# A Word Intelligibility Approach to the Study of Speech Change in Oral Cleft Patients

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Although the attainment of speech adequacy has been a primary aim in the habilitation of children born with oral clefts and palatopharyngeal insufficiency, clinical observation suggests that the majority of these individuals do not achieve 'normal' speech. The burden of proof to demonstrate the effectiveness of therapy for oral cleft patients is increasing, and a prerequisite for this is the development of meaningful procedures for studying changes in speech behavior.

A number of studies with cleft palate subjects have been reported recently in which listeners made value judgments regarding speech changes which followed therapeutic procedures (*4, 8, 11*). This approach has a certain logical validity since, in the final analysis, the goal for the speaker is to 'sound good to his listeners.' Evaluations which involve listener judgments along selected scales, however, require trained judges in order to establish reliability and validity, and such procedures do not relate specific elements of the speech signal to the changes which are perceived.

Approaches which do not require value judgments by listeners also have begun to be employed in studying speech variations in cleft palate (*3, 7, 14, 16, 17*). Further development of these approaches as indices of speech function in oral cleft patients seems important since they should facilitate: a) the development of measures of speech status which do not require trained judges and b) the identification of specific speech elements by which subjects may be differentiated and the effects of treatment procedures described.

The purpose of the present study was to investigate the use of word intelligibility as a measure of the changes in speech which may accompany therapy programs for oral cleft patients with palatopharyngeal insufficiency and related articulation and resonation disturbances.

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**Procedures**

SUBJECTS. The subjects were 10 males between the ages of 11 and 16. Seven of these subjects had postoperative palatal clefts, two had unoperated submucosal bony clefts of the hard palate, and one had an idiopathic palatopharyngeal incompetency during speech.

SPEECH SAMPLES AND ANALYSES. Recordings were made while each subject read a selected randomized 50-item word list from the Fairbanks Rhyme Test (*6*) at the outset of an eight-week residential therapy program and at two-week intervals thereafter. No two subjects recorded the same word list from the Rhyme Test, and all were given a practice period to become familiar with the words and with the microphone, prior to each recording session. Recordings were made using an Ampex Model 601 tape recorder and an Electro-Voice microphone.

The therapy program provided both individual and group sessions each day. As the need was demonstrated by each patient, emphasis was directed toward improving placement during articulation, strengthening palatopharyngeal function, and improving oral direction of the air stream during speech. Carry-over speaking activities to strengthen gains made in direct therapy sessions were integrated as a major portion of the program.

The Rhyme Test, (*6*) was designed for use in discrimination testing so that the listener's task would bear a valid relation to the discrimination demands of real speech (*6*, p. 596). In each 50-item word list of the Rhyme Test, 18 different initial consonant phonemes were used which account for 90% of all consonant occurrences. Those consonants omitted were: /ɵ/, /ð/, /tʃ/, /ʃ/, /ŋ/, /ʒ/, and /hw/. The Rhyme Test provided a reservoir of monosyllabic words from which a virtually unlimited number of different randomized word lists can be drawn. This made it possible to have each subject read the same list on repeated trials with the assurance that the listener would not be familiar with a given word list nor be able to use a recording by one subject to score correctly the recording of another.

Intelligibility analyses of the Rhyme Test recordings were made as follows. The individual recordings by each subject were dubbed to master tapes in random order. A four-second interval between words was used in order to allow time for the listener to write down each recorded word. Recordings of subjects 1, 2, and 3 were played to a group of 23 listeners during a single session of one-hour's duration. The recordings of subjects 4 through 10 were played to a group of 13 listeners in two sessions, each of one-hour's duration. The listeners in each case were college students untrained in speech pathology or phonetics. The playback equipment consisted of an Ampex Model 601 tape recorder and an Ampex 620 amplifier-speaker system. In all listening sessions, identical instructions were given and each listener was required to write down on a score sheet the entire word which he thought was spoken. For each subject, listener responses were scored in three ways: a) the number of errors in identifying words on

a 50-item list; b) the number and proportion of errors as a function of different initial consonant phoneme classes; and c) the type of consonant confusion error as a function of phoneme class.

In order to look further for evidence of those parameters of the speech signal which might be related to intelligibility change, selected pre- and post-therapy word recordings from the Fairbanks test were analyzed using a Sound Spectrograph, Kay Electronic Corporation, Model 661A. Broad-band displays of words and narrow band amplitude sections of vowels were made. The sound spectrograph has demonstrated its sensitivity in identifying certain parameters related to gross changes in cleft palate speech (*7, 3, 14*), and it has also been used to study the multiplicity of acoustic factors which seem to be related to the perception of nasality (*5, 9, 10, 14*). Other than Nylen's recent study (*14*), spectrographic findings do not appear to have been used in evaluating changes in cleft palate speech resulting from therapy, particularly in relation to listener errors in identifying sounds and words in pre- and post-therapy recordings.

Measures of Palatopharyngeal Efficiency. Palatopharyngeal valve efficiency was measured at the outset of therapy and at two-week intervals thereafter. This provided an additional measure of a function which might show changes during the course of therapy and which also has been related to speech variations (*15, 16, 17*). Measures were obtained during vigorous blowing by use of a Dwyer Magnehelic pressure gage with an open air system, precluding the possibility of achieving valve efficiency by trapping air in the buccal cavity through linguo-palatal coarctation. Pressure gage readings were taken at the highest level each subject could maintain for a two-second period. Efficiency ratios were calculated by dividing the pressure reading obtained with nostrils occluded into the reading resulting when the nostrils remained open. Each subject's efficiency score during a given testing session resulted from a mean of two trials with the nostrils both occluded and open.

## Results and Discussion

Speech Intelligibility and Related Factors. In Table 1, results are shown of the loss of whole word intelligibility in each subject's pre- and post-therapy recordings of the Fairbanks test. The variability of mean error scores among different speakers, and the variability within the same speaker as a function of therapy, suggests that evaluation of word intelligibility on the Rhyme Test has utility in demonstrating differences in the speech status of cleft palate subjects. It is evident that subjects 1 through 6 and subjects 8 and 10 show a trend toward increased intelligibility after therapy, with all post-therapy mean error scores falling below the pre-therapy mean. Subjects 7 and 9 show little magnitude or directionality of change. The variations in mean values among pre- and post-therapy readings suggest some random fluctuation of scores other than that

TABLE 1. Mean number of errors made by listeners in identifying the 50-item word list from the Fairbanks Rhyme Test for each subject in pre- and post-therapy conditions. For subjects 1 through 3, means are based upon responses by 23 listeners. For subjects 4 through 10, means are based upon responses by 13 listeners. Members of listening groups were different in each case and were untrained college students.

| *Subject** | *Pre-therapy* | *Post-therapy* | | |
|---|---|---|---|---|
| | | *1 (3rd wk.)* | *2 (5th wk.)* | *3 (7th wk.)* |
| | *Mean (SD)* | *Mean (SD)* | *Mean (SD)* | *Mean (SD)* |
| 1 | 9.83 (3.16) | 2.35 (1.49) | 1.43 (1.22) | 4.26 (1.92) |
| 2 | 24.00 (2.86) | 17.04 (3.07) | 19.96 (2.89) | 15.13 (2.93) |
| 3 | 29.81 (1.67) | 13.30 (2.53) | 6.52 (2.30) | 10.00 (2.71) |
| 4 | 5.69 (1.14) | 4.00 (1.41) | 2.08 (1.54) | 2.31 (1.13) |
| 5 | 22.38 (3.28) | 9.38 (2.63) | 7.31 (1.31) | 7.31 (1.80) |
| 6 | 13.62 (2.53) | 10.69 (1.65) | 13.15 (2.82) | 7.23 (1.83) |
| 7 | 6.08 (2.32) | 7.85 (2.70) | 8.85 (2.09) | 7.46 (1.56) |
| 8 | 30.62 (2.86) | 25.86 (2.96) | 21.23 (3.12) | 23.77 (3.20) |
| 9 | 12.00 (2.21) | 11.00 (3.03) | 10.38 (2.51) | 15.69 (3.10) |
| 10 | 13 92 (2.57) | 9.92 (2.05) | 8.77 (2.83) | 10.23 (1.81) |

which might be related to intervening therapy. However, in those subjects whose post-therapy error scores were below pre-therapy scores, the $t$ values resulting from the comparison of the pre-therapy mean with the mean from the seventh week were significant at the 5% level. It may be noted that the majority of the subjects with a reduction in post-therapy errors show the greatest proportion of error decrement during the third post-therapy week. The tendency for a relatively marked increase in intelligibility during the third week raises the question of whether this might in part reflect the patient's adaptation to the recording procedure.

As a means of studying intelligibility variation more precisely, the accuracy of listeners' perception of different initial consonant phoneme classes was examined in order to look for patterns among unintelligible phonemes in pre-therapy recordings and to determine those phoneme classes which tended to show the most post-therapy improvement. In Table 2, the proportion of listener errors in identifying various initial consonant phonemes by class is shown for every subject. Proportions were computed from the total number of listener identifications made. For example, for subject 1, 5% of all pre-therapy identifications of initial plosives were in error. Following therapy, errors in identification of plosives were reduced to .5%. It is of interest to note that subjects 1, 2, 4, and 9 had their greatest proportion of pre-therapy errors occur in production of the vocalic consonants /l/, /r/, /w/, and /j/. In addition, subjects 1, 2, 9, and 10 had their highest proportion of post-therapy unintelligibility occur among the vocalic group. This is in contrast to the data reported by Subtelny and Subtelny (*17*) which suggest that, as a group, speakers

TABLE 2. Listener errors in identifying various initial consonant phoneme classes on the Rhyme Test in both pre-therapy and post-therapy conditions. Pre- and post-therapy scores are shown as the proportion of listener errors relative to the total number of listener identifications made. The total number of listener responses on a given phoneme class is shown in parentheses.

| *Subject* | *Plosives* /p,b,t,d,g,k/ | | *Sibilants* /s/ | | *Fricatives* /f,v,h/ | | *Nasals* /m,n/ | | *Vocalics* /l,r,w,j/ | | *Affricates* /dʒ/ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Pre* | *Post* | *Pre* | *Post* | *Pre* | *Post* | *Pre* | *Post* | *Pre* | *Post* | *Pre* | *Post* |
| 1 | .05 (529) | .005 | .02 (161) | .00 | .06 (92) | .01 | .00 (69) | .00 | .07 (276) | .02 | .00 (23) | .00 |
| 2 | .10 (460) | .01 | .44 (138) | .00 | .31 (161) | .02 | .10 (138) | .01 | .54 (253) | .31 | .00 (0) | .00 |
| 3 | .10 (460) | .00 | .48 (138) | .06 | .04 (138) | .01 | .18 (138) | .00 | .22 (253) | .04 | .91 (23) | .21 |
| 4 | .00 (247) | .05 | .00 (65) | .00 | .00 (65) | .00 | .02 (39) | .00 | .10 (234) | .01 | .00 (0) | .00 |
| 5 | .28 (299) | .04 | .23 (13) | .08 | .52 (130) | .10 | .51 (39) | .08 | .16 (156) | .02 | .54 (13) | .30 |
| 6 | .13 (247) | .02 | .00 (104) | .00 | .16 (65) | .01 | .20 (91) | .15 | .06 (117) | .01 | .00 (26) | .00 |
| 7 | .02 (234) | .00 | .06 (52) | .12 | .12 (117) | .12 | .00 (52) | .00 | .04 (156) | .05 | .00 (26) | .00 |
| 8 | .48 (312) | .06 | .86 (78) | .62 | .10 (52) | .15 | .02 (52) | .02 | .19 (156) | .32 | .00 (0) | .00 |
| 9 | .12 (299) | .11 | .01 (65) | .03 | .00 (65) | .03 | .00 (65) | .03 | .29 (156) | .31 | .00 (0) | .00 |
| 10 | .03 (247) | .06 | .24 (104) | .02 | .12 (65) | .00 | .04 (91) | .02 | .06 (130) | .15 | .84 (13) | .00 |

with incompetent palatopharyngeal valves have relatively less difficulty on the glides which in their study included the /l/ and /r/. Subjects 3, 5, 6, 7, 8, and 10 tended to have their highest proportion of pre-therapy errors on the plosive, sibilant, and fricative groups which demand greater oral pressure than the vocalics (*1*). These subjects fit better the description of speech problems related to moderate palatopharyngeal incompetency as reported in other studies (*16*, *17*).

Further analysis of phoneme intelligibility was done in order to discover the particular types of sound confusions which listeners made in identifying various phoneme classes in pre-therapy recordings. The data

TABLE 3. Matrix of initial consonant phoneme class confusions resulting from listener responses to pre-therapy Fairbanks Rhyme Test recordings. In order to show the major trends in listener confusions of phonemes, only those per cent scores are shown for a given phoneme class which accounted for over 25% of the total errors in identifying that class. Subjects are indicated by number. No affricates were confused for other phonemes.

| *Initial phoneme class recorded* | *Phoneme classes confused* | | | | |
|---|---|---|---|---|---|
| | *Plosives* | *Sibilants* | *Fricatives* | *Nasals* | *Vocalics* |
| Plosives /p,b,t,d,k,g/ | S1—29%<br>S3—49%<br>S9—54% | | S6—37% | S1—32%<br>S5—41%<br>S6—46% | |
| Sibilants /s/ | | | S2—95%<br>S10—88% | S3—99% | |
| Fricatives /f,v,h/ | S1—50%<br>S2—73%<br>S6—73% | S1—50%<br>S8—86% | S7—99% | | S5—26% |
| Nasals /m,n/ | | | | S3—92% | S5—90%<br>S6—99% |
| Vocalics /l,r,w,j/ | S6—28% | | S3—27% | S1—45%<br>S2—70%<br>S4—65%<br>S9—91% | S1—25%<br>S3—54%<br>S6—71%<br>S8—73% |
| Affricates /dʒ/ | S5—71% | | | | S10—100% |

are given in Table 3. This table shows how the percentage of errors in identifying initial consonants is distributed. For example, for subject 1, 29% of all errors in identifying initial plosives resulted from listener confusion with other plosives and 32% resulted from the confusion of nasals. Perhaps the most interesting result of this analysis was the emergence of an operational approach to the definition of nasality, that is, the degree to which listeners tend to misidentify orally produced consonant phonemes as nasal phoneme classes. As defined in this manner, it can be seen that

the speech of all subjects, with the exception of 7, 8, and 10, tended to be rendered unintelligible on certain phoneme classes because of nasalization. However, the nasality did not occur in relation to the same phonemes for all subjects. In some cases it was found mostly when plosives were produced (subjects 5 and 6) and in others when vocalics or sibilants were involved (subjects 1, 2, 3, 4, and 9).

Of considerable interest is the fact that two of the subjects, 7 and 8, who had little intelligibility loss resulting from nasality as defined in this study, tended to be more limited than most of the other subjects in terms of maximum achievable pre-therapy palatopharyngeal efficiency during vigorous blowing (Table 4). Relative to this, it can be noted in Table 4 that ratio scores which suggest valve competency during blowing may be limited in precision as a result of moment-to-moment performance variability by subjects during a given testing session. In addition, the relationship of valve efficiency during blowing to that used in speech function is not clear. It is quite possible that subjects who show fairly adequate function in blowing may not use this valve potential at all in speech activity. In spite of this, however, it seems likely that the percentage of efficiency, as measured during blowing, could not be exceeded by the individual during speech function. From this standpoint, it is remarkable that nasal confusions were not prevalent in listeners' phoneme perception errors for subjects 7 and 8.

The results suggest that, operationally, nasality (i.e., confusion of nasal for non-nasal consonants) was not a function of a single anatomic-physiologic variable, namely palatopharyngeal function, nor was it more apt to occur in relation to particular consonant phoneme classes as might have been predicted from findings reported by Lintz and Sherman (*12*). The fact that other anatomic factors, in accompaniment with velopharyngeal function, might be important to the consideration of nasality was pointed out by McDonald and Koepp-Baker (*13*) a number of years ago. Although palatopharyngeal coupling has been demonstrated to be a critical ingredient in nasality (*10, 16*), it seems reasonable that, for a given individual, nasality may also vary as a function of articulatory movements, pharyngeal structure and surface characteristics, relative laryngeal positioning, and the acoustic nature of the glottal sound source.

Spectrographic Findings. Subjects 1 and 4 are of particular interest. They had relatively few listener errors in response to their recordings (Tables 1 and 2). Also, as shown in Table 3, errors tended to be concentrated around the perception of nasal phonemes when plosive and/or vocalic consonants were produced. For subject 1, 32% of all plosive errors resulted from nasal consonant confusion, and for subjects 1 and 4, 45% and 65% of all vocalic errors resulted from the confusion of nasal phonemes (Table 3). Thus, nasality, as operationally described here, appears to have contributed a great deal to their pre-therapy intelligibility problem and its reduction to the increase in post-therapy intelligi-

TABLE 4. Per cent scores of palatopharyngeal valve efficiency during vigorous blowing as measured by a manometer with an open air system. Individual scores resulted from a mean of two trials which were conducted prior to therapy (1) and at two-week intervals thereafter (2, 3, and 4). The range of per cent scores is shown in parentheses. The marked change in efficiency of valve function for subject 4 may be accounted for by the fact that he was fitted with an obturator just prior to the beginning of therapy.

| *Trial periods* | *Subjects* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 (Pre-therapy) | 89 (89–89) | 100 | 100 | 11 (11–11) | 78 (77–78) | 90 (84–95) | 63 (57–68) | 76 (72–80) | 40 (40–40) | 100 |
| 2 (3rd week) | 97 (95–99) | 100 | 81 (79–83) | 76 (75–77) | 91 (90–91) | 78 (55–100) | 62 (60-64) | 73 (70–76) | 53 (50–55) | 94 |
| 3 (5th week) | 82 (80–84) | 86 (77–94) | 74 (67–80) | 77 (70–83) | 85 (84–85) | 89 (86–92) | 77 (71–82) | 63 (58–68) | 64 (64–64) | 93 (85–100) |
| 4 (7th week) | 89 (87–100) | 77 (75–79) | 55 (50–60) | 91 (91–91) | 72 (65–78) | 88 (76–100) | 63 (63–63) | 72 (70–73) | 63 (60–66) | 100 |

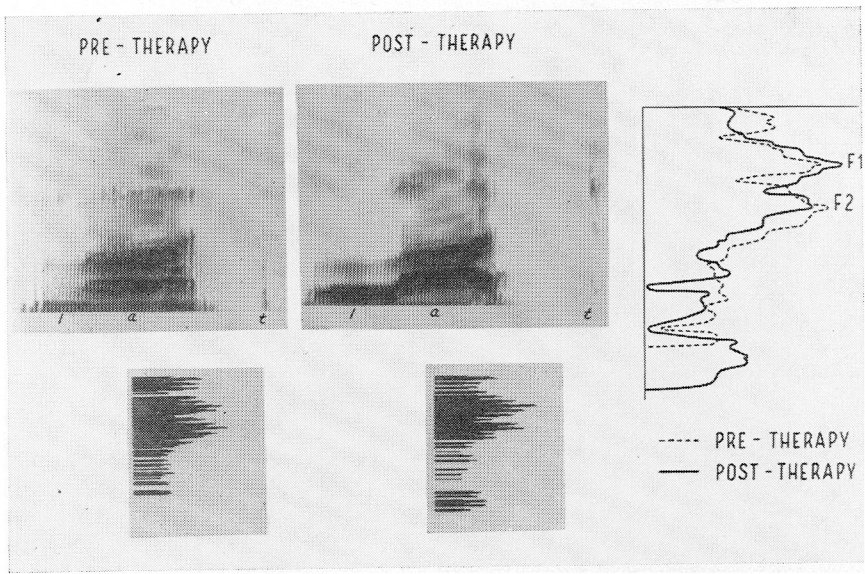


FIGURE 1. Broadband spectrograms of the word *lot* as spoken before and after therapy with narrowband amplitude sections of the vowel. Nine of 23 listeners heard the initial /l/ as /n/ in the pre-therapy recording. All 23 listeners identified the post-therapy recording correctly. Superimposed envelope tracings of the amplitude sections are shown on the right and formants ℵ1 and ℵ2 are indicated.

bility scores as shown in Table 2. For both subjects, the post-therapy listener errors, which are shown in Table 2 for the plosive and vocalic consonants, did not involve any nasal consonant confusions.

Because a concentration of pre-therapy intelligibility errors for subject 1 involved confusion of nasal for oral consonants, and because this type of error was non-existent after therapy, certain of subject 1's pre- and post-therapy word recordings were selected for spectrographic analysis. In Figure 1, broadband spectrograms and narrowband amplitude sections of the vowel are shown for the word *lot* as read by subject 1 when recording the Fairbanks Rhyme Test before and after therapy. Nine of 23 listeners identified the initial /l/ as /n/ in the pre-therapy recording, whereas the word was identified correctly by all listeners in the final recording. In addition, spectrograms of the word *nod*, as recorded before and after therapy, are shown in Figure 2. This word was selected because its production requires nasal cavity coupling at the outset, followed immediately by oral directioning of the air stream for the vowel. A number of differences in pre- and post-therapy vowel spectra appear significant for both words: a) There is pronounced resonance just above the baseline in the pre-therapy recordings. This is absent in the post-therapy recordings, and is apparent in both the broadband and amplitude section displays. b) Formant ℵ1 is damped in the pre-therapy amplitude section as compared with post-therapy. c) In the pre-therapy broadband and amplitude sec-

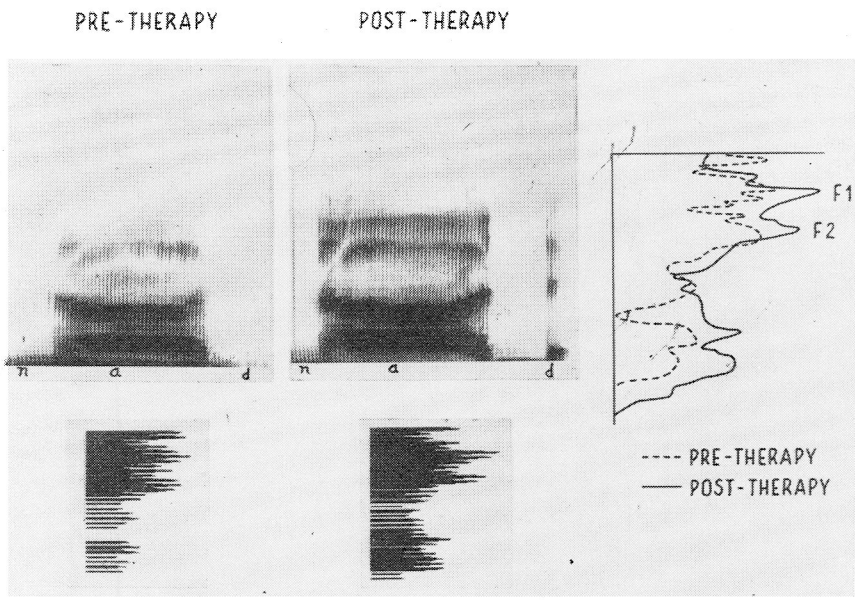


FIGURE 2. Broadband spectrograms of the word *nod* as spoken before and after therapy with narrowband amplitude sections of the vowel. Superimposed envelope tracings of the amplitude sections are shown on the right and formants ⌘1 and ⌘2 are indicated.

tion displays, a loss of energy is evident in the higher harmonics. In the word *nod*, there is a notable tendency for an overall damping and broadening of resonance peaks.

These results are of particular interest when compared with the studies of synthesized nasal consonants and vowels by House (*9*) and House and Stevens (*10*). House (*9*) reported that a baseline resonance at about 200 cps is one of the most characteristic features of the nasal consonants. Also, he and Stevens found that as nasal cavity coupling increased during the production of vowels there was a reduction of energy in the first formant, an overall damping and broadening of all resonance peaks in the vowel spectra, and a loss of high frequency energy. These characteristics are evident in the amplitude sections of the pre-therapy recordings.

The spectrographic findings add support to the impression gained from the phoneme intelligibility evaluation which suggested that nasalization was a major contributor to the unintelligibility of the pre-therapy word recordings of subject 1. Also, the spectrographic results tend to support the validity of the approach to describing nasality operationally as outlined above.

## Summary

The purpose of the present study was to evaluate the utility of intelligibility measures as potential indices of the changes in speech and related

behaviors which may accompany therapy programs for patients with palatopharyngeal inadequacy and related articulation and resonation disturbances. The subjects were 10 males, nine who were born with oral clefts and one with palatopharyngeal insufficiency in speech of unknown origin. The subjects were enrolled in an intensive, eight-week residential therapy program in which direct therapy was provided daily in both group and individual sessions.

A pre-therapy tape recording of a different randomly selected 50-item word list from the Fairbanks Rhyme Test was made by each subject. Recordings of the same list were repeated by each subject at two-week intervals throughout the therapy program. Using a bleed valve, pressure gage evaluations of palatopharyngeal efficiency during vigorous blowing were made for every subject prior to therapy and at two-week intervals thereafter.

Word list recordings were randomized on a master tape and analyzed by listeners' identification of the words read by each subject. Spectrographic analyses of selected pre- and post-therapy recordings were obtained and palatopharyngeal efficiency measures were compared for individual subjects in pre- and post-therapy conditions.

The results suggest that recorded word lists from the Fairbanks Rhyme Test offer a procedure for following intelligibility variations of word units and particular phonemes, and for defining nasality operationally. Pre- and post-therapy spectrograms for a selected subject described variations in certain acoustic dimensions which appeared related to a decrement in nasality for that subject. Palatopharyngeal valve efficiency measures during blowing appeared not to be reflected directly in speech intelligibility or nasality, nor did therapy have a generalized effect in changing valve efficiency during blowing activity.

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