The role of auditory perceptual analysis of speech in predicting velopharyngeal gap size in children with velopharyngeal insufficiency

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Context
Assessment of velopharyngeal (VP) function starts with careful perceptual speech analysis, because it is the degree of speech impairment that dictates the need for intervention.

Aim
The aim of this study was to evaluate the role of auditory perceptual analysis of speech in predicting VP gap size in children with VP insufficiency.

Design and setting
This was a prospective correlation study conducted in a hospital-based setting.

Materials and methods
Referred sample of 38 participants with VP insufficiency and age ranging from 4 to 16 years were included in the study. The subjective evaluation of patients' speech was carried out using four-point severity scales. This included degree of hypernasality, audible nasal emission of air, the compensatory articulations (glottal and pharyngeal articulation), and the overall intelligibility of speech. Nasalance scores for oral and nasal sentences were measured. A combination of nasopharyngoscopy and multiview videofluoroscopy was used to measure VP gap size, which was rated using the scale proposed by Golding-Kushner and colleagues. The studied patients were classified into three groups on the basis of the estimated gap size (small, moderate, and large VP gap groups).

Statistical analysis
Statistical analysis was carried out using analysis of variance and post-hoc tests.

Results
There was a positive correlation between all studied auditory perceptual analysis variables and VP gap size. The degree of hypernasality and overall speech intelligibility had the strongest predictive values, followed by glottal articulation, nasal emission, pharyngeal articulation, and oral sentence nasalance score.

Conclusion
The study finding suggests that the size of the VP opening can be predicted on the basis of perceptual assessment of speech, which helps to anticipate the appropriate line of intervention without the need for invasive procedures.

Keywords:
auditory perceptual analysis, cleft palate speech, hypernasality, velopharyngeal gap size, velopharyngeal insufficiency

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Introduction

The typical features of cleft palate speech production can be related to the anatomical and functional constraints the cleft imposes on the speech mechanism, and to the degree to which individual speakers attempt to circumvent these constraints in the construction of an intelligible phonological output system [1]. When no attempt is made to compensate for the effects of the cleft, we may expect to hear atypical production features related to the abnormal coupling of the oral and nasal cavities: hypernasality, nasal emission, and nasal turbulence, as well as the weak pressure consonants; it is termed as structurally based misarticulations or passive strategies [2].

Compensatory adaptations (active strategies) originate in the speaker's aim to avoid the inappropriate escape of air through the nasal cavity. Active cleft-type speech characteristics include a range of retracted articulations [3]. The most common forms of compensatory misarticulation are glottal stops, pharyngeal stops and fricatives, and posterior nasal fricative [4]. They arise from the presence of velopharyngeal insufficiency (VPI) that persists long after surgical repair of the palate that constitute articulatory avoidance behaviors and linguapalatal valving constraints. Ultimately, this can impair speech intelligibility and is difficult to correct, even with intense speech therapy [1].

The diagnosis of VPI is typically ascertained with a combination of perceptual speech, instrumental evaluation, and reliance on the trained ear. Perceptual analysis, the gold standard of VPI evaluation, includes listening to the spontaneous or prompted production of specific pressure phonemes including plosives, fricatives, and affricatives while monitoring for misarticulations, hypernasal speech, nasal emission, and compensatory articulations.

Nasometry is an objective, indirect acoustic method that is used to measure nasality, and several studies proved its validity. It allows the reproducible calculation of a ratio between nasal and oral sound emissions, known as nasalance, which can be compared with normative values. However, the role of nasometry in the localization or quantification of VP gap size is still questionable [5].

The most common clinical tests of velopharyngeal (VP) anatomical and physiological function include nasendoscopy (NE) and multiview videofluoroscopy (MVF). NE provides a bird's eye view of the velopharynx during phonation, allowing assessment of the shape and pattern of VP closure during speech, and it is most frequently used for qualitative measurements of palatal and lateral pharyngeal movement. MVF demonstrates the same mechanism from various projections. Anterior–posterior, lateral, and basal views are used to assess lateral pharyngeal and palatal movement. MVF may reveal the cephalocaudal level of attempted VP closure and abnormal compensatory movements that occur during phonation [5]. Although it may be used to describe the velopharynx quantitatively, qualitative measurements of lateral pharyngeal and palatal movement are more frequently used clinically [1]. The main limitation of MVF is that the components of VP closure are measured on different projections. Most clinicians recommend performing both NE and MVF for evaluating VP function and make treatment recommendations [6].

Assessment of VP function starts with careful perceptual speech analysis, because it is the degree of speech compromise that dictates the need for intervention [7]. Some studies have examined the relationship between perceptual characteristics of speech and the anatomical and physiological characteristics of the VP mechanism [8]. Certain authors have noted that the relationship between the perceived degree of hypernasal resonance and size of the VP gap is nonlinear [9]. The degree of nasality reflects the complex interaction of a number of factors, including articulation (variations in oral, pharyngeal, and nasal cavity size), vocal pitch and intensity, respiratory effort, and the ratio of oral and nasal acoustic impedances. Additional variables that may affect the perception of nasality include articulatory timing, the amount of time the orifice is open, and the speaker's articulatory compensations for the VP opening [10]. Kummer *et al.* [11] conducted a preliminary study to determine whether a relationship exists between the size of the VP gap and perceptual characteristics of speech, which are associated with VP dysfunction, and suggested that the size of the VP opening may be predicted, to some extent, on the basis of perceptual assessment. In one large retrospective cohort, assessment of perceptual speech features such as hypernasality and nasal rustle was useful in predicting relative VP gap size in the absence of instrumental assessment [8].

Although there is some evidence to suggest that an estimate of VP gap size can be made on the basis of some perceptual features of the speech, there is scarcity in the studies investigating this relationship. If a high correlation exists between specific speech characteristics and VP gap size, this information may prove useful to speech-language pathologists and surgeons. Predicting the size of the gap through auditory perceptual analysis (APA) could help the speech-language pathologist anticipate appropriate treatment. If the gap size is thought to be very small, a trial period of speech therapy could be considered. This would be especially appropriate if the nasal emission or rustle is inconsistent, the child is stimulable for correction, and instrumental assessment is not immediately available.

The aim of the present study was to evaluate the role of APA of speech (hypernasality, nasal emission, compensatory articulation, and overall speech intelligibility) in predicting VP gap size in children with VP insufficiency. The present prospective study includes information on overall speech performance and intelligibility and compensatory articulation behaviors that have attracted little attention in previous studies. It included combined perceptual and objective nasometric measures to assess for nasality, which is not widely used in similar studies. Moreover, information from nasopharyngoscopy and multiview fluoroscopy in many cases were used for more accurate estimation of VP gap size.

Materials and methods

This study included 38 participants who suffered from VP insufficiency secondary to repaired overt or submucus cleft palate and attended the Phoniatrics Unit, Dubai Hospitals, as a part of their routine preoperative assessment. There were 16 male and 22 female patients with an age range of 4–16 years (mean age=7 years). Institutional review board at Dubai hospital approved the protocol of this study, and informed consent was obtained.

Auditory perceptual assessment of the patient's speech

A standard speech sample and free conversation were recorded digitally and analyzed. All APA elements were graded along a four-point scale, in which 0 = normal, 1 = mild, 2 = moderate, and 3 = severe affection. The subjective evaluation of patients' speech included degree of hypernasality, audible nasal emission of air, the compensatory articulations (glottal and pharyngeal articulation), and the overall intelligibility of speech.

Nasometer

All participants were assessed using Kay Elemetrics Nasometer (model 6200-2, version 1.5, Kay Elemetric Corp. Lincoln Park. N.J. USA) for measurement of nasalance scores for oral and nasal sentences. Nasalance is measured in percentage on the basis of the following equation: nasalance %=nasal energy/(nasal+oral energy)%.

MVF and NE of VP valve

Palatal, lateral pharyngeal, and posterior pharyngeal wall motion, from both NE and MVF assessments, were rated prospectively using the scale proposed by Golding-Kushner *et al.* [12]. Briefly, the degree of wall motion relative to the resting position was estimated based on the fractional amount of gap closure during phonation. The movement of each lateral wall was assessed on a scale from 0 to 0.5, in which 0 represents no movement and 0.5 represents movement to the midline. Palate movement was similarly rated on a scale from 0 to 1, in which 0 represents no movement and 1 indicates velar contact with the posterior pharyngeal wall. All videofluoroscopic or nasopharyngoscopic examinations were videotaped. Two examiners viewed the tape of the participants together. The overall gap size was classified as large (VP closure less than 50%), moderate (closure between 50 and 80%), or small (closure greater than 80%). In all cases, the rating of overall gap size was reached through the consensus of the two raters, which was easily achieved. Of the 13 participants who underwent both videofluoroscopy and nasopharyngoscopy, there was no discrepancy in the judgment of gap size between the two procedures. We use MVF as the primary measure for VP gap size, as previous studies proved greater accuracy of MVF compared with NE in assessing lateral wall displacement on phonation, and assume that the MVF findings are the standard against which other findings are compared [6].

Statistics

The data were collected and analyzed using SPSS program, version 14 (SPSS Inc., Chicago, Illinois, USA). Analysis of variance and post-hoc tests were used for measuring the sensitivity of the APA and nasalance score to divide VP gap size into three grades corresponding to NE and MVF.

The question addressed was 'Do APA-related variables predict velopharyngeal gap size?'. To investigate it, VP gap size was regressed on the APA variables (degree of hypernasality, nasal emission, glottal articulation, pharyngeal articulation, and overall speech intelligibility, in addition to oral and nasal sentence nasalance score) using a stepwise regression procedure in SPSS 14.0 (SPSS Inc.). In a stepwise regression, variables compete for entry. The variable accounting for the greatest amount of variance enters first, followed by the variable accounting for the next greatest variance, until no additional variables are significant.

Results

The patients were classified into three groups on the basis of the estimated overall VP gap size: the small gap group (closure greater than 80%) comprised 15 patients, the moderate gap group (closure between 50 and 80%) comprised 13 patients, and the large gap group (VP closure less than 50%) comprised 10 patients.

Analysis of variance and post-hoc tests were used for measuring the sensitivity of the APA and nasalance values to divide VP gap size into three grades corresponding to NE and MVF, as shown in Table 1. The APA results showed significant intergroup differences as regards degree of hypernasality, nasal emission, glottal articulation, pharyngeal articulation, and overall speech intelligibility. There was a positive correlation between all studied APA variables and VP gap size.

On individual data analysis, posterior nasal fricatives (nasal rustles) were noted in only four participants, three of them had small gap and only one patient had moderate gap, which indicates negative correlation between nasal rustels and gap size.

Table 2 reveals multiple linear regression for all APA and nasalance values for identifying predicting factors for the VP gap size. The degree of hypernasality and overall speech intelligibility had the strongest predictive values, followed by glottal articulation, nasal emission, pharyngeal articulation, and oral sentence nasalance score. Therefore, participants with severe APA speech impairment were more likely to have a larger gap size compared with those who exhibit milder degree of speech impairment.

Table 1 Results of ANOVA and post-hoc tests measuring the sensitivity of the APA and nasometer to classify VP gap size into three grades corresponding to NE and MVF

Gap size group	Small VP gap size group number (15)		Moderate gap group (13)		Large gap group (10)		*F* ratio
APA	Mean	SD	Mean	SD	Mean	SD	
Degree of hypernasality	1.3	0.6	1.9	0.06	2.4	0.5	49.2*
Nasal emission	1.7	0.4	1.8	0.9	2.3	0.9	44.4*
Glottal atriculation	1.1	0.4	2.1	0.6	2.8	0.4	52.9*
Pharyngeal articulation	1.3	0.7	1.8	0.5	2.5	0.7	63.6*
Speech intelligibility	1.4	0.5	1.9	0.8	2.4	0.3	56.7*
Oral sentence nasalance	35.32	11.6	51.9	15.06	71.4	18.5	121.2*
Nasal sentence	65.7	21.4	59.8	19.9	72.3	27.9	244.4

ANOVA, analysis of variance; APA, auditory perceptual analysis; MVF, multiview videofluoroscopy; NE, nasopharyngoscopy; VP, velopharyngeal; $^*P < 0.01$.

Table 2 Multiple linear regression for all APA and nasalance values to identify predicting factors for the velopharyngeal gap size

Predicting factor	β	*T*	Significance
Degree of hypernasality	0.517	17.69	0.000
Nasal emission	0.145	3.36	0.015
Glottal atriculation	0.538	4.72	0.003
Pharyngeal articulation	0.332	3.25	0.017
Speech intelligibility	0.121	4.36	0.000
Oral sentence nasalance	0.456	3.56	0.046
Nasal sentence	0.623	4.12	0.251

APA, auditory perceptual analysis.

Discussion

Clinicians have long attempted to correlate their auditory perception of VP incompetence with data from instruments designed to evaluate VP closure [13]. This is very important because the perceptual assessment with the trained ear remains the only sure method against which other objective methods are compared [14].

Results of the present study indicate that there is a significant and clinically relevant relationship between VP gap size and the perceived characteristics of speech as regards degree of hypernasality, nasal emission, glottal articulation, pharyngeal articulation, and overall speech intelligibility. Results showed that the size of the gap increases as the severity of speech impairment increases. This finding suggested that the size of the VP opening may be predicted, to some extent, on the basis of perceptual assessment of speech. Abou-Elsaad *et al.* [15] found similar results and explained the correlation by the fact that the VP valve should be closed during the production of oral sounds; the more the degree of VP incompetence the greater the degree of perceived hypernasality, glottal articulation, pharyngeal articulation, nasal emission, and intelligibility of speech.

Perceptual ratings of hypernasality and nasal emission contributed significantly to the prediction of a large gap size, and these findings were in agreement with the findings of many similar studies. Warren *et al.* [16] reported a moderate correlation between hypernasality ratings and VP orifice area as measured through aerodynamic procedures. Other investigations show that a strong correlation between the degree of perceived hypernasality and actual size of the gap does not exist. This is partly due to the fact that the ratio of oral and nasal cavity impedances can affect the perception of hypernasality, and this impedance relationship changes with effort, articulatory configuration, and the size of the vocal tract, relative to the degree of oral–nasal coupling [8]. Timing of VP closure is also a variable that can affect the perception of hypernasality, especially because the timing of VP opening/closure can be complex in running speech [11].

The perception of nasal emission is also affected by a variety of factors, including the total volume of air that passes through the VP opening and the degree of nasal airway resistance. The size of the VP gap also affects the perception of nasal emission, although the relationship between gap size and perception may be nonlinear. Nasal rustle contributed significantly to the prediction of a small gap size. Nasal rustle has been considered to be the most distracting form of nasal emission. Although it is perceived as a more severe speech deviation, it appears that, its presence reflects a less severe anatomical or physiological variation. In this case, the type of distortion can predict the size of the gap, but the severity of the distortion does not correlate with the severity of VP dysfunction and gap size. Kummer *et al.* [8] makes the excellent point that clinicians need to be aware that perceptual severity does not necessarily translate into physiologic severity when audible nasal escape is described. The overall speech intelligibility correlated to the gap size. Many factors contribute in reduced speech intelligibility in cleft palate children, including degree of hypernasality and nasal emission, articulatory proficiency, and compensatory articulation; all these factors are correlated to VP gap size. Raymond [17] found a tendency for articulation and intelligibility scores to be correlated, and a tendency for intelligibility and VP function to be correlated.

Children with cleft palate and VP dysfunction have been described to exhibit a variety of compensatory misarticulations, and they occur in response to VP inadequacy. Large VP gap size leads to oral–nasal coupling and reduced oral pressure with associated compensatory behavior by shift in articulatory constriction to a location inferior to the VP sphincter, to prevent nasal escape to reduce airflow and keep sufficient air pressure so as to preserve the manner of production [17]. The present study found compensatory articulations, which were also correlated with gap size. Antonio *et al.* [18]. found that compensatory articulations are associated with poor VP function and that they cause further restriction of VP closure, as patient directs his/her effort to establish compensatory behaviors rather than to attempt actual VP closure. Antonio found that the ratios of movement of VP structures were significantly increased and that the size of the gap was significantly reduced after compensatory articulation had been corrected. They support the statement that articulation disorders in association with hypernasality in cleft palate patients should be corrected before surgery for VP insufficiency after palate closure [18].

Objective measures of hypernasality using nasometer proved predictive value for oral sentence nasalance score in detecting gap size, but the power is less compared with APA variables [19]. Alexus and Semmon [20] found significant association between VP closure rating and nasalance score in his studied patient. In contrast, James *et al.* [21] found that nasometry does not allow the localization or quantification of VP gap size.

Perceptual assessment is a necessary first step in the evaluation of abnormal speech because treatment is indicated only when a problem is perceived. In fact, perceptual assessment is believed to be an important source of information on how well the VP structures function during speech. The combination of nasopharyngoscopy and multiview videofluoroscopy was used to measure VP gap size, and it is widely accepted as the best approach for the clinical analysis of the VP sphincter [6]. The subjective nature of APA was partially overcome by using the nasometer, which has previously been proved to be satisfactory in this respect.

The purpose of the present work was to study the role of APA in predicting the VP gap size. The results of this study suggested that the size of the VP opening may be predicted on the basis of perceptual assessment. However, all VP perceptual and instrumental informations are important in deciding the line of therapy, whether behavior modification of speech or surgical repair of VP gap.

APA can give us clue to the need for surgery, but the type of surgery can be more readily chosen when enough information about the functions of each component of the VP port is available. The gap size indicates surgical intervention, but the type of surgical technique depends on many other variables such as palatal and lateral pharyngeal wall movements, closure pattern, and vertical level of closure, which can be monitored ideally by visual assessment of VP valve using NE and MVF.

Conclusion

The role of APA of speech in predicting gap size is still not clear. The aim of the study was to evaluate the role of APA of speech in predicting VP gap size. The study finding suggests that the size of the VP opening may be predicted on the basis of perceptual assessment of speech. Perceptually predicting the gap size could help the speech-language pathologist to anticipate the appropriate line of intervention without the need for invasive procedures.

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Conflicts of interest

There are no conflicts of interest.

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