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Validation of the Mirror-Fogging Test as a Screening Tool for Velopharyngeal Insufficiency§

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Abstract: *Purpose*: Comprehensive evaluation of velopharyngeal insufficiency (VPI) typically includes auditory-perceptual assessment, nasometry, and anatomical evaluations. At times, these examinations are limited by the resources, invasiveness, time and expertise required to perform them. In such instances, the mirror-fogging test would be an ideal screening tool for VPI as it can be performed simply and quickly with minimal resources. However, the sensitivity and specificity of this screening tool have yet to be documented. This study sought to validate the mirror-fogging test as a screening tool for VPI when compared to auditory-perceptual assessments and nasometry.

Methods: The charts of 60 participants from our VPI clinic at a tertiary care hospital were retrospectively reviewed: 40 exhibited VPI and 20 were negative for VPI according to auditory-perceptual testing and nasometry. Nasometry scores identified a priori as two standard deviations above normal were judged to be diagnostic for VPI. Auditory-perceptual testing was deemed diagnostic for VPI with hypernasality and audible emission scores above 1 using the American Cleft Palate Association (ACPA) clinical scale for VPI. The sensitivity and specificity for the mirror-fogging test was determined using auditory-perceptual testing and nasometry as diagnostic standards.

Results: The mirror-fogging test had a sensitivity of 0.95, a specificity of 0.95 and a positive predictive value of 0.97. Significantly higher auditory-perceptual scores were demonstrated for the features of hypernasality ($p < 0.008$), audible nasal emission ($p < 0.001$), and velopharyngeal function ($p < 0.001$) in the mirror-fogging test positive group.

Conclusion: The mirror-fogging test is highly correlated with both auditory-perceptual speech assessment and nasometry, thus, validating its utility as a screening tool for VPI.

Keywords: Mirr, screening tool, velopharyngeal insufficiency.

INTRODUCTION

Velopharyngeal insufficiency (VPI) is defined as an inadequate or incomplete physiologic closure between the nasopharynx and oropharynx by the soft palate. Individuals with this deficit may experience varying severities of hypernasal speech, excessive nasal emission, dysfunctional phonation, and/or nasal regurgitation of liquids [1]. Numerous etiologies are known to cause VPI including genetic syndromes such as velo-cardio-facial syndrome to those related to iatrogenic complications [2-4]. Most commonly, VPI is seen in those who have undergone surgical repair of a cleft palate, where the incidence can range from 30-50% [5-7]. VPI can also arise as a complication of adenoidectomy surgery, occurring in approximately 1 in 1500 to 1 in 10,000 cases [4]. This risk is higher for those with any pre-existing deficit in the velopharyngeal closure mechanism, including submucosal cleft palate where nasopharyngeal closure may depend on a dysfunctional palate closing against adenoid tissue [4,6]. Irrespective of the etiology, speech deficiencies that result from VPI can lead to social isolation, poor academic performance, decreased employment opportunities, a reduced self-concept, presumed unattractiveness and an overall decrease in perceived quality of life [8]. Thus, early and accurate detection of VPI would help facilitate early intervention and potentially minimize the negative impacts

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of speech dysfunction related to this structural and physiologic abnormality.

Evaluation of VPI ideally requires a multidisciplinary approach involving qualified Speech-Language Pathologists and Otolaryngologists. Auditory-perceptual evaluation of speech is the gold standard for diagnosing VPI as it assesses multiple aspects of speech production including oral and nasal resonance, nasal air emission, consonant strength/oral air pressure and phonation/voice in specific contexts [9]. Auditory-perceptual evaluation is often complemented by nasometry, which provides an objective instrumental measure of the ratio of nasal-to-oral acoustic energy. Finally, both nasopharyngoscopy and multiview videofluroscopy (MVF) provide anatomical information on the nasopharynx during speech production.

Although a variety of assessment methods exist, not all are accessible in some centers. This is especially true for auditory-perceptual methods where the ability to successfully detect changes in velopharyngeal function does require considerable experience. Additionally, the caseloads seeking the diagnosis of velopharyngeal insufficiency are ever expanding in most centers and thus, the provision of service to children with VPI can be substantial. Under such circumstances, the ability to quickly and accurately screen for VPI may be of considerable value in order to appropriately triage children who may need additional consultations with Speech Language Pathology or Otolaryngology.

The commonly utilized mirror-fogging test may be an ideal screening tool for VPI [10]. In this test, a small mirror is held under the nose of the patient while they are asked to repeat high-pressure oral consonant sounds within syllables, words, and short phrases. The stop-plosive sounds (/p, b, t, d, k, g/) are those that require a build up of considerable high pressure within the oral cavity prior to their rapid release. With the exception of the nasal sounds, /m/, /n/, and /ng/, all other English consonants require a complete barrier (velopharyngeal closure) between the nasopharynx and oropharynx. Thus, during production of stop-plosive sounds, the mirror-fogging test is considered positive when condensation forms on the mirror, which is indicative of some degree of nasal air leakage, suggesting the possibility of VPI.

Given the simplicity, noninvasiveness and non-tech nature of the mirror-fogging test, it would be an ideal screening tool from a resource perspective. However, there have been no formal studies documenting the sensitivity and specificity of the mirror-fogging test and hence, the validity of the mirror-fogging test is limited. Thus, the purpose of the present study sought to validate the mirror-fogging test as a screening tool for VPI when compared to nasometry and auditory-perceptual evaluation of speech. We anticipated that the mirror-fogging test would be a simple and cost-effective screening tool for VPI that can be utilized by both Otolaryngologists, primary care physicians, and Speech-Language Pathologists.

METHODS

Participants

Sixty pediatric participants who had been referred to the London Health Science Center VPI Clinic between 2005 and 2010 provided data for this study. In doing so, charts of all participants were reviewed retrospectively. All of these participants underwent nasometry, auditory-perceptual assessment of speech and a mirror-fogging test as part of their VPI assessment; all evaluations were conducted by one registered Speech-Language Pathologist with expertise in VPI. In addition to VPI assessment data, information regarding each patient's age, history of developmental delay, genetic syndrome, and/or cleft palate and previous surgeries were collected.

In our study population, 40 participants were determined to have VPI while 20 participants were identified as being negative for VPI as determined through either nasometry or auditory-perceptual assessment. The median age of participants with VPI was 10 while the median age for the VPI negative group was 7 (Table **1**). The gender ratio was approximately equal in the VPI positive group (19 males; 21 females) but was skewed with a predominance of males (80%) in the VPI negative group (16 males; 4 females). To our knowledge, gender should have had no impact on our ability to assess for VPI [11]. Within the VPI positive group, 18 participants (45%) had previously undergone a cleft palate repair and two (5%) had undergone an adenoidectomy. In contrast, in the VPI negative group two participants (10%) had a previous cleft palate repair and four (20%) had undergone an adenoidectomy. Fifteen (38%) of participants from the VPI positive group had a genetic syndrome, with Pierre Robin Syndrome being predominant, while two (10%) of VPI negative participants presented with a genetic syndrome.

Table 1. Patient demographics of study population (n=60).

Population Demographic		VPI Positive	VPI Negative
Age (years)	Range	4 - 51	4 - 16
	Mean	11.2	8.4
	Median	10	7
Gender	Female	21 (53%)	4 (20%)
	Male	19 (47%)	16 (80%)
Past Surgeries	Cleft palate/lip repair	18 (45%)	2 (10%)
	VPI surgery	5	0
	Adenoidectomy or tonsillectomy	2 (5%)	4 (20%)
Genetic Syndrome	Pierre Robin	5	
	22q11 deletion spectrum	3	
	Kleinfelters	1	
	Van Der Woude Syndrome	2	
	TAR syndrome	1	
	Goldenhar syndrome	1	
	Fetal alcohol	1	
	Neurofibromatosis 1	1	
	Apert's syndrome		1
	Waardenburg syndrome		1

Mirror-Fogging Test

A small circular mirror (~4cm in diameter) without any markings was used for the mirror-fogging test. Words with expected nasal emissions such as “mommy” were used as a positive control. Plosive test words requiring proper velopharyngeal function such as “puppy” was used to assess for VPI. The patient would be asked to say the test word repeatedly while the mirror was placed and held underneath the nostrils after the initiation of speech. Any presence of fogging on the mirror would be indicative of VPI while the absence of fogging on the mirror would be a negative or normal test.

Auditory-Perceptual Testing

The American Cleft Palate Association (ACPA) Clinical Database Committee Perceptual Speech Assessment tool was used to assess for VPI. Six speech variables from the ACPA clinical database were assessed by one Speech Language Pathologist experienced with cleft palate and VPI. Five of these were measured on a 6-point ordinal scale: hypernasality, hyponasality, audible nasal emission, articulation proficiency and overall intelligibility. A score of 1 indicated a normal perceptual speech assessment and a score of 6 indicated a severe assessment. The speech sample for the perceptual and articulation assessment included: single words and syllables, sentences, automatic speech and conversational speech. Auditory-perceptual testing was considered positive for VPI with the identification of hypernasality and audible emission scores above 1.

Nasometry

Nasal resonance was measured using the Nasometer II (Kay-PENTAX, Model 6400, Montvale, NJ). A headset, comprised of a sound separator with microphones positioned at the level of the mouth and at the nose, detected the oral and nasal acoustic components of the participant's speech. The Nasometer mask was placed on the participant’s head in the appropriate position in accordance with instrumentation guidelines provided by the manufacturer. Each participant was asked to repeat the 15 test sentences using the Simplified Nasometric Assessment Procedures-Revised (SNAP-R) test - 2005. The sentences were recorded using the Nasometer with subsequent analysis of nasalance. The Nasometer was calibrated at the beginning of each day in accordance with the recommendations of the manufacturers (Kay-PENTAX). A nasometry score that was determined to be two standard deviations above normal was considered a positive result indicative of VPI.

Statistical Analysis

The sensitivity, specificity, and positive predictive value (PPV) of the mirror-fogging test were calculated with use of the auditory-perceptual assessment as the gold standard. This was also repeated with the nasometry test results. The sensitivity was calculated as the number of true positives (correct detection of VPI *via* the mirror-fogging test) divided by the total number of true positives and false negatives (the inability to detect VPI when it does exist). Specificity was determined as the number of true negatives (correct identification of no VPI *via* the mirror-fogging test) divided by the total number of true negatives and false positives (the incorrect identification of VPI *via* mirror-fogging when it does not exist). The PPV was calculated as the number of true positives divided by the total sum of true positives and false positives.

In addition, the average ACPA perceptual clinical scores were determined for participants in both the mirror-test positive and negative populations. Comparison between the mirror-fogging test positive and negative participant groups was performed for each of the six auditory-perceptual categories (hypernasality, hyponasality, audible nasal emission, velopharyngeal function, articulatory proficiency, and intelligibility). Statistical significance was determined using an unpaired *t*-test with Bonferroni correction and a pre-established probability level of $p < 0.05$ for significance. Statistical analyses were performed using PASW Statistics 18 (Chicago, IL).

RESULTS

Auditory-perceptual assessment of speech is deemed the gold standard in VPI assessment. As such, this was used to determine the sensitivity and specificity of the nasometry test. The sensitivity and specificity of the nasometry test was 0.95 and 0.90, respectively (Fig. **1**).

		Auditory Perceptual Assessment	
	VPI	Positive	Negative
Nasometry	Positive	38	1
	Negative	2	18
		40	20

Sensitivity 0.95
Specificity 0.90
Positive predictive value 0.95
Negative predictive value 0.90

Fig. (1). Sensitivity and specificity of nasometry compared to auditory perceptual speech assessment.

The sensitivity and specificity of the mirror-fogging test was determined to be 0.95 and 0.95, respectively, as compared to auditory-perceptual assessment of speech and nasometry (Fig. **2**). The positive predictive value of the mirror-fogging test was determined to be 0.97.

To better understand what a positive mirror-fogging test may represent in terms of the auditory-perceptual assessment scores, the average score in each category of the ACPA clinical scale was determined in the mirror-fogging test positive and negative study groups (Fig. **3**). No significant differences were identified between groups for the auditory-

Auditory Perceptual Assessment

	VPI	Positive	Negative
Mirror	Positive	38	1
	Negative	2	19
		40	20

Sensitivity 0.95
Specificity 0.95
Positive predictive value 0.97
Negative predictive value 0.90

Nasometry

	VPI	Positive	Negative
Mirror	Positive	38	1
	Negative	2	19
		40	20

Sensitivity 0.95
Specificity 0.95
Positive predictive value 0.97
Negative predictive value 0.90

Fig. (2). Sensitivity and specificity of mirror-fogging test as compared to: (top) auditory perceptual assessment and (bottom) nasometry.

perceptual categories of hyponasality, articulatory proficiency, or intelligibility. However, significantly higher auditory-perceptual scores were demonstrated for the features of hypernasality (t =10.532; df, 58, p <0.008), audible nasal emission (t =9.237, df, 58, p <0.001), and velopharyngeal function (t = 15.268, df, 57; p <0.001) (Table **2**).

DISCUSSION

This study assessed the clinical validity of the mirror-fogging test as a screening tool for VPI in comparison to nasometry and auditory-perceptual assessment of speech. In seeking to validate the mirror fogging test, we determine the sensitivity, specificity, and positive predictive value of this screening measure. This is the first study to formally evaluate and validate the potential accuracy of the mirror-fogging test as a clinical screening tool for VPI. Our findings reveal that the mirror-fogging test exhibited high sensitivity and specificity, both at 0.95, supporting its value as a clinical screening tool for VPI. One caveat to the results would be that our study population is from a tertiary care center and a Speech-Language Pathologist experienced with VPI performed all the evaluations. Together, this might have had a positive influence on the sensitivity and specificity of the test. That is, because of internal consistency of the rater, it is assumed that variability in assessments would be reduced. Consequently, correct identification of whether VPI was present or absent would be enhanced.

Variations of the mirror-fogging test have also been described to help grade the severity of nasal emission. In the Glatzel mirror-fogging test, the mirror is imprinted with four concentric circles, each representing the degree of condensation and severity of nasal emission. Using logistic regression analysis, Van Leirde *et al.* identified the Glatzel mirror-fogging grade as one of the variables in their nasality severity index (NSI) [12]. The NSI, a linear equation consisting of four variables with each variable carrying a different weight, which provides an objective measurement

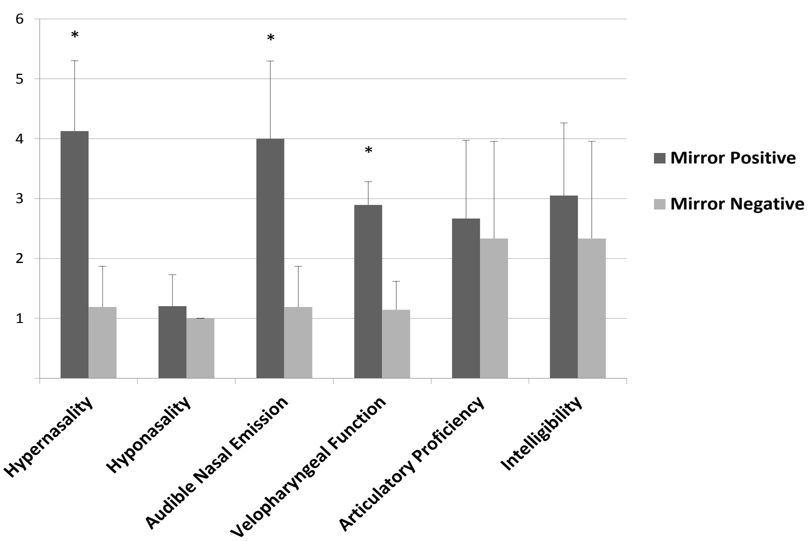

Fig. (3). Mean auditory perceptual speech assessment scores in mirror-fogging test positive and negative participants. The six auditory perceptual assessment features include hypernasality, hyponasality, audible nasal emission, velopharyngeal function, articulatory proficiency and intelligibility. * Denotes significant difference between mirror-fogging test positive and negative patient auditory perceptual speech assessment scores; p<0.03.

Table 2. Group summary of means and standard deviations for auditory-perceptual features for each assessment group.

Auditory-Perceptual Feature	Mirror Positive Test (n=39)	Mirror Negative Test (n=21)
	Mean Score ± Standard Deviation	
Hypernasality	4.128 ± 1.174*	1.190 ± 0.680
Hyponasality	1.205 ± 0.522	1.000 ± 0000
Audible nasal emission	4.000 ± 1.298*	1.190 ± 0.680
Velopharyngeal function	2.895 ± 0.388*	1.143 ± 0.478
Articulatory proficiency	2.667 ± 1.305	2.333 ± 1.623
Intelligibility	3.051 ± 1.213	2.333 ± 1.623

*Denotes significant difference between mirror-fogging test positive and negative patient auditory perceptual speech assessment scores. $p<0.03$.

tool for determining the severity of nasalance. Based on the findings of Van Leirde *et al.*, the NSI sensitivity was found to be 88% and its specificity 95%. This previous finding further supports the present data on the value of the mirror-fogging test in assessing VPI.

The mirror-fogging test is a complimentary addition to a variety of clinical examinations that can be classified as functional and anatomical assessments. The auditory-perceptual evaluation of speech takes into account all aspects of speech production including voice, articulation, oral motor sequencing, nasal air emission and compensatory speech behaviors [9]. However, the subjective nature of such measures in the context of other factors such as the developmental maturity of the patient in relation to following instructions, and most of all, the time required and availability of a qualified Speech-Language Pathologist to perform such evaluation limits this form of assessment in many instances.

Auditory-perceptual assessment of speech in those with VPI is often associated with hypernasality and audible nasal air emission. This perceptual phenomenon also can be objectively assessed *via* an instrumental measure of the ratio of the acoustic energy between nasal to oral airflow (i.e., *via* nasometry). In the present study, nasometry had a sensitivity and specificity of 0.95 and 0.90, respectively, when compared to auditory-perceptual assessments. Our current values are comparable to the findings of Watterson *et al.* who reported a sensitivity of 0.84 and specificity of 0.88 for nasometry when compared to perceptual speech assessment of nasality [13]. In their study, a non-validated seven-point interval scale was used to rate nasality and seven individuals provided the ratings. Because Watterson *et al*. employed categorical type of measures provided through interval scaling, their sensitivity and specificity values may have been reduced from those generated in the present study. That is, the correct identifications of VPI, are not adequately represented through interval scaling. As a result, the utility of sensitivity-specificity holds the potential for greater levels of accuracy in the detection of VPI. In addition, when interpreting nasometry scores, it is important to keep in mind that the threshold value is an approximation of the borderline of abnormal resonance and that a small number of normal speakers will exhibit scores in the abnormal range. As such, nasometry scores should not be used in isolation for diagnostic and treatment planning for VPI. Rather, nasometry measures should serve to augment the data from auditory-perceptual speech assessments, especially in cases of hypernasal resonance.

Our data from statistical evaluation of the auditory-perceptual features assessed for both groups provides additional support for the use of the mirror-fogging test as a viable and valid means of assessing velopharyngeal function. In our evaluations between the mirror-fogging test groups, highly significant differences were identified for hypernasality, audible nasal emission, and velopharyngeal function. From a physiologic standpoint, these findings are not surprising in that both auditory-perceptual speech assessments and the ability to detect mirror-fogging during speech reflect changes in the dynamic integrity of the velopharyngeal valve. These findings clearly serve as further confirmation of the sensitivity/specificity data that we have reported herein. However, in lieu of the significant differences noted across groups for three of the auditory-perceptual features, one might question why differences between groups were not observed for the others? First, we would not have anticipated differences between groups for hyponasality as no airflow should emerge from the nasal valve; hence, in some respects, this feature serves as a control for the others that were assessed. In contrast, the two remaining features of articulatory proficiency and intelligibility were not found to differ significantly between those with a positive mirror-fogging test *versus* those who had a negative test.

Because articulation of speech is strongly influenced by variations in vocal intensity and speech timing and other aspects of speech production, as well as a given participant's developmental stage, more variability is to be expected from child-to-child. Thus, judgments made on more specific auditory-perceptual features such as hypernasality, nasal emission, and velopharyngeal function are more likely to represent and detect changes in the overall integrity of the velopharyngeal system. As such, deficits in the features of articulatory proficiency and intelligibility are more likely to emerge with increasing levels of severity specific to overall velopharyngeal function. In this circumstance velopharyngeal dysfunction is almost certainly going to be detected by both family members and professionals in the form of a substantial reduction in the child's speech intelligibility. This explanation suggests that the mirror-test may offer an even greater clinical advantage in those cases where speech is perceptually judged to not be dramatically abnormal, but where a change in velopharyngeal integrity that potentially impacts speech does in fact exist. For this reason, the value and utility of the mirror-fogging test would be enhanced further within the clinical environment.

In terms of anatomical assessments, multiview videofluoroscopy (MVF) and flexible nasopharyngoscopy are the main modalities utilized during the formal diagnostic process. Nasopharyngoscopy provides information on the mobility of the soft palate and lateral pharyngeal walls, assesses the orientation of the levator veli palatini musculature, and helps to estimate the size of the velar orifice to plan for surgery [1]. This method also has a good level of intra- and inter-rater reliability, especially for qualitative assessment of velopharyngeal gap size [14,15]. This method is, however, limited by lens distortion, underestimation of lateral wall movement, cooperation in young patients and has demonstrated an inconsistent correlation with speech performance [16]. MVF provides complimentary radiographic documentation of velopharyngeal closure in the anterior-posterior and lateral views. Compared to MVF, nasopharyngoscopy has been demonstrated to better correlate with VPI severity [17]. Recent studies have also implicated the potential value of magnetic resonance imaging (MRI) studies for VPI assessments [1,18,19]. Proponents of MRI studies suggest that such approaches provide the ability to analyze velopharyngeal mechanisms during both rest and sustained phonations, as well as provide quality images of soft tissues for surgical planning without radiation exposure. On the other hand, criticisms of MRI based VPI assessments question whether the images obtained truly represent the pharyngeal anatomy at the precise time of sound production during speech and also the inability to perform the images during normal speech production. From a practical standpoint, limited resources and the associated expense prevent the widespread usage of MRI for VPI assessment. Lastly, MRI in young children often requires sedation, which negatively affects their speech production in addition to its own associated risks. Because clinical efforts often seek to maximize early identification of VPI in an effort to similarly provide essential services at a critical point in time, the risks associated with the use of MRI cannot be discounted. Thus, simple, easy, and time-efficient screening tools that provide valid information on the presence or absence of VPI become even more valuable within a variety of settings.

Although a range of VPI assessment modalities exist, they are all limited to some extent by the availability of resources, clinical expertise, and time. This is particularly apparent in the school setting where a variety of speech, language, voice, and resonance assessments are requested from school-based Speech-Language Pathologists. Couple this consideration with the increased demands associated with the requisite initial screenings at the start of the school year, the resultant potential need for more detailed assessments, program planning, teacher consultations, and similar other duties, the need for a validated screening tool is clear. Thus, efforts to optimize the screening process would seem to offer substantial advantages. Based on the present data, the mirror-fogging test would appear to offer a user-friendly, non-invasive, cost-effective, and very time efficient VPI screening tool. It must be noted, however, that the true value of the mirror-fogging test is not to replace comprehensive evaluations by the Speech Language Pathologist and the Otolaryngologist. Instead, the mirror-fogging test can provide highly sensitive and specific information regarding VPI in busy and resource limited settings like schools or during post-adenoidectomy clinical visits, so that children can be triaged for further evaluation of VPI appropriately.

The present study provide empirical data that support the use of the mirror-fogging test as an important and valuable screening tool in the context of VPI and its associated deficits. Thus, application of the mirror-fogging test would appear to be a valuable metric to consider for use in the clinical setting for VPI screening.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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