check the correlation between nasalance values from ASP and nasometry.

RESULTS

The study was a preliminary attempt to investigate and compare the nasalance values of the ASP software with the nasometer in TDC and children with RCP. The nasalance values were compared between the clinical group (RCP) and the control group (TDC), across stimulus type (oral sentences, nasal sentences, and oronasal sentences) and between the instruments (ASP software and nasometer). The mixed ANOVA results revealed that there was a significant interaction effect between: stimulus

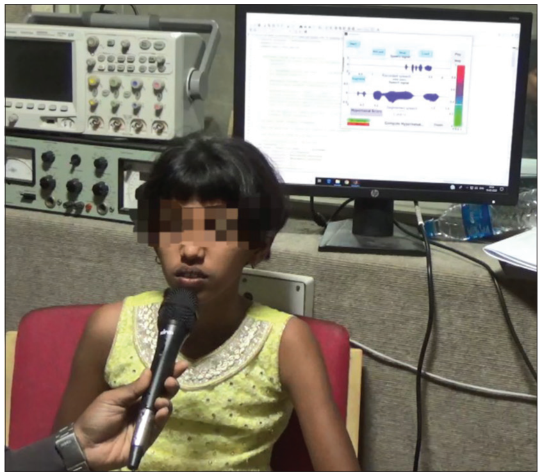

Figure 3: A child seated for the recording of speech samples in the automatic speech processing system

type and participant group; instrument type and participant group; Stimulus type, instrument type and participant group [Table 2].

Hence, repeated measures ANOVA was carried out separately for the two participant groups. Within TDC, there was a significant main effect of stimulus type and instrumentation type, and the stimulus type *instrument type interaction was also significant [Table 3].

Within RCP too, there was a significant main effect of stimulus type and instrument type, but the stimulus type * instrumentation type interaction was not significant [Table 3]. Further results are reported under the following subsections.

Comparison of nasalance values across the stimuli using nasometer and automatic speech processing software in typically developing children

The nasalance values of TDC across the stimuli were derived from the ASP software and nasometer. The mean and standard deviation of these nasalance values is depicted in Figure 5.

Within TDC, the nasalance values of the nasometer ranged from 15.70% to 51.15%, whereas the nasalance values of the ASP software ranged from 20.65% to 50.25%. In both instrument types, the nasalance values were high for nasal sentences, followed by oronasal sentences and oral sentences. The paired samples t-test results showed that there was a statistically significant difference in the nasalance values across all the stimuli, in both instruments [Table 4].

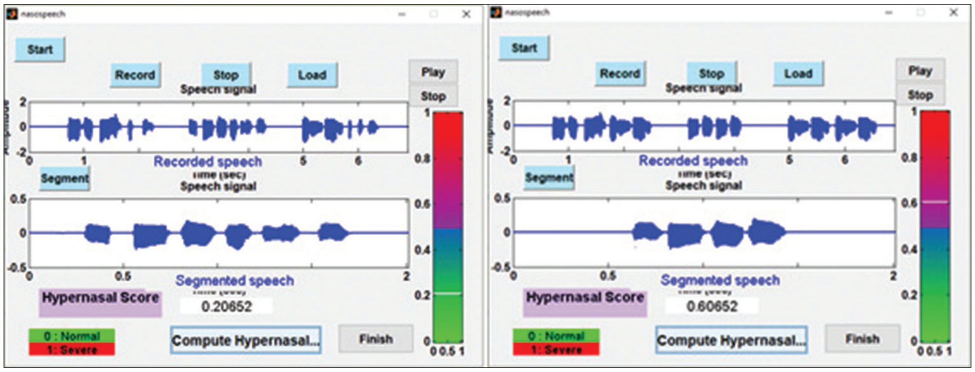

Figure 4: Computation of nasalance values of an oral stimulus (left) and a nasal stimulus (right)

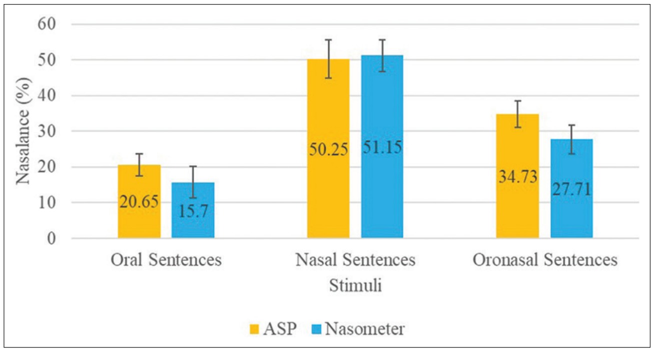

Figure 5: Mean and standard deviation of nasalance values in percentage from automatic speech processing software and nasometer in typically developing children

Comparison of nasalance values across the stimuli using nasometer and automatic speech processing software in children with repaired cleft palate

The nasalance values of children with RCP across the stimuli were derived from the ASP software and nasometer. The mean and standard deviation of these nasalance values is depicted in Figure 6.

Within RCP, the nasalance values of the nasometer ranged from 45.74% to 55.66%, whereas the nasalance values of the ASP software ranged from 57.18% to 67.76%. In both instrument types, the nasalance values were high for nasal sentences, followed by oronasal sentences and oral sentences. The paired samples *t*-test results showed that there was a statistically significant difference in the nasalance values across all the stimuli, in both instruments [Table 5].

Comparison of nasalance values across the stimuli between the groups (typically developing children vs. repaired cleft palate) in both nasometer and automatic speech processing software

In both instrument types, the nasalance values of children with RCP were higher than the nasalance values of TDC in all the stimuli. The independent samples *t*-test results showed that there was a statistically significant difference in the nasalance values between TDC and RCP, in both the instrument types, across all the stimuli [Table 6].

Table 2: Mixed ANOVA results of the interaction effect in between-subject and within-subject factors

Factor	df	*F*	*P*
Stimulus type × participant group	2	134.69	<0.001*
Instrument type × participant group	1	7.875	0.008*
Stimulus type × instrument type × participant group	2	6.017	0.005*

**P*<0.05 (significant difference)

Table 3: Repeated measures ANOVA results of the interaction effect in within-subject factors

Participant group	Factor	df	*F*	*P*
TDC	Stimulus type	2	1579.47	<0.001*
	Instrument type	1	15.59	<0.001*
	Stimulus type × instrument type	2	54.69	<0.001*
RCP	Stimulus type	2	20.01	0.001*
	Instrument type	1	6.81	0.028*
	Stimulus type × instrument type	2	1.79	0.227

**P*<0.05 (significant difference), TDC: Typically developing children, RCP: Repaired cleft palate

Comparison of nasalance values between the instruments (nasometer and automatic speech processing software) across the stimuli in both the groups

Within TDC, the nasalance values of ASP were higher than the nasalance values of nasometer in oral sentences and oronasal sentences but not in nasal sentences. The paired samples *t*-test results showed that, within TDC, there was a statistically significant difference between the nasalance values of ASP and nasometer in oral sentences and oronasal sentences, but not in nasal sentences. In

Table 4: Paired samples *t*-test results of the comparison of nasalance values between the stimuli in typically developing children, in both the instrument types

Stimuli	ASP		Nasometer	
	t	*P*	*t*	*P*
Oral sentences versus nasal sentences	−33.09	<0.001*	−50.52	<0.001*
Oral sentences versus oronasal sentences	−29.91	<0.001*	−26.67	<0.001*
Nasal sentences versus oronasal sentences	23.29	<0.001*	48.51	<0.001*

*$P<0.05$ (significant difference). ASP: Automatic speech processing

Table 5: Paired samples *t*-test results of the comparison of nasalance values between the stimuli in children with repaired cleft palate, in both the instrument types

Stimuli	RCP			
	ASP		Nasometer	
	t	*P*	*t*	*P*
Oral sentences versus nasal sentences	−4.12	0.003*	−9.28	<0.001*
Oral sentences versus oronasal sentences	−3.07	0.013*	−4.51	0.001*
Nasal sentences versus oronasal sentences	3.23	0.010*	8.58	<0.001*

*$P<0.05$ (significant difference). RCP: Repaired cleft palate, ASP: Automatic speech processing

Table 6: Independent samples *t*-test results showing the comparison of nasalance values between typically developing children and repaired cleft palate, in both the instrument types, across all the stimuli

Stimulus type	TDC versus RCP			
	ASP		Nasometer	
	t	*P*	*t*	*P*
Oral sentences	−13.959	<0.001*	−16.038	<0.001*
Nasal sentences	−7.102	<0.001*	−2.525	0.016*
Oronasal sentences	−11.861	<0.001*	−11.678	<0.001*

*$P<0.05$ (significant difference). TDC: Typically developing children, RCP: Repaired cleft palate, ASP: Automatic speech processing

RCP, however, there was a statistically significant difference for nasal and oronasal sentences, but not in oral sentences [Table 7].

Correlation of nasalance values across the stimuli between nasometer and automatic speech processing software in both the groups

The correlation between the nasalance values of the ASP software and the nasometer was determined separately for oral, nasal, and oronasal sentences, in TDC and children with RCP by administering Pearson's correlation [Table 8]. The results revealed that none of the correlations were significant ($P > 0.05$).

The correlation results between the nasalance values of nasometry and ASP software showed negative values

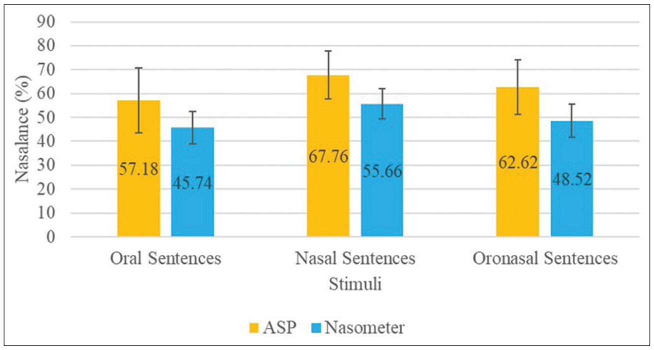

Figure 6: Mean and standard deviation of nasalance values in percentage from automatic speech processing software and nasometer in children with repaired cleft palate

in children with RCP whereas positive values in TDC, but they were not statistically significant.

DISCUSSION

The results are discussed under the following subsections.

Comparison of nasalance values across the stimuli using nasometer and automatic speech processing software in typically developing children

Across the stimuli, the ASP software and nasometer followed the same trend, where the nasalance values were high for the nasal sentences followed by the oronasal sentences and the oral sentences. This can be attributed to the physiological reason that the velum remains elevated, and velopharyngeal (VP) closure is maintained for the oral stimuli, whereas the velum lowers and the VP port is opened for the nasal stimuli. The nasalance for the speech segments with combination oral and nasal stimuli falls in between.[2] This finding agrees with the results of the previous nasometer studies.[14-17] The comparison of nasalance values between each stimulus showed a statistically significant difference in both the instruments. This shows that both the ASP software and nasometer are equally efficient in differentiating oral sentences, nasal sentences, and oronasal sentences using nasalance values. This

Table 7: Paired samples *t*-test results of the comparison of nasalance values between automatic speech processing software and nasometer within a different type of stimulus in typically developing children as well as children with repaired cleft palate

ASP versus nasometer	TDC		RCP	
	t	*P*	*t*	*P*
Oral sentences	−5.122	<0.001*	−2.122	0.063
Nasal sentences	0.735	0.468	−2.712	0.024*
Oronasal sentences	−7.126	<0.001*	−2.891	0.018*

*P<0.05 (significant difference). TDC: Typically developing children, RCP: Repaired cleft palate, ASP: Automatic speech processing

Table 8: Correlation between the nasalance scores of automatic speech processing software and nasometer in oral sentences, nasal sentences, and oronasal sentences in typically developing children and children with repaired cleft palate

Groups	Oral sentences		Nasal sentences		Oronasal sentences	
	r	*P*	*r*	*P*	*r*	*P*
TDC	0.055	0.771	0.039	0.840	0.040	0.832
RCP	−0.313	0.379	−0.460	0.181	−0.380	0.279

TDC: Typically developing children, RCP: Repaired cleft palate, *r*: Correlation coefficient, *P*: Level of significance

result ensures that acoustic parameters are useful in identifying hypernasality.

Comparison of nasalance values across the stimuli using nasometer and automatic speech processing software in children with repaired cleft palate

In children with RCP, the nasalance values of the nasometer and ASP software followed the same trend as that in TDC where the nasalance values were high for the nasal sentences followed by the oronasal sentences and the oral sentences. The comparison of nasalance values between each stimulus showed a statistically significant difference in both the instruments. Despite the oral-nasal imbalance due to VP dysfunction in children with RCP, there will be some amount of closure of the VP port for oral stimuli, which depends upon the severity of nasality. This result is in harmony with the results of the previous nasometer studies.[12,13] This result again ensures the efficiency of the ASP software in identifying nasal resonance.

Comparison of nasalance values across the stimuli between the groups (typically developing children vs. repaired cleft palate) in both nasometer and automatic speech processing software

Independent samples *t*-test revealed significantly higher nasalance values for children with RCP than for TDC across all the stimuli in both the instruments. This can be attributed to the oral-nasal imbalance due to VP dysfunction in children with RCP. The amplitude of this oral-nasal balance increases with the increased severity of VP impairment.[13,36] ASP software was successful in identifying nasalance and providing values in TDC and children with RCP. In addition, this result is consistent with previous ASP studies.[20-22]

Comparison of nasalance values between the instruments (nasometer and automatic speech processing software) across the stimuli in both the groups

Paired samples *t*-test revealed a significant difference between the nasalance values of ASP and nasometer in oral and oronasal sentences in TDC and nasal sentences and oronasal sentences in RCP. Whereas, such a difference was not found in nasal sentences in TDC and oral sentences in RCP. This discrepancy in the results might be because of the difference in the filter characteristics of the nasometer and ASP software. The upper limit (nasalance for nasal stimuli) of both the instruments is more or less equal, whereas the lower limit (nasalance for oral stimuli) is slightly higher in the ASP software [Tables 2 and 3]. This leads to a difference in the dynamic range between the two instruments. The sample size might be an important factor that has led to this difference in the nasalance values across the stimuli between the instruments, especially in RCP.

Correlation of nasalance values across the stimuli between nasometer and automatic speech processing software in both the groups

The nasalance values across the stimuli between nasometer and ASP software in both the groups showed no significant correlations. This shows that the way of nasalance measurement is different in both the instruments. Again, this might be because of the difference in the filter characteristics of the instruments and their dynamic range.

CONCLUSIONS

The present study shows that the ASP software was successful in identifying nasalance in TDC and children with RCP. Like nasometer, the nasalance values of ASP software were significantly different across oral sentences, nasal sentences, and oronasal sentences with nasalance values. However, a major issue needs to be addressed concerning the dynamic range of the software. Future studies should focus on investigating the performance of the software without a sound-treated room. Furthermore, to ensure that the ASP software is an efficient diagnostic tool, it has to be validated on a large number of populations.

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Conflicts of interest

There are no conflicts of interest.

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APPENDIX

Appendix 1: Speech Stimuli

1. **Oral sentences:**
   /ba: lu t̠abala ba: risu/
   /beɖa ka:ɖige oɖid̠a/
   /gi:t̠a be: ga ho: gu/
   /di: pa da: ri da:ʈidaɭu/
   /ad̠u ʤo: ga ʤalapa:t̠a/
2. **Nasal Sentences:**
   /manu a: nejannu noɖid̠a/
   /navi: na manejind̠a band̠anu/
   /na: nu a: nejannu noɖid̠e/
   /manga maneja me: lid̠e/
   /ma: ma: mandʝad̠ind̠a band̠anu/
3. **Oronasal Sentences:**
   /kamala u:ʈa ma:ɖid̠aḷu/
   /navi: na pa:ʈa o:d̠id̠a/
   /na: nage ʧamaʧa Koɖu/
   /bet̠t̠d̠a me: le hod̠alu/
   /ra: mana ʤot̠ejalli band̠e/