

Plosive Phoneme Duration as a Function of Palato-Pharyngeal Adequacy

MICHAEL I. ROLNICK, Ph.D.
H. RAY HOOPS, Ph.D.

Detroit, Michigan 48202

One interesting and seldom mentioned speech phenomenon related to impaired palatopharyngeal function is a breakdown in consonant boundaries with a subsequent increase in plosive phoneme duration. This problem is easily identified through broad band spectrographic analysis (4). If it can be assumed that adequate intra-oral air pressure during speech production is the primary factor responsible for proper articulation of the plosive phoneme and if this buildup of air pressure is the result of adequate palatopharyngeal function, then the prospect of what happens to these plosive phonemes during palatopharyngeal inadequacy can become an important question. It would be of interest to observe the duration characteristics of these sounds in relation to palatopharyngeal adequacy.

A pilot study was carried out (4) which consisted of the measurement of the duration characteristics of the plosive phonemes /p, t, k/ as produced by three subjects wearing palatal lift prosthetic appliances designed to aid in palatopharyngeal function. The sound spectrograph was utilized to make duration measurements of those utterances produced while the subjects wore their appliances and then removed them. In all cases the duration measurements of the plosive phonemes for the appliance-in condition were less than those of the appliance-out condition. This pilot study suggested the need for further analysis of plosive phoneme duration.

Except for this study, the use of the sound spectrograph to measure plosive phoneme duration with respect to palatopharyngeal adequacy has not been proposed in the literature. Although Gibbons and Bloomer (2) noted a number of consonant changes on a spectrogram representing nasal speech, no direct mention of increased phoneme duration was made.

This study, then, has been designed to investigate the phenomenon of plosive phoneme duration in the presence of palatopharyngeal insufficiency, created by removal of oral prosthetic appliances designed to aid in palatal function. As a secondary objective, the study attempted to evaluate the effectiveness of the oral prosthetic appliance in the treatment of palatopharyngeal malfunction.

Procedure

SUBJECTS. Twenty subjects were utilized for this study. They ranged in age from 17 to 72 years with a mean age of 47 years. All wore palatal

prosthetic appliances designed to improve function for speech production. The length of time the appliance had been worn ranged from ten months to twenty years with a mean time of 11 years.

The twenty subjects fell into two categories: eleven wore appliances to correct surgically induced palatal defects resulting from oral carcinoma and nine wore appliances to correct oral defects resulting from congenital cleft palate. All but one of the nine cleft palate subjects had undergone some type of palatoplasty or pharyngoplasty in an attempt to correct their oral defect. The remaining subject exhibited a sizeable cleft of the hard and soft palate that was considered inoperable.

STIMULUS MATERIAL. Samples of speech selected to facilitate investigation of intelligibility and degree of nasality were recorded. The Rhyme Test developed by Fairbanks was used to provide a different randomly generated word list for each speaker. These word lists provided the basis for measurements of intelligibility. The Rainbow Passage was recorded for later nasality judgments. Words from the Rhyme Test were used for spectrographic analysis.

DATA COLLECTION. Each of the twenty subjects was seated in an I.A.C. sound treated room with an ambient noise level of 42 dB on the A scale as measured by a General Radio Co. sound level meter. Each subject was asked to perform two tasks under each of two conditions. Instructions were first given to read the Rainbow Passage and a list of Rhyme Test words (including carrier phrases) with the appliance in place. The subject then removed his appliance and again read the Rainbow Passage and a different list of words from the Rhyme Test. Subjects were encouraged to maintain consistent vocal effort as they read. Recordings were made at 15 ips at a constant mouth-to-microphone distance.

Forty randomized orders of the 50-item word list from the Rhyme Test were utilized for data recording in this study. This was necessary as the speech of each of the twenty subjects was judged twice; once with appliance in and once with appliance removed. Each of the 50 words was preceded by the carrier phrase, "I will say the word . . ." Interspersed among these items were nine additional words and carrier phrases drawn from the 250 item Rhyme Test stimulus list for use in the spectrographic analysis. Each subject, therefore, read two word lists; 59 items in length and no list was read twice.

ASSESSMENT OF INTELLIGIBILITY. Measurements of intelligibility were made by two groups of listeners; three sophisticated and five unsophisticated. The three sophisticated listeners were graduate students in the area of speech pathology and all had had at least one year of professional experience. The five unsophisticated listeners were college graduates with no more than one beginning speech course. All listeners reported normal hearing.

Instructions to the listeners included a very brief discussion of the range of problems they would hear and the necessity to make some decision as

to what word they thought was heard. The listeners were told that each speech sample would be an actual word and not a nonsense syllable. Each stimulus word was presented with a two second interval between items. A short practice session with ten stimulus words and a sample score sheet preceded the formal judgmental procedure. The listeners were given response sheets showing 50 word items in order of stimulus. Each item was preceded by a blank space in which one letter was to be placed thus completing the word the listener thought he had heard. The listening session took place in a locally produced sound treated listening room with an ambient noise level of approximately 55 dB on the B scale.

JUDGMENT PROCEDURE. Judgments of nasality were made by 65 unsophisticated judges from recordings of the Rainbow Passage as read by each subject with both his appliance in place and then removed. The judges were instructed to rate each of the forty readings of the Rainbow Passage presented to them on a seven point equal appearing interval scale of nasality with the number one representing the least amount of nasality and the number seven representing the greatest degree of nasality. The instructions to these listeners included a brief discussion of nasality and three examples of speakers demonstrating varying degrees of this disorder.

DURATIONAL ANALYSIS. Nine words containing the three voiceless plosive phonemes in the initial position were produced by each subject under each of the two aforementioned conditions. Therefore, three words with /p/ (pop, page, pink), three with /t/ (tell, ten, tore), and three with /k/ (coon, kid, cod) were utilized. Because each of the words was included in a carrier phrase, the analysis was made of phonemes contained in connective speech rather than in isolation. The utterances of the twenty subjects were analyzed spectrographically.

For analysis purposes, criteria were developed for designation of phoneme beginning and termination. This was accomplished by considering the first vertical striation occurring after the end of the final word of the carrier phrase as the beginning of that following plosive phoneme. Termination of that phoneme was considered to be the initiation of formant structure for the following vowel sound. In some cases, there occurred heavy vertical striations suggestive of audible tongue movement or shifting of the prosthetic appliance. The identification of these occurrences as such was obvious when again listening to the master recording. These markings were not considered part of the plosive phonemes.

Results

DURATIONAL MEASUREMENTS. The mean durational measurements of each of the three plosive phonemes produced by all subjects indicated increased duration upon appliance removal for 19 of 20 subjects.

As Table 1 indicates, the total mean duration of the /p/ phoneme was 7.80 csec. with appliance in place and 12.57 csec. with appliance removed. The mean duration of the /t/ phoneme was 9.89 csec. with appliance in

TABLE 1. Mean duration measurements of each of the three voiceless plosive phonemes and the grand mean for both appliance in and out conditions.

	<i>appliance In</i>	<i>appliance Out</i>
mean duration /p/	7.80	12.57
mean duration /t/	9.89	13.84
mean duration /k/	10.44	12.73
grand mean	9.35	13.02

place and 13.84 csec. with appliance removed. Mean duration of the /k/ phoneme was 10.44 csec. with appliance in place and 12.73 csec. upon appliance removal. The grand durational mean for all the /p/, /t/, and /k/ phonemes produced by the entire group of subjects with appliance in place was 9.35 csec. and 13.02 csec. with appliance removed. In all instances an increase in mean plosive phoneme duration occurred upon removal of the subjects' appliances.

The results of a single factor analysis of variance procedure for repeated measures to ascertain whether or not the grand mean differences that exist between the durational measurements made from spectrograms representing plosive phonemes produced with appliance in place and then with appliance removed produced a significant F ratio. The grand mean represents the mean of the duration values averaged across all three phonemes for each subject. This analysis produced an F value of 24.63 which, at the .05 level of confidence, is statistically significant. It can be stated, therefore, that a significant difference exists between the durational measurements of the plosive phonemes /p/, /t/, and /k/ when produced with appliance in place and when produced with that appliance removed. Subjects, when wearing their oral prosthetic appliances, exhibited significantly shorter plosive phoneme durational measurements than when they removed those appliances.

INTELLIGIBILITY. The mean Rhyme Test intelligibility scores for the 20 subjects with their appliances in place ranged from 70 to 100 percent with a total mean for the group of 92 percent. When the patients removed their appliances and were again scored the range was from 58 to 98 percent with a mean of 76 percent. Nineteen of the twenty subjects improved in intelligibility upon insertion of their appliances. One individual's intelligibility improved upon removal of his appliance. The range of improved speech intelligibility varied from 35 additional percentage points when the appliance was in place, better than one-third, to a decrease in intelligibility for one subject of five percentage points.

An analysis of variance for repeated measures designed to determine if any significant difference in speech intelligibility exists between the appliance-in and appliance-out conditions resulted in an F ratio of 32.46 which is statistically significant at the .05 level of confidence. These data indicate that a significant difference exists in intelligibility scores achieved

when the appliance is in place and when it is removed. Subjects, when wearing prosthetic appliances, had significantly better intelligibility scores than when the appliances were removed.

DEGREE OF NASALITY. The mean judgments of degree of nasality for each of the 20 subjects in the appliance in condition ranged from 1.15 to 5.32 on the seven point scale with a mean score of 2.98. When the subjects removed their appliances the range was 3.21 to 6.70 with a mean score of 5.67.

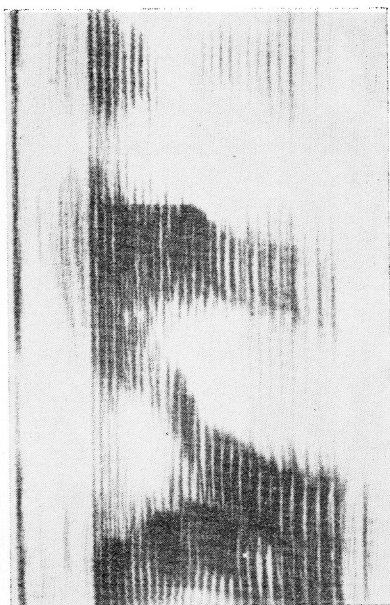
An analysis of variance procedure for repeated measures utilized to determine if any significant differences in degree of judged nasality existed between the appliance-in and appliance-out conditions yielded an F ratio of 77.20 which is significant at the .05 level. A significant difference exists in the degree of judged nasality between the appliance-in and appliance-out conditions. Subjects, when wearing their appliance, exhibited a significant decrease in nasality as compared to when they removed their appliance.

An investigation of the relationship of magnitude of change for the three variables of plosive phoneme duration, speech intelligibility and degree of judged nasality was carried out. A Spearman Rank Order Correlation Coefficient was obtained for the duration and intelligibility measurements resulting in a coefficient of .472, significant at the .05 level of confidence (critical level: .422). Analysis of the duration and nasality measurements yielded a coefficient of .466, also significant at the .05 level. It would seem that not only are the previously reported differences in plosive phoneme duration statistically significant, they tend to change in proportionate magnitude as does speech intelligibility and degree of judged nasality in the presence of reduced palatopharyngeal adequacy.

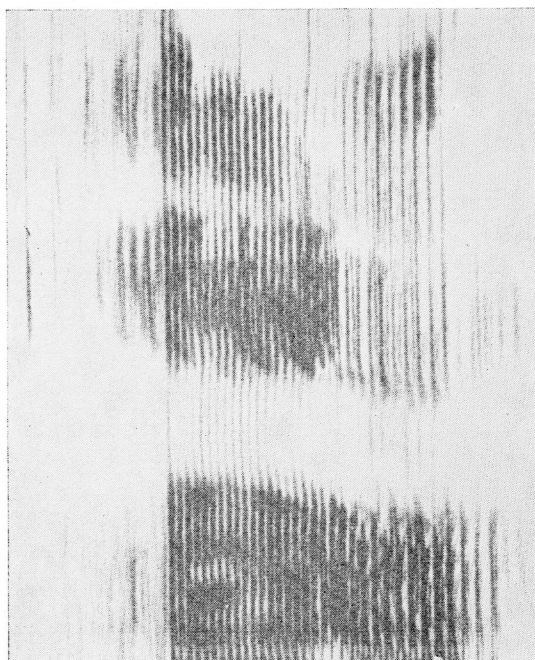
SPECTROGRAPHIC ANALYSIS. Observed increases in phoneme duration can be generally classified in two categories: increased duration due to the portrayal of extra vertical striations preceding the expected spike which normally initiates a plosive phoneme and increased duration due to drawn out aspiration following the initial spike. In most cases the extra vertical striations appeared in the higher frequency regions. There were, however, instances where this additional energy occurred only in the low frequencies, only in the middle frequencies, and occasionally throughout the entire frequency spectrum.

Figure 1 shows two spectrograms representing the word /teɪ/ produced by the same subject, first with appliance in place and then with it removed. The first spectrogram is essentially normal as a sharp, heavy vertical striation (spike) initiates the plosive phoneme /t/. The duration is only slightly greater than normal. When the patient removed his appliance a breakdown in this spike occurred and the aspiration portion of the phoneme increased. This is a relatively typical example of increased phoneme duration resulting from an increased aspiration portion of the phoneme.

Figure 2 is an example of increased phoneme duration due to extra

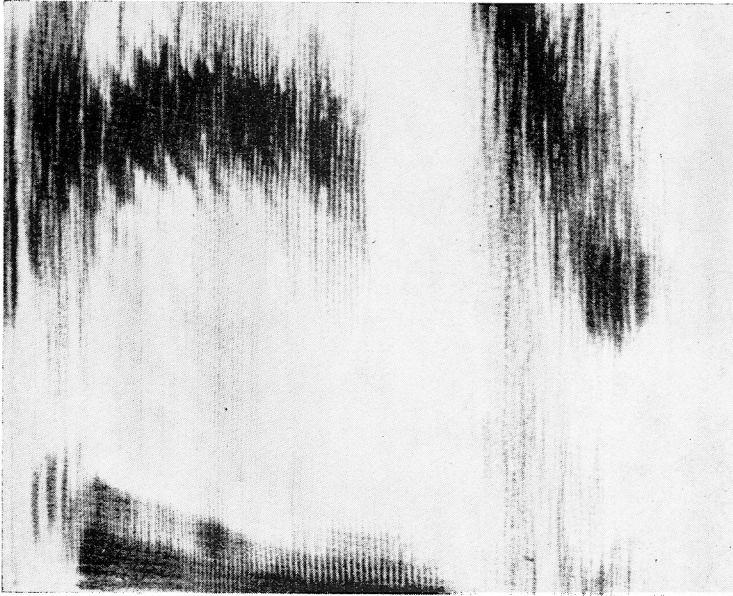


/tɛl/
Appliance-In

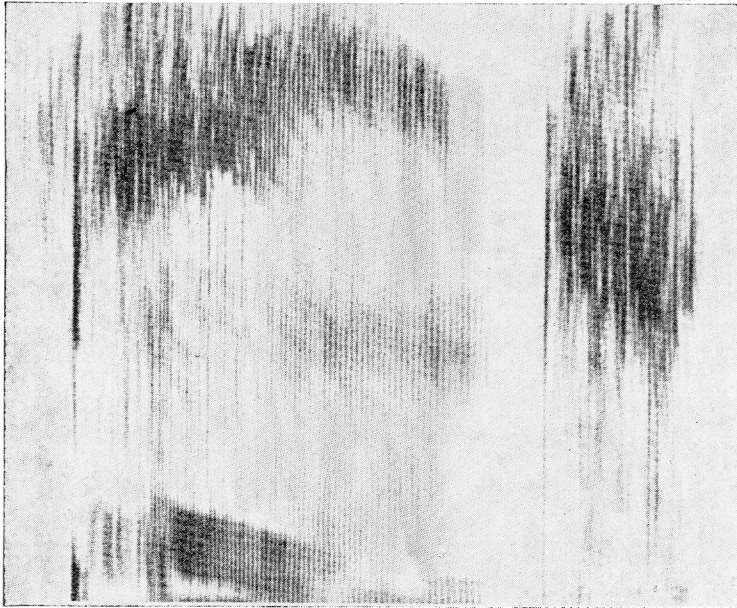


/tɛl/
Appliance-Out

FIGURE 1. Spectrograms representing the word /tɛl/ with appliance both in and out. A typical example of increased plosive phoneme duration with a prominent “spike” preceding both phonemes.

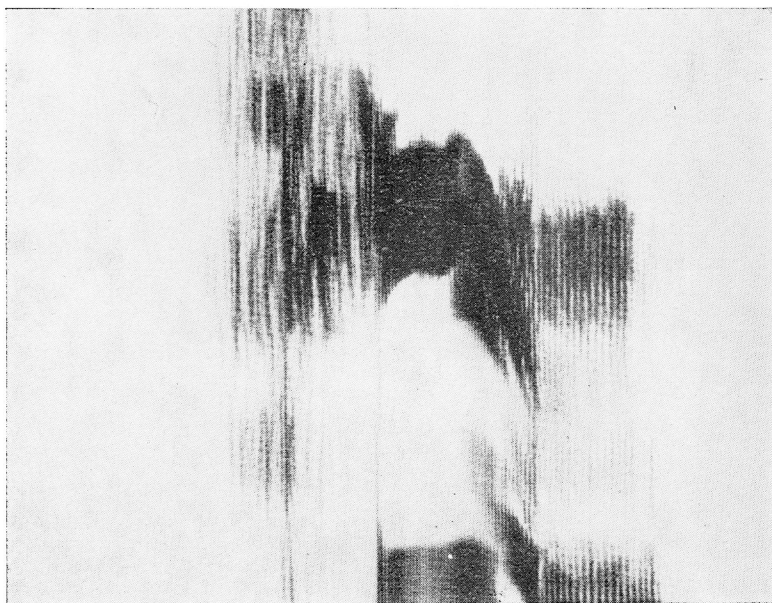


/peɪdʒ/
Appliance-In

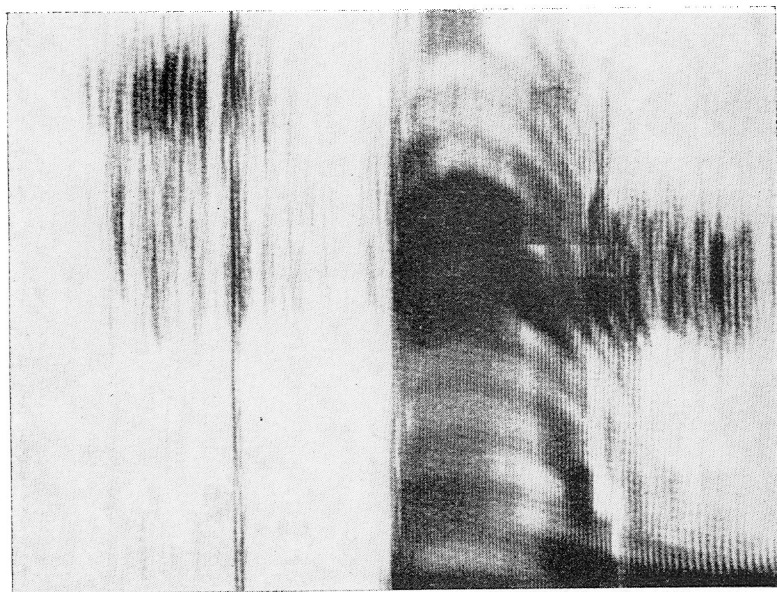


/peɪdʒ/
Appliance-Out

FIGURE 2. Spectrograms representing the word /peɪdʒ/ with appliance both in and out. High frequency energy can be seen to add to the durational measurement of the plosive phoneme.



/ten/
Appliance-In



/ten/
Appliance-Out

FIGURE 3. Spectrograms representing the word /ten/ with both appliance in and out. An extreme example of increased plosive phoneme duration. Note excessive energy in both appliance in and out conditions.

vertical striations in the high frequency region. In both spectrograms a visible spike can be identified. As Potter, Kopp and Kopp (3) point out, this phenomenon is representative of bilabial closure for the /p/ phoneme. When the subject removed his appliance, however, high frequency energy appeared preceding the normal spike. On the basis of the measurement criteria set up for this experiment, the extra energy was included in the duration measurement of the /p/ phoneme.

Figure 3 indicates an extreme example of plosive phoneme duration increase for the word /ten/. Excessive energy for both the appliance-in and appliance-out conditions is evident causing increased duration in both cases. Extra formants, indicative of nasal resonance, are clearly visible in the appliance-out condition.

Discussion

The oral prosthetic appliances worn by all subjects in this study were designed to improve palatopharyngeal adequacy. Nineteen of these twenty subjects produced plosive phonemes of increased duration upon removal of their appliances. Inasmuch as the act of appliance removal reduced the efficiency of the palatopharyngeal mechanism it can be stated that increased plosive phoneme duration is related to palatopharyngeal inadequacy. Although there might conceivably be other factors influencing this significant increase in plosive phoneme duration upon appliance removal, it is only reasonable to assume that degree of palatopharyngeal inadequacy was the major factor in such an increase since this was the function the prosthesis was designed to perform. Furthermore, because the adequate buildup of intraoral air pressure is a prerequisite for the production of plosive phonemes it would seem that the appliances were aiding in developing this necessary air. If it is assumed that adequate palatopharyngeal function results in the proper buildup and maintenance of intraoral air pressure then an abnormal increase in plosive phoneme duration would seem to indicate a malfunctioning palatopharyngeal valve.

There were occasional instances of dramatic reductions in the durational measurements as the result of the use of a subject's appliance. In one instance the /p/ phoneme increased in duration, upon appliance removal, from 12.68 csec. to 33.38 csec., the /t/ from 14.55 csec. to 27.08 csec. and the /k/ from 18.08 csec. to 29.18 csec. It would seem most unusual for an individual to produce such a lengthy plosive phoneme at the normal speaking rate but, apparently, the subject was attempting to compensate for lack of intra-oral air pressure and, in doing so, produced such a sound. This subject presents an extreme example of increased plosive phoneme duration resulting from inadequate palatopharyngeal function.

A physiologic interpretation of the many spectrograms produced for this study provides the basis for discussion of the relationship between plosive phoneme duration and impaired ability to generate intra-oral air

pressure as caused by inadequate palatopharyngeal function. The basis for the following speculative interpretation is outlined by Potter, Kopp and Kopp (3).

One of the sound classifications used by these authors is characterized by their term "spike." This is a description of the explosion of air needed to produce a plosive phoneme. The spike is always preceded by a voiceless gap indicative of a buildup of intra-oral air pressure. Voiced plosive phonemes typically show an area of low frequency energy along the baseline of the spectrogram within this gap and preceding the spike. In the case of the voiceless plosive phonemes analyzed in this study, some alteration and/or addition to the spike occurred, thus increasing the normal time factor. This distortion took the form of either a portrayal of extra vertical striations preceding the spike or drawn-out aspiration following the spike. In both cases voiceless plosive phoneme duration increased significantly.

Since this spike and its preceding voiceless gap represent the buildup and release of intra-oral air pressure it seems reasonable to assume that increased plosive phoneme duration results from an inability to produce and/or maintain this air pressure. The extra energy portrayed on the spectrogram, representing impaired air pressure buildup, is apparently caused by the frictional emission of the airstream through the nasal passages. When palatopharyngeal adequacy was improved by appliance insertion, less air apparently escaped, resulting in fewer vertical striations indicating near normal plosive phoneme duration.

The analysis of variance procedure to test for significant differences between the durational measurements made with the appliance in and out indicates significant differences between these measurements. Because the prosthetic appliances were designed to improve palatopharyngeal adequacy, these significant differences in duration would seem to be the result of differences in the functioning of the palatopharyngeal mechanism under the two conditions. Inasmuch as increased plosive phoneme duration has not been reported in the literature to date as a concomitant of palatopharyngeal inadequacy, this phenomenon is the major finding of this study. These durational increases would seem to be worthy of analysis when considering the function or malfunction of the palatopharyngeal mechanism.

All the data collected and analyzed for this study points to the effectiveness of the oral prosthetic appliance as a speech aid when designed to improve palatopharyngeal adequacy. Plosive phoneme duration approached normal, speech intelligibility was greatly improved and degree of perceived nasality was considerably reduced upon appliance insertion.

Summary and Conclusions

This study undertook to investigate the phenomenon of plosive phoneme duration in relation to inadequate palatopharyngeal function. The

technique of spectrographic analysis was employed to make these measurements which were compared to judgments of nasality and measurements of speech intelligibility.

A subject sample of twenty-individuals, all wearing oral prosthetic appliances designed to improve palatopharyngeal function, was utilized. Each subject, first with his appliance in place and then with it removed, produced utterances containing the initial plosive phonemes /p/, /t/, and /k/ for purposes of spectrographic analysis of duration. The Rainbow Passage was then read for use in judgments of degree of nasality and stimulus items of the Rhyme Test were produced for measurements of speech intelligibility. All speech samples were recorded on magnetic tape.

The productions of the Rainbow Passage were rated on a seven point scale of degree of nasality by 65 judges. The Rhyme Tests were scored by eight listeners to obtain measurements of intelligibility. Mean judgments of nasality and mean intelligibility scores were thus obtained for each subject with both appliance in and out.

The spectrographic analysis of duration was accomplished by identifying the initial vertical striation preceding the plosive phoneme in question as the beginning of that phoneme and the initiation of formant structure for the following vowel as the termination. This measurement was made with a millimeter rule and converted to centiseconds. Mean durational measurements for the /p/, /t/, and /k/ phonemes were obtained representing the conditions of appliance in and out.

Three separate analysis of variance procedures were employed to determine if significant differences existed between the appliance in and appliance out conditions with respect to 1) durational measurements of the plosive phonemes 2) judgments of degree of nasality and 3) measurements of speech intelligibility. An analysis of the relationship of magnitude of change for these three variables was also carried out.

The following conclusions are presented within the limitations of subject sample, experimental design, equipment characteristics and statistical technique:

1. A significant increase in the duration of the plosive phonemes will occur in the speech of an individual upon removal of his oral prosthetic appliance designed to aid in palatopharyngeal function.
2. A significant increase in the judged nasality of an individual wearing an oral prosthetic appliance designed to aid in palatopharyngeal function will occur upon removal of that appliance.
3. The speech intelligibility of an individual wearing an oral appliance designed to aid in palatopharyngeal function will decrease upon removal of that appliance.
4. Plosive phoneme duration varies in proportionate magnitude with both speech intelligibility and judged nasality in the presence of reduced palatopharyngeal adequacy.

References

1. FAIRBANKS, G., Test on phonemic differentiation: the rhyme test. *J. Acoust. Soc. Amer.*, 30, 596-600, 1958.
2. GIBBONS, P., and H. BLOOMER, A supportive-type-prosthetic speech aid. *J. of Prosthetic Dentistry*, 8, 362-369, 1958.
3. POTTER, R. K., G. A. KOPP, and H. C. KOPP, *Visible Speech*. New York: Dover, 1966.
4. ROLNICK, M. I., A suggested method of assessing velopharyngeal function by means of spectrographic analysis. *The J. of Communication Pathology*, 1, 16-18, 1968.