Photodetector Assessment of Velopharyngeal Activity

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Five normal speakers were used to test a novel photodetector apparatus for obtaining continuous and instantaneous recordings of velopharyngeal area during speech. The results indicate that this inexpensive instrument is able to "track" changes in velopharyngeal port size. A high correlation was found between photodetector output and velopharyngeal port size, as determined using pressure-flow measurements. Its potential use in conjunction with nasopharyngoscopic assessment and in biofeedback training is discussed.

KEY WORDS: Photodetector, velopharyngeal area, nasopharyngoscope, biofeedback

Considerable research has been conducted in recent years in an attempt to develop valid and reliable instrumental measures of velopharyngeal inadequacy. Implicit in this research is the assumption that the trained diagnostician is not sufficient to assess velopharyngeal dysfunction adequately. To be sure, "the human ear is the final detector and arbiter" of the communicative significance of a disturbance to velopharyngeal activity (Kantner, 1948). However, information obtained from listener judgments of speech in a clinical setting tend to be somewhat unreliable (Bradford, et al., 1964; Counihan and Cullinan, 1970). Aside from problems of reliability, information obtained from a subjective assessment does not enable one to specify the degree of velopharyngeal impairment. That is, the relationship between perceived degree of hypernasal resonance and area of velopharyngeal port deficit is non-linear (Isshiki, et al., 1968; Carney and Morris, 1971; Andrews and Rutherford, 1972).

Information concerning the nature and extent of velopharyngeal inadequacy is of considerable value in the management of patients. Therefore, a good deal of attention has been given to the development of instrumental measures of velopharyngeal inadequacy. Information obtained from these measures presumably is intended to supplement, rather than supplant, impressions obtained by trained speech and language pathologists during the diagnostic process.

Among the various instrumental methods of velopharyngeal assessment that do not involve radiation, the pressure-flow technique originally described by Warren and Dubois (1964) is the only one reported that yields quantifiable information concerning total velopharyngeal area. This technique:

is based upon a modification of the Theoretical Hydraulic Principle and assumes that the area of an orifice can be determined if the differential pressure across the orifice is measured simultaneously with rate of airflow through it (1964, p. 62).

Velopharyngeal area may be computed according to the formula proposed by Warren...
and DuBois and modified by Lubker (1969):

\[
VPA = \frac{\dot{V}n}{0.0073 \sqrt{2\left(\frac{\Delta P}{D}\right)}}
\]

where

- \(VPA\) = velopharyngeal area in \(\text{mm}^2\)
- \(\dot{V}n\) = rate of airflow through the velopharyngeal orifice in \(\text{cc/sec}\)
- \(\Delta P\) = differential pressure across the velopharyngeal orifice in \(\text{cm H}_2\), converted to \(\text{dynes/cm}^2\) (1 cm \(H_2\) = 980.6 dynes/cm²)

and

- \(D\) = density of air = 0.001 \(\text{gm/cm}^3\).

Simplification of this formula results in the following:

\[
VPA = \frac{\dot{V}n}{10.22 \sqrt{\Delta P}}
\]

Despite this simplification, the primary disadvantage of this analysis is that calculation of VPA is time-consuming unless one can employ computer analysis to calculate area from the available nasal airflow and differential air pressure data. This, coupled with equipment costs, limits the utility of this technique in most clinical settings.

The purpose of the present study was to test the utility of employing a modified “nasograph” in obtaining continuous and instantaneous recordings of changes in velopharyngeal area during on-going speech. As originally conceived by Ohala (1972), “The nasograph consists of a light and light sensor encased in a flexible transparent plastic tube (4 mm o.d.) which is inserted into the subject’s nose and pharynx such that the light is in the pharynx and the light sensor is in the nasal cavity” (1972, p. 1167). Variations in velopharyngeal aperture dictate variations in voltage present at the photodetector output.

The specific purposes of the present investigation were: 1) to assess the reliability of this instrument in recording changes in velopharyngeal closure during speech, and 2) to determine the relationship between photodetector output and measures of velopharyngeal area utilizing the pressure-flow technique.

**Method**

Figure 1 presents a diagrammatic representation of the equipment utilized in this study. Nasal airflow was recorded utilizing a one-inch² wire mesh pneumotachograph connected to plastic tubing of sufficient size to fit snugly in the subject’s right nostril. The pressure drop across the velopharyngeal orifice was obtained by placing one catheter* within the buccal sulcus, perpendicular to the direction of airflow through the mouth, and the other catheter* in the subject’s left nostril. The nasal catheter was secured by a rubber stopper which occluded the nostril, thereby creating a stagnant air column. The photodetector probe also passed through this stopper and was situated such that the tip of the source fiber extended approximately 5 mm below the resting level of the posterior pillars (Figure 2). The outside diameter of the single, coated source fiber lying in the area of velopharyngeal closure was 0.75 mm, and the weight of the probe resting upon the soft palate was less than 1 gram. Thus, the probe was considered to be a negligible impediment to velopharyngeal function.

**Equipment Calibration.** The differential pressure recording system was calibrated by introducing known amounts of pressure to the Statham Model PM 131 transducer via a water manometer. The nasal airflow recording system was calibrated using a Fisher Porter rotameter.

“Calibration” of the photodetector system involved placing the probe in a closed container and varying the output of the light source to obtain a dynograph stylus deflection of 4 centimeters. To ensure that the photo-

*Polyethylene tubing Intramedic® PE 260.
FIGURE 1. Schematic diagram of apparatus used for simultaneous pressure-flow and photodetector recordings.

detector system was capable of tracking movements occurring in the velopharyngeal area, the pick-up fiber was exposed to a stroboscopic light source whose rise-fall time was 2 msec. The rise-fall time of the photodetector system shown in Figure 1 was found to be 8 msec. Since velar closure movements do not occur in less than 60 msec (Kuehn and Moll, 1976), this system clearly was adequate for tracking velopharyngeal movements during speech.

Procedure. Two male and three female speech pathologists, ranging in age from 22 to 38, served as subjects in this study. Their speech was judged by the author to be free of hypernasality and articulation errors. A topical anesthetic (2% Lidocaine) was sprayed into the left nostril of each subject to eliminate discomfort associated with insertion of the probe. Use of the anesthetic also minimized irritation-induced mucosal discharge which could affect the sensitivity of the pick-up fiber.

Session One. The photodetector probe alone was used during this session. Each subject was instructed to engage in conversational speech while monitoring the output of the system on an oscilloscope. The subjects also were encouraged to simulate varying degrees of hypernasality and nasal emission while observing the scope trace. Session One was terminated when the subjects felt that they understood the relationship between their velopharyngeal movements and the output of the photodetector system.

Session Two. Each subject was instructed to produce a randomized series of speech tasks (Table 1) with only the photodetector probe and nasal air pressure catheter in place. The subjects were instructed to relax completely between each of the utterances. Without removing the stopper used to secure the photodetector probe and nasal air pressure catheter, each subject was then fitted with the nasal airflow tube and oral air pressure catheter and asked to produce a series of /pa/ syllables, attempting to produce them with varying degrees of velopharyngeal opening. The airflow tube and oral...
FIGURE 2. Placement of the Photodetector probe.

TABLE 1. Speech tasks performed by each subject

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<td>9. /u tutu/</td>
<td></td>
</tr>
<tr>
<td>2. /a/</td>
<td>10. /i mimimi/</td>
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<tr>
<td>3. /u/</td>
<td>11. /a mamama/</td>
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<td>4. /i kikiki/</td>
<td>12. /u mumumum/</td>
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<tr>
<td>5. /a kakaka/</td>
<td>13. zimper</td>
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<td>6. /u kukuku/</td>
<td>14. zinter</td>
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<td>7. /i tititi/</td>
<td>15. zinker</td>
<td></td>
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<tr>
<td>8. /a tatata/</td>
<td>16. Come to my house tonight for ice cream cake</td>
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pressure catheter were then removed and the subjects produced a second randomization of the speech tasks. Finally, the tube and catheter were reinserted and the subjects once again produced a series of /pa/ syllables varying in degree of velopharyngeal patency.

Session Three. The tasks for Session Three were identical to those of Session Two except that two different randomizations of the speech tasks were employed for each subject. Approximately one week elapsed between sessions.

Measurement Procedure. Once the photodetector was inserted, and before testing began, the fiberoptic light source was switched off and the resultant stylus trace on the dynograph was noted as the baseline. Measurements of photodetector output (Ph), differential air pressure across the velopharyngeal port (ΔP) and nasal airflow ($V_n$) were made at the time point coincident with peak ΔP during successive productions of /p/ in the test syllable. Ph, ΔP, and $V_n$ values were obtained by measuring the distance in millimeters from the baselines to the appropriate point on each trace. The ΔP and $V_n$ measurements were converted into centimeters of water pressure (cm H2O) and cubic centimeters of airflow per second (cc/sec), respectively. Velopharyngeal area (VPA) calculations were made from these data utilizing the simplified formula mentioned above.

Results

No discernible photodetector output was evident during production of sustained vowels or VCVCVCV syllables employed in the present investigation (Table 1). This finding is in contrast to reports of other investigators that the velopharyngeal port is not always closed during vowel productions and that there is a tendency for the port to be more open during phonation of low vowels (Moll, 1960; Lubker, 1968). The reason for this discrepancy is not readily apparent. It may be that the speakers studied here did effect complete closure, as did the speakers investigated by Bzoch (1968) and Moll and Shriner (1967). On the other hand, it may be that the degree of port opening was so small that only a negligible amount of light was transmitted through it. These two possibilities could not be tested with the current instrumental set-up since pressure-flow analysis, using customary pressure transducers, is insensitive to the pressures and flow rates associated with vowel productions. The physical presence of the probe should have had only a minimal effect upon light transmission through the velopharyngeal port since its total area was 0.44 mm².

Table 2 presents the means and standard deviations of maximum photodetector output during the production of three nonsense words differing in place of articulation of the intervocalic nasal consonant-oral consonant blen ([mp], [nt], and [ŋk]). No significant
differences existed among these three words, suggesting that tongue position did not appreciably affect photo-detector output ($F < 1.00$; df $= 2, 57$). This finding is important since tongue placement during speech could conceivably change the reflectivity characteristics of the oral cavity, thereby spuriously altering the amount of light impinging upon the pick-up probe in the nasal cavity. However, it would appear likely that backing of the tongue during production of pharyngeal stops ($/f, F/$) and pharyngeal fricatives ($/s, Z/$) could have a pronounced effect upon the amount of light available for transmission across an open velopharyngeal port. This potential limitation has not been investigated to date.

Coarticularatory effects upon velopharyngeal activity would be expected to vary in response to alterations in speaking rate, and no attempt was made to control speaking rate in this investigation. Therefore, no quantitative measures were obtained on the photodetector tracings generated during production of the test sentence included among the speech tasks performed by each subject. Nevertheless, superimposition of the four recordings of this sentence produced by each subject revealed obvious similarities and reasonably consistent recordings of repeated productions of connected speech both within and between sessions (Figure 3).

Velopharyngeal area calculations and photodetector output measurements of 25/pa/ utterances were made on two separate occasions during each of the test sessions for a total of 100 analyses per subject (25 utterances $\times$ 2 sequences per session $\times$ 2 sessions). Figure 4 displays the photodetector output of four sentence productions generated during sessions two & three by each subject.

**TABLE 2. Photodetector trace displacements (in mm) during four productions of three nonsense words by five normal speakers**

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<tbody>
<tr>
<td>Subject 1</td>
<td>17.0</td>
<td>2.83</td>
<td>17.8</td>
</tr>
<tr>
<td>Subject 2</td>
<td>15.8</td>
<td>2.99</td>
<td>17.5</td>
</tr>
<tr>
<td>Subject 3</td>
<td>17.3</td>
<td>6.70</td>
<td>17.3</td>
</tr>
<tr>
<td>Subject 4</td>
<td>17.8</td>
<td>0.96</td>
<td>20.5</td>
</tr>
<tr>
<td>Subject 5</td>
<td>16.0</td>
<td>2.52</td>
<td>19.25</td>
</tr>
<tr>
<td>total</td>
<td>17.7</td>
<td>3.67</td>
<td>18.5</td>
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**FIGURE 3. Photodetector system output of four sentence productions generated during sessions two & three by each subject.**
FIGURE 4. Relationship of photodetector output to velopharyngeal area determined by pressure—flow technique.

demonstrates the relationship between photodetector output and velopharyngeal area as measured by pressure-flow analysis. Across all five subjects, the correlation between these two variables was 0.9070. Thus, it would appear that the photodetector system described here yields information about velopharyngeal function that is comparable to that provided by pressure-flow analysis.

Discussion

The demonstrated correlation between photodetector output and velopharyngeal area, measured utilizing pressure-flow instrumentation, introduces the possibility of using photodetection to quantify nasopharyngoscopic images. Nasopharyngoscopy is being employed with increasing frequency in clinical assessments of velopharyngeal function. One inherent drawback of this instrumentation is that no objective measurements of velopharyngeal port area are possible, although some preliminary attempts have been made (Croft et al., 1978). It should be possible to construct a scope, as shown in Figure 5, with a channel for a single illumination fiber which could be extruded a known distance from the end of the scope and into the oropharynx. Connection of the standard eyepiece to a photodetector system could then yield...
data of the sort described here. In this way, a clinician could determine the physical extent of velopharyngeal inadequacy in a patient as well as obtain subjective information concerning the nature of that defect.

An additional use of the photodetector system described here would be to generate an instantaneous form of feedback which would provide a patient with accurate information concerning the extent to which the velopharyngeal port is open. Unlike currently available forms of biofeedback used with velopharyngeal patients (e.g., Fletcher, 1976; Shelton et al., 1975), this device would not alter auditory feedback and would yield readily interpretable information that would be amenable to modification utilizing standard behavior shaping techniques. For example, the trace of one channel of a standard two-channel oscilloscope could be set at a particular level on the scope screen and the patient instructed to prolong a steady-state vowel in such a way as to match his trace to the “model.” Once able to perform this task reliably, the clinician or the patient would adjust the “model” trace upward and repeat the task. In this way, it would be possible to determine the extent to which a given patient was capable of increasing velopharyngeal activity. Since on-going speech is not impeded in any way, treatment could progress from steady-state vowel productions to spontaneous speech. Any improve-

ment in velopharyngeal activity occasioned by this treatment would increase the “margin for error” in a patient destined to undergo pharyngeal flap surgery or, in some cases, might actually preclude the need for surgical intervention.

To date, this photodetector system has been employed for biofeedback purposes in only one patient. He was a 23-year-old, college-educated male with a moderate sensori-neural hearing loss. Although clearly capable of effecting velopharyngeal closure, he did not do so on a consistent basis during conversational speech. After using the probe for a total of five, 30-minute sessions, this patient showed significant improvement in velopharyngeal closure, as evidenced by short-term elimination of hypernasality in his spontaneous speech. Due to personal matters, the patient was unable to continue in therapy and no clear documentation of progress was obtained. Nevertheless, these preliminary, anecdotal findings were very encouraging and suggest the potential utility of this device in a clinical setting.

The photodetector system described here is easily fabricated and relatively inexpensive. Clinicians with access to a standard laboratory oscilloscope can build this device for approximately $350, inclusive of photodiode, power supply, and fiber-optic light source.

References


