*MODIFICATION OF NASAL RESONANCE IN
CLEFT-PALATE CHILDREN BY INFORMATIVE FEEDBACK¹*

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Vibration of the walls of the nasal cavities during production of an English vowel or diphthong defined a hypernasal response. A crystal transducer on one side of the nose activated a voice-operated relay when vibration exceeded an arbitrary limit to provide an apparatus definition of the response. During training sessions, responses without nasal vibration turned on a white light in the sound-treated chamber. Subject 1 had a repaired cleft palate and mild hypernasal speech. Introduction of the differential feedback, reversal, and reinstatement of the feedback conditions resulted in a rapid decrease, increase, and decrease in percentage of nasalized productions of the /eI/ sound. Subject 2 had a cleft of the soft palate and severe hypernasal speech. Introduction of feedback produced a gradual decline in the percentage of hypernasal productions of the /ɔ/ sound over 22 sessions. Removal and reinstatement of feedback resulted in a rapid increase and decrease respectively in the percentage of nasalized responses.

Operant conditioning procedures have proven successful in changing some aspects of the topography of human vocal behavior. Lane (1964) reported changes in duration of vocal responses by college students as a function of monetary reinforcement, while the vocal pitch level of students with normal voices was altered by presenting a visual stimulus contingent upon electronically defined fundamental frequency levels (Roll, *unpublished*; Shriberg, 1971). Moore and Holbrook (1971) demonstrated that changes in fundamental frequency could be maintained by intermittent schedules of response-produced feedback, and that the patterns of on-target responding produced by the various intermittent schedules were similar to the patterns exhibited by animals performing motor operants (Ferster and Skinner, 1957).

Roll (*unpublished*) demonstrated the practical application of these procedures by changing the

modal fundamental frequencies of four male subjects from a falsetto range of 165 to 230 Hz to a more normal male range of 120 to 140 Hz. A female subject with an extremely hoarse voice was changed from a modal fundamental frequency of 230 Hz to 180 Hz. Three of the five subjects were found for follow-up testing nine months after the final therapy session and testing without feedback showed that all had remained within 10 Hz of their newly conditioned pitch levels. The same procedure also proved successful in changing the pitch levels of deaf adults by providing immediate feedback to replace the missing auditory feedback (Holbrook and Crawford, 1970).

These successes in modifying the vocal pitch levels of normal and abnormal voices and the phonation duration of normal voices suggest a general set of procedures for voice therapy. When the behavior producing the abnormal voice can be specified accurately, and either the mechanical component of the behavior or its acoustical outcome defined by an apparatus, then a stimulus effective in changing the response can be scheduled as a consequence of the response.

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The present study was designed to test this approach to the modification of hypernasal voice quality. A nasal speech tone is produced by the resonance characteristics of the walls of the nasal cavities. In the normal production of the phonemes /m/, /n/, and /ŋ/ the soft palate (velum) is relaxed and there is an opening between the pharynx and the nose. Since the mouth is closed in the formation of these nasal consonants, most of the acoustic energy produced by vibration of the vocal folds passes through the nose, setting the walls of the nasal cavity into vibration at frequencies of the natural resonance for those tissues. In the normal production of English vowels and diphthongs, the soft palate at least partially closes the nasopharyngeal port and the mouth is open, so that the major portion of acoustic energy passes through the oral cavity (Moll, 1962). Since the resonance characteristics of the oral and nasal cavities are markedly different, the quality of sound produced by acoustic energy passing through these ports is clearly different. Hypernasality can be defined as the production of English vowel and diphthong phonemes with resonance characteristics that are normally observed only in the production of the nasal consonants.

Although hypernasal speech is frequently a functional disorder without physiological concomitants, it is most commonly associated with individuals who have cleft palates. Since the direction of vocal energy is determined by the soft palate, a cleft of the palate makes it physically impossible to block the nasopharyngeal port and direct the air stream carrying the sound energy through the oral cavity. Treatment of cleft palate usually involves surgical repair, which in successful cases restores the physical capability for complete velar closure. However, if the repair is completed after the child has developed much speech, the behaviors learned in producing sounds are resistant to change (Morley, 1970). Thus, a problem that was at first clearly physically determined becomes a learning problem after surgical treatment.

Traditional speech therapy techniques for individuals with repaired cleft palates have concentrated on exercises of the muscles in the soft palate with the assumption that once the muscles are able to function properly the patient will emit the appropriate behaviors. Exercises include blowing, relaxing the jaw and throat in production of sustained vowels, and vocalizing yawning (Van Riper and Irwin, 1958; Morley, 1970). In an effort to correct a patient's ability to monitor his own voice, training of auditory discriminations between nasal and non-nasal sounds has also been recommended (Morley, 1970). In the present study, the resonance characteristics of vowel sounds were treated as operant behaviors and differential immediate feedback was arranged for nasal *versus* non-nasal responses.

METHOD

Subjects

Two children participating in the Florida State University Summer Residential Speech Program served as subjects. Subject 1 was a 10-yr-old boy with a unilateral cleft of the lip, hard palate, and soft palate, all of which had been surgically repaired. He had demonstrated the ability to close completely the nasopharyngeal port and intelligibility of his speech was only mildly affected by hypernasality.

Subject 2 was a 13-yr-old girl with a cleft of the soft palate. This subject had also demonstrated the ability to close the nasopharyngeal port and did so with instruction on some sounds. Although the anatomical aspects of the cleft for Subject 2 were not as severe as for Subject 1, speech was affected to a much greater extent. In addition to hypernasal tone quality, which made discrimination between vowel sounds difficult, intelligibility of this subject's speech was impaired by the nasal quality of all voiced sounds and the inability to make plosive sounds without emission of air through the nose.

Behavioral Definition

The walls of the nasal cavities vibrate during production of nasal sounds and they do not vibrate during non-nasal sounds. Hypernasality was behaviorally defined as vibration of the walls of the nasal cavities during production of an English vowel or diphthong.

Apparatus Definition

The subjects sat in a sound-treated chamber (IAC Model 406) with an Electrovoice 666 dynamic microphone placed approximately 6 in. (15.2 cm) in front of and 6 in. (15.2 cm) below the chin. The piezo-electric crystal from a Lafayette harmonica contact microphone was used to transduce the mechanical vibration of the walls of the nasal cavities into electrical energy. The crystal was held on an adjustable rod extending from a head band.² At the beginning of each session, the crystal was placed on the left side of the nose so that firm contact was made, but the nasal passages were completely open. The signals from the acoustic and contact transducers were amplified and fed into a two-channel voice-operated relay system originally described by Holbook and Meador (1969) for use in modification of vocal pitch.³ Functionally, a vocal response with no nasal vibration activated a relay in the acoustic channel of the relay system. A vocal response that produced nasal resonance activated a second relay and overrode the possibility of a closure of the acoustic channel. During all sessions, closure of the relays operated separate counters.

Effective stimulus consequences. During sessions in which response-contingent feedback was scheduled, closure of the relay in the non-nasal channel turned on a 200-W light above the sub-

ject, significantly increasing the normal illumination of the chamber provided by a 60-W white light. Activation of the nasal channel turned on a 25-W red light (Knight, 4515) mounted 3 ft in front of the subject at eye level.

Response precision. The apparatus definition of hypernasality was complicated by the need to remove the transducer between sessions. Even a slightly different placement on succeeding days would make response definition unreliable, with the possibility that changes in recorded amount of nasal vibration could actually result from changes in transducer placement. To avoid this, the following procedure was used each day. The dynamic microphone amplifier was calibrated to a preselected gain setting, the subject seated in the booth, the headband put on, and the transducer placed on the side of the nose. The subject then produced a sustained /m/ sound at an intensity that caused the VU meter to hover around zero, while the experimenter varied the position of the crystal until the voltage generated by nasal vibration was that recorded on the original placement at the same vocal intensity. The voltage necessary to activate the nasal channel of the relay system was arbitrarily set at 75% of the voltage generated by the /m/ sound. The intensity of the vocal response needed to activate the relay in the non-nasal channel was the same as that used for calibration, so that the subjects could not produce a false positive by simply speaking at a lower intensity. The calibrations were repeated at the end of each session, and the few sessions in which the readings changed were dropped from consideration in the analysis of the data.

Response selection. Since any of the vowels or sounds could have served as the initial response, a systematic procedure was used to determine a sound that each of the subjects nasalized consistently, but showed some probability of changing without shaping. In the first two sessions, the subjects were asked through an intercom system to "repeat the following sounds after me". The experimenter then read a list of the vowel and diphthong phonemes with each

²In clinical use, we have found that simply taping the crystal to the side of the nose with hypoallergenic adhesive is preferable to the headband arrangement.

³An instrument with the same functional properties described in this paper is now available commercially as the FLORIDA II from Saber Corporation, P.O. Box 1055, Cocoa Beach, Florida 32931. List price: \$1475.00.

sound repeated five times in random order. The voltage produced through the nasal transducer was recorded for each response. Subject 1 consistently nasalized the phonemes /eI/, /u/, and /i/, but not other phonemes were consistently nasalized. The diphthong /eI/ (day, say) was selected as the response for this subject because it produced the least voltage change of those sounds consistently nasalized.

Subject 2 nasalized all vowels and diphthongs at voltage levels near that produced by the nasal consonant /m/. The /ɔ/ (all, law) sound was chosen for this investigation because it is the vowel produced with the greatest opening of the oral cavity.

EXPERIMENTAL CONDITIONS

The children were treated five days a week at the same time each day. They were seated in the chamber and the transducer calibration completed. The subject was asked to "Say /eI/ (/ɔ/) until I ask you to stop." After every 10 responses, the experimenter told the subject through an intercom system to rest for a few seconds. After a rest of 15 to 20 sec the subject was asked to start repeating the sound again. Sessions ended when 150 responses had been made.

No Feedback₁. No feedback was scheduled for any vocal responses, and the number of nasalized and non-nasalized responses were accumulated on digital counters. The first No-Feedback condition was carried out until 250 responses were made by each subject. This made up all of the first session and two-thirds of the second session.

Feedback₁. The subjects were given differential visual feedback for nasal and non-nasal responses. In the first session in this condition the subjects were asked to:

Continue repeating the /eI/ (/ɔ/) sound, but now every time you make the response this white light will come on (light switched on mechanically). When

you make the sound wrong this red light will come on (light switched on mechanically) and the white light can't come on. I want you to try to make the white light come on every time you say your sound.

No further instructions were given on how to make the correct response. This condition remained in effect until the subject had emitted 200 consecutive non-nasal responses.

No Feedback₂. The conditions of No Feedback were reintroduced. Since a total lack of feedback would have been confusing to the subjects, they were given instructions to try to make the response that turned the white light on without the help of the lights.

Feedback Reversal. When No Feedback₂ was in effect, Subject 1 maintained a low rate of nasalized sounds. Since the children were in a full-time program aimed specifically at changing their speech, it was necessary to determine convincingly whether the changes observed in the vocal response of this subject were under the control of the feedback procedures and instructions or a concurrent therapeutic activity. During feedback reversal, the instructions read at the beginning of the Feedback₁ sessions were reread to the subject. However, the lights were reversed so that the white light was turned on by nasal sounds and the red light by non-nasal sounds.

No Feedback₃. This condition was also included only for Subject 1. He was asked to try to make the same response that turned on the white light without the help of the lights.

Feedback Reinstated. This was a reintroduction of the original feedback condition and occurred following No Feedback₂ for Subject 2 and No Feedback₃ for Subject 1.

RESULTS

Subject 1

Figure 1 shows the percentage of responses in which sufficient vibration of the nasal walls occurred to activate the nasal channel of the voice-operated relay system. The data from two

baseline sessions were not recorded due to inconsistent calibration readings before and after the sessions. The data points are based on 50 repetitions of the phoneme /eI/. All responses were nasalized when no feedback followed responses, but the percentage of nasalized responses rapidly decreased in the first session of differential visual feedback.

Fig. 1. Percentage of /eI/sounds nasalized by Subject 1 on each block of 50 trials under Feedback, No-Feedback, and Reversed-Feedback conditions. Feedback consisted of a white light produced by non-nasal responses and red light by nasal responses.

The criterion of 200 consecutive non-nasal responses was met in the eighth session. The subject maintained non-nasal responding when feedback was removed and he was asked to see how well he could do without lights (No Feedback₂). Control of the place of major resonance by feedback and instructions was demonstrated by the subject's reversal in responding when nasal, rather than non-nasal, responses turned on the white light (FB Reversal).

In the third No-Feedback condition, Subject 1 again maintained the most recently correct response with few errors. Reinstatement of the Feedback condition in which non-nasal responses turned on the white light associated with correct responses resulted in a rapid recovery of non-nasal responding.

Subject 2

All 250 /ɔ/ responses activated the nasal channel of the voice relay when no feedback was

scheduled for Subject 2. The introduction of informational feedback resulted in a slow trend towards lower percentages of nasalized responses over the 22.66 sessions necessary for criterion performance. The variability in responding, which is evidenced in Figure 2, occurred within as well as between sessions. The data show that there was no consistent improvement from the first third to the final third of the sessions, as might be expected. Although good control of the nasal resonance was shown after considerable training, the percentage of nasalized responses increased rapidly in the first session of No Feedback₂. Reinstatement of the differential feedback brought about a rapid return to non-nasal responding, indicating that Subject 2 had gained control of the place of major resonance for the vowel /ɔ/ when informational feedback followed responses. The data from one baseline session and three conditioning sessions were not recorded due to changes in the transducer calibrations before and after the sessions.

DISCUSSION

Differential visual feedback successfully produced changes in the place of major resonance in both cleft-palate children. The validity of the

Fig. 2. Percentage of /ɔ/ sounds nasalized by Subject 2 on each block of 50 trials under Feedback and No-Feedback conditions. Feedback consisted of a white light produced by non-nasal responses and a red light produced by nasal responses.

apparatus definition for hypernasality was supported by the fact that Subject 2, who had the greater amount of perceived nasal voice quality and the greater degree of nasal vibration according to the voltage output from the crystal transduction, required the greater amount of training and showed less control of the response without feedback. The present data add generality to the approach outlined in this paper for treatment of voice disorders. Place of major resonance, as well as vocal pitch level and phonation duration, can be modified by response-contingent feedback.

Although no controls were used to determine the motivational properties of the red and white light, the instructions and information provided by the lights were probably sufficient to change the behavior. This supports the suggestion by O'Brien and Azrin (1970) that undesirable operant behaviors can be reduced or eliminated by simply providing immediate information about their occurrence when the subjects are motivated to change the behavior. In the case of Subject 2, either the motivation was not provided by the subject or the new response was physically difficult to produce. In either case, the effect of more powerful consequent events in increasing the rate of change should be investigated when low rates of changes are encountered.

Two questions must be answered by further research before the procedures reported here should be used in the treatment of hypernasality. First, the method that subjects used to change the direction of airflow must be determined. Although the desired outcome of decreasing nasal vibration was attained, the subjects may have accomplished this by blocking the nasopharynx with a movement of the tongue to the rear of the oral cavity rather than proper movement of the soft palate. Some vowel sounds can be produced with normal resonance characteristics using the tongue blocking, but the soft palate must close for proper production of plosive and fricative sounds, as well as vowels in which the tongue must be in a forward

position as an articulator. If the tongue is used to change the place of major resonance, methods must be found to eliminate this possibility during training.

In informal testing during the final days of the program, Subject 1 was able to pronounce correctly words such as say, day, and pay within the apparatus criterion of non-nasal responses in a no-feedback situation. These words were all consistently nasalized during early diagnosis and pilot sessions. Unfortunately, further study of generalization was not possible due to the termination of the summer program. However, correct articulation of "day" required placing the tip of the tongue on the roof of the mouth, and "pay" required velar closure to build air for the plosive sound (/p/). Thus, use of the tongue to change the place of resonance was quite unlikely for this subject and proper nasal resonance did not produce improper articulation in the few observations that were made.

The second question involves the most efficient way to eliminate hypernasality in connected speech. The possibility of reducing the amount of nasal resonance during the reading of meaningful prose could be investigated by creating passages in which no nasal consonants occur. The present study demonstrated that control of place of resonance can be learned for production of an isolated vowel or diphthong. The procedure of systematically training the correct production of each vowel in isolation and in varying consonant environments might be eliminated if these procedures can be used while the subject is engaged in connected speech.

The apparatus definition of the hypernasal response provided several advantages. Among these were reliability of measurement and consistency and immediacy of feedback to both the patient and therapist. The quantitative index of nasality provided by recording the voltage levels produced by different sounds also generated a useful tool for diagnosis and selection of the target responses. The definition of a non-nasal sound as 25% of the voltage level produced by an /m/ sound was sufficient to change the

quality of the target phonemes to a more than acceptable level. Since English vowel and diphthong phonemes in normal speech have varying degrees of nasal resonance, further research will be necessary to determine the criteria for proper oro-nasal resonance balance.

In addition to these advantages provided by the apparatus definition of the target responses, the present procedure has practical therapeutic advantages. The patients spend the entire treatment session emitting the target response, rather than listening to therapist descriptions of how responses should be made. Furthermore, the emphasis in therapy was changed from the typical use of instructions on how to use the soft palate (Morely, 1970; Van Riper and Irwin, 1958) to providing consequences for the appropriate vocal result without making specific requirements on how that result was obtained. Thus, the patients could determine the most comfortable way to produce the required sounds within their own physiological structure.

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