Observed Effects of Velopharyngeal Orifice Size on Vowel Identification and Vowel Nasality

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This study was designed to investigate possible effects of oral-nasal coupling on the nasality of both voiced and whispered test vowels and on the identification of voiced test vowels. One adult subject with cleft palate was fitted with a specially designed speech appliance that permitted alterations in the size of the velopharyngeal orifice. At each of the seven oral-nasal coupling conditions, the subject produced five repetitions of each of two test vowels (/i/ and /u/), first in a whisper and then with voicing. Magnetic recordings of the test samples were evaluated by a panel of nine listeners. The listeners rated the nasality of each sample and, for the voiced vowels, specified the vowel phoneme they perceived each to represent. The results suggest that listeners may be able to scale nasality more reliably for voiced than for whispered vowel samples. They also suggest that nasality and identifiability for vowels may vary complexly as a function of the size of the oral-nasal orifice.

KEY WORDS: oral-nasal coupling, hypernasality, vowels, cleft palate, velopharyngeal orifice, velopharyngeal closure

Introduction

Excessive nasality is often defined as a perceived change in vowels resulting from excessive nasal resonance (Morris, 1968). Clinically, excessive nasality or hypernasality is commonly heard in conjunction with inadequate velopharyngeal valving, and it is frequently associated with anatomical or physiological palatal defects. A review of previous writings regarding nasality suggests that one may not only "detect" excessive nasality by listening for it in vowels but may also discriminate among isolated vowel samples on the basis of the degree of nasality they manifest. Thus, acoustic vowel features may exist that "cue" the perception of nasality and enable listeners to discriminate perceptually among different degrees of nasality. It is challenging to observe that remarkably few facts are clearly established at this time about the nature of such nasality cues in speech. It has been suggested, however, that the major cues may include alterations in vowel formant frequency, intensity, and bandwidth that occur as a consequence of increased oral-nasal coupling (Fant, 1960; House and Stevens, 1956; Lindblom, et al., 1977). At this time, the relationship between the degree of perceived nasality and the size of the velopharyngeal orifice remains unclear.

If vowel formant changes provide essential cues to nasality, it is of interest to consider the possibility that excessive nasality may be associated with whispered as well as with voiced vowel samples. Indeed, we have seen no clinical reports to suggest that individuals who present excessive nasality "lose" that speech disturbance when they whisper. The hypothesis seems tenable on theoretical grounds as well. It would be expected, on the basis of speech-acoustic theory (Dunn, 1950; Fant, 1960), that, while whispered and voiced vowels must differ with respect to air-stream management at the glottis, they should not differ with respect to their velopharyngeal valving requirements.

The idea that excessive oral-nasal coupling during vowel production (either voiced or whispered) may cause disturbances in vowel

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formant features suggests another hypothesis. It would appear that, because of resonant distortions resulting from excessive oral-nasal coupling, hypernasal vowels might be more difficult for listeners to identify than vowels produced with the velopharyngeal valving behavior thought to be necessary for the particular vowel involved. Although the data necessary to test the above hypothesis appear to be sparse, there are some relating specifically to vowels. Klinger (1956) found, for example, that listeners could accurately transcribe 90% of the vowels produced by normal speaking subjects but only 53% of those produced by subjects with cleft palate. Cullinan and Counihan (1971) found that listeners could accurately identify only 57% of the vowels produced by their subjects with cleft palate. More recently, Lindblom et al. (1977) reported, on the basis of an acoustic spectral analysis of hypernasal vowels, that such vowels are "less distinct" than "oral" vowels. Because there have been few such studies, there is a need to investigate further the relationship between vowel nasality and vowel identification.

It was our intent to study the effects of oral-nasal coupling on the nasality and the identification of voiced test vowel productions and on the nasality of whispered vowels. Our experimental design required that the test vowel samples be collected as the size of the velopharyngeal orifice was varied. As was suggested by McDonald and Koepp-Baker (1951), it appeared possible that the effects of coupling on vowel nasality and identification might not become apparent until some critical degree of oral-nasal coupling was reached. The necessity for such control imposed a practical limit on the number of subjects that could be used. We were able to study just one subject in whom the velopharyngeal orifice could be modified systematically as the design required.

Method

The methods and subject used in this study were described in detail in a previous report (Watterson and Emanuel, 1981). Briefly, one female adult with cleft palate was fitted with a specially designed speech appliance (Figure 1). The appliance was a duplicate of the subject's own appliance, which afforded her essentially normal resonance balance in speech. Using "coupling plugs" in the speech bulb of the special research appliance made it possible to alter the subject's oral-nasal orifice so that it ranged from an "occluded" condition, identified as coupling condition I (CC I), to circular areas of 12.57 mm^2, 28.27 mm^2, 50.26 mm^2, 78.53 mm^2, and 153.94 mm^2 (CC II through CC VI, respectively). In addition to these six coupling conditions, a seventh (CC VII) was included where the speech appliance was not worn at all.

Audio Recording. Under each coupling condition, the subject produced five repetitions of each of two test vowels, /i/ and /u/, first, in a whisper and then with voicing. Those samples were recorded on audio tape. Thus, a total of 140 test samples became available for analysis (7 coupling conditions $\times$ 2 vowels $\times$ 5 repetitions $\times$ 2 modes of phonation). For the whispered test vowel samples, production intensity was controlled to 55 dB SPL at a 7.6 cm mouth-to-microphone distance and, for the voiced samples, to 75 dB SPL at a 15.2 cm mouth-to-microphone distance. Though produced at different intensities that were comfortable for the subject, both whispered and voiced test samples were magnetically recorded at the same level (−2 VU). Next, a two-second intensity-steady, central portion of each vowel recording was selected. By procedures described below, each of those two-second test samples was subsequently evaluated by a panel of nine listeners, all graduate students in communication disorders. Their quantified judgments constituted the experimental data regarding vowel identification and nasality.

Vowel Identification. For the vowel identification judgment task, the voiced test vowel samples were randomized and re-recorded on one continuous master tape. The samples were then played at −2 VU in a sound isolated environment and each listener independently indicated the identify of each vowel sample by circling on a response sheet one of seven phonetic vowel symbols (/æ/, /ε/, /I/, /i/, /u/, /U/, /o/). For this task, the listeners were not informed that the subject had intended to produce one or the other of the two test vowels (/i/ and /u/) in every instance.

To examine the listeners' responses, confusion matrices were constructed. Separate matrices were made for voiced /u/ and voiced

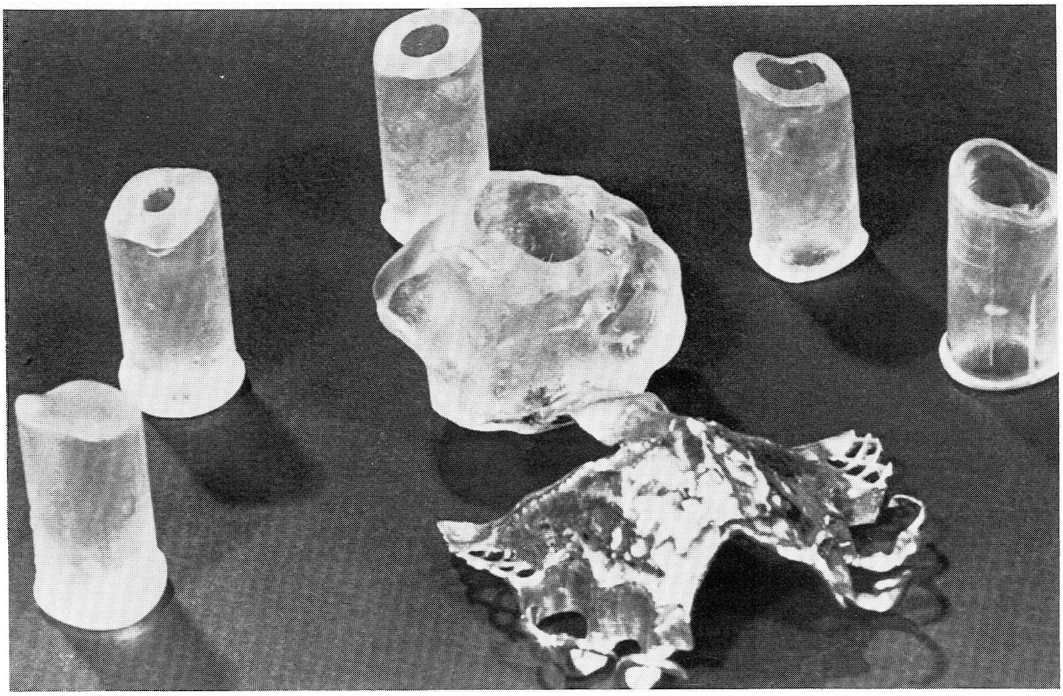

FIGURE 1. The experimental speech appliance and the coupling plugs used to control the size of the velopharyngeal orifice. The unplugged hole in the speech appliance represented CC VI (153.94 mm^2), and the coupling plugs from left to right, respectively, represented CC I (occluded), CC II (12.59 mm^2), CC III (28.27 mm^2), CC IV (50.26 mm^2), and CC V (78.53 mm^2).

/i/ samples. Within each matrix, the responses were ordered by oral-nasal coupling condition. Because nine listeners "identified" five repetitions of each test vowel at each coupling condition, 45 identification judgments were available for each coupling condition in each matrix. As an index of the perceived identity of the test productions, a count was obtained at each coupling condition of the number and percentage of times out of 45 that a listener's judgment was congruent with the vowel intended by the subject. Additionally, a count was also obtained of the number of times a listener identified a test production as a vowel other than that intended by the subject.

VOWEL NASALITY RATING. For the vowel nasality rating task, another listening tape was prepared with both the whispered and voiced test vowel samples dubbed in the following order: voiced /i/ samples, whispered /i/ samples, voiced /u/ samples, whispered /u/ samples. Before each group of vowel samples was played for listener rating, the intended vowel was disclosed to the listeners because nasality ratings are to some extent vowel-dependent (Counihan and Cullinan, 1970; Carney and Sherman, 1971; Lintz and Sherman, 1961). It was thus reasoned that, if the intended vowels were not known to the listeners, the nasality ratings might vary among the listeners in part because of interjudge "disagreement" regarding the identity of the vowel. Further, to aid the listeners in their nasality judgments, two vowel samples from each of the four vowel groups were selected to serve as anchor stimuli. During the rating of each group of test vowels, the appropriate anchor stimuli were presented after every third test sample. Also, preliminary practice sessions were provided until all judges reported that they were "confident" of their nasality ratings.

The listeners individually scaled the degree of nasality each preceived in each test vowel sample. The perceptual scale used ranged from 1 to 5, with "1" representing "least" and "5" representing "most" nasality. As an index of the nasality associated with the individual test samples, the median of the nine judges' nasality ratings for each vowel was obtained. Then, a mean was taken of the median ratings obtained for the five repeated productions of each test vowel at each coupling condition. The mean of the medians taken for the five productions was labelled the condition mean nasality rating (CMNR) for each test vowel.

Results

Reliability. Some of the observations that were made regarding the judges' reliability in rating the test vowel samples for nasality seem most appropriately placed among the results of this study. As previously mentioned, the test samples were rated for nasality in four separate groups: voiced /i/, whispered /i/, voiced /u/, and whispered /u/. To provide a reliability sample, ten test samples in each group were presented twice to the judges. Intrajudge reliability in rating the nasality of each of the four groups of test vowels was first evaluated by obtaining a Pearson r correlation coefficient that indicated the relationship between first and second ratings of the repeated test samples. As Table 1 shows, all but two of the eighteen coefficients obtained for voiced vowel samples were positive and statistically significant ($p < 0.05$). In rating the whispered samples, however, the judges were generally less reliable. Eleven of the eighteen Pearson r coefficients for twice-rated whispered samples were not significant. Additionally, some judges demonstrated acceptable reliability in rating the nasality of voiced vowels but were not reliable in rating the nasality of whispered vowels.

The reliability associated with the nasality judgments was also assessed by obtaining average intraclass correlation coefficients (Ebel, 1951). The data available for analysis were individual ratings by each of the nine judges for the 35 test vowel samples in each of the four vowel groups. Thus, there was a total of 315 nasality ratings for each of the four vowel groups (7 coupling conditions $\times$ 5 repetitions $\times$ 9 judges = 315). The coefficients for voiced samples were .92 for voiced /i/ and .94 for voiced /u/. The coefficients were smaller, however, for the whispered test vowels. They were .77 for whispered /i/ and .61 for whispered /u/.

The obtained correlation coefficients for the voiced test vowels indicate that nasality ratings by individual judges are not necessarily reliable estimates of vowel nasality, but that satisfactory reliability can be obtained by using the average nasality ratings of nine judges. The finding that a panel of judges is more reliable than individual judges is consistent with the results of previous studies (e.g., Counihan and Cullinan, 1970). For the whispered test vowels, however, the panel of judges was not very reliable.

Nasality Ratings. Figure 2 shows the CMNR for voiced /i/ and voiced /u/ test samples. For both test vowels, it can be seen that the CMNR neither increased nor decreased systematically as oral-nasal coupling was increased. Rather, judgments were erratic; but there was a tendency for the CMNR for both test vowels to increase or decrease simultaneously from one coupling condition to the next. The only exception is seen in the change from CC IV to CC V, where the CMNR for /u/ slightly increased, while that for /i/ slightly decreased. The significance of the CMNR differences among coupling conditions was evaluated statistically with the New Multiple Range Test (Winer, 1962). That analysis showed, for both the voiced /i/ and voiced /u/ test samples, that productions obtained at CC I and CC III, and CC VI

TABLE 1. Pearson r Correlation Coefficients Showing the Relationship between Repeated Nasality Ratings for Whispered and for Voiced Test Vowel Samples, for Each of Nine Judges

	Judges								
	1	2	3	4	5	6	7	8	9
Whispered /i/	−.21	.27	.43	.14	.34	.71*	.87*	.60	.73*
Whispered /u/	.48	.50	.67*	.83*	.43	−.04	.27	.74*	.65*
Voiced /i/	.80*	.61	.84*	.81*	.93*	.74*	.75*	.46	.77*
Voiced /u/	.90*	.83*	.91*	.81*	.67*	.80*	.71*	.94*	.99*

* Significant at the .05 level of confidence.

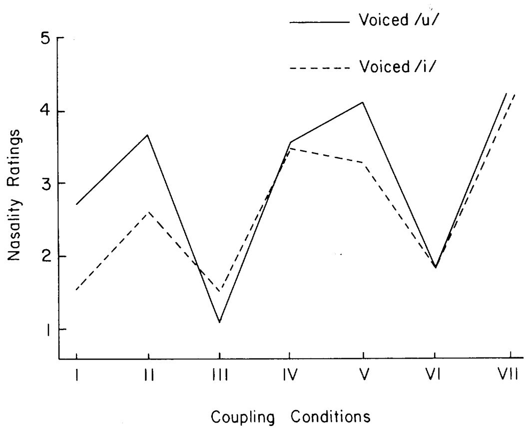

FIGURE 2. Coupling condition mean of median nasality ratings (CMNR's) for voiced /u/ and voiced /i/ productions at each of seven oral-nasal coupling conditions.

were marked by significantly less nasality ($p < 0.05$) than those obtained at CC II, CC IV, CC V, and CC VII. Thus, the results indicated that, in some instances, the perceived nasality of voiced test vowel productions actually decreased significantly when the area of oral-nasal coupling was increased.

In contrast to those for the voiced test samples, the CMNR for whispered /i/ and whispered /u/ productions manifested dissimilar trends among coupling conditions (Figure 3). That is, the CMNR for whispered /i/ productions showed a tendency to increase as coupling increased, while those for whispered /u/ productions were more erratic from one coupling condition to another. The New Multiple Range Test revealed that whispered /i/ productions obtained at CC I, CC II, CC III, and CC IV were significantly less nasal ($p < 0.05$) than those obtained at CC V, CC VI, and CC VII. For whispered /u/ productions, the samples obtained at CC I, CC III, CC V, and CC VI were significantly less nasal ($p < 0.05$) than those obtained at CC II, CC IV, and CC VII. Thus, the nasality ratings for whispered /i/ samples were greatest when oral-nasal coupling was greatest, but those for whispered /u/ samples did not increase systematically as a function of orifice area.

The standard errors associated with all of the CMNR's were small in every case, ranging from .02 to .45. Some of the standard errors were too small to graph and are, therefore, not included in Figures 2 and 3. (They are available on request.)

VOWEL IDENTIFICATION. Table 2 displays data regarding the vowel identifications made by the listeners for the voiced /u/ productions at each of seven oral-nasal coupling conditions. It can be seen that the percentage of voiced /u/ test samples correctly identified did not change systematically as a function of coupling. Interestingly, the highest percentage of correct identifications was for productions obtained at CC III. Thus, identification of voiced /u/ productions was "best" in the presence of some oral-nasal coupling. When the voiced /u/ test samples were not correctly identified, they were most frequently identified as /U/ instead of /u/.

Table 3 presents similar data for the voiced /i/ test samples. For the voiced /i/ productions, the highest percentage of correct identifications was for samples obtained at CC I and the lowest for samples obtained at the largest coupling conditions, CC VI and CC VII. Thus, for the voiced /i/ test samples, there was some tendency for orifice area and correct vowel identification to be inversely related. When the voiced/i/ test samples were not properly identified, they were most frequently identified at /I/.

NASALITY AND IDENTIFICATION. It was also of interest to examine the relationship between voiced vowel identification and ratings of vowel nasality. (Similar data for whispered samples were obtained, but because of the poor reliability of the nasality ratings, they are not reported.) Tables 4a and 4b show the results of chi square analyses (Siegel, 1956) between the nasality ratings and the number of correct identifications for voiced /i/ and voiced /u/. Because of scheduling difficulties, only six judges were able to participate in both the nasality rating and the vowel identification sessions. Chi squares are based on those six listeners. For both vowels, the analyses indicated that the judges generally assigned higher nasality ratings to those test samples that were most difficult to identify; or, conversely, listeners less frequently identified the vowel heard as that intended when the samples judged were relatively nasal. This inverse relationship between nasality ratings and the ability to identify correctly was statistically significant ($p < 0.001$) for both test vowels.

Discussion

One question of interest in this study was whether or not nasality can be perceived and rated in whispered vowels as well as in voiced vowels. The listeners for this study could rate the nasality of the whispered test vowel samples but were less reliable than they were for voiced vowel samples. It may be that their relative inexperience in judging the quality of whispered productions accounts, at least in part, for differences in reliability. That possibility cannot be ruled out even though each judge was permitted to practice rating whispered and voiced vowel nasality until he or she felt confident of rating skills.

On the other hand, fixed and equal orifice areas may not result in similar degrees of oral-nasal coupling or in acoustic cues that are equally evident to listeners' perceptions for both whispered and voiced vowel productions. There is a possibility that the acoustic-perceptual impact of coupling was influenced by the markedly different source-spectrum characteristics of the voiced and whispered vowel productions. That is, nasalization effects may be partially determined by the characteristics of the glottal source. Presently, there are few data available to test that hypothesis, although Hamlet (1973) has shown

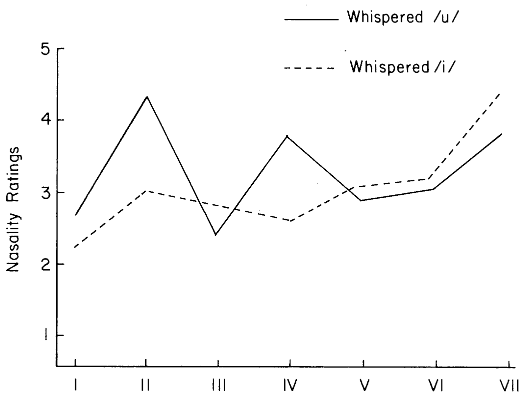

FIGURE 3. Coupling condition mean of median nasality ratings (CMNR's) for whispered /u/ and whispered /i/ productions at each of seven oral-nasal coupling conditions.

TABLE 2. Matrix Showing Vowel Identification Results for Voiced /u/ Productions at Each of Seven Oral-Nasal Coupling Conditions (N = 9 Judges × 5 Samples = 45 Judgments Per Condition)

Coupling Condition	*/u/ Identified as*							*Percentage Correctly Identified*
	/æ/	*/ɛ/*	*/I/*	*/i/*	*/U/*	*/o/*	*/u/ (Correct)*	
I	1	0	2	3	9	6	24	53%
II	7	2	0	0	14	5	17	38%
III	0	0	0	0	7	1	37	82%
IV	7	2	0	0	14	9	13	29%
V	5	0	0	0	19	8	13	29%
VI	1	1	1	0	8	0	34	76%
VII	14	2	1	2	16	3	7	16%

TABLE 3. Matrix Showing Vowel Identification Results for Voiced /i/ Productions at Each of Seven Oral-Nasal Coupling Conditions (N = 9 Judges × 5 Samples = 45 Judgments Per Condition)

Coupling Condition	*/i/ Identified as*							*Percentage Correctly Identified*
	/æ/	*/ɛ/*	*/I/*	*/u/*	*/U/*	*/o/*	*/i/ (Correct)*	
I	0	2	3	0	0	0	40	89%
II	3	0	12	0	0	0	30	67%
III	0	2	8	2	0	0	33	73%
IV	0	2	11	0	0	0	32	71%
V	0	0	10	2	0	0	33	73%
VI	5	3	19	2	0	1	15	33%
VII	9	5	6	7	3	1	14	31%

TABLES 4a AND 4b. Chi Square Contingency Tables for Nasality Ratings and the Number of Voiced /i/ (4a) and Voiced /u/ (4b) Test Samples Identified as Intended

TABLE 4a

Nasality Ratings	*Identified as /i/*	*Not Identified as /i/*	*Total*	*Percentage Identified as /i/*
1	39	12	51	76.47%
2	35	18	53	66.04%
3	34	18	52	65.38%
4	14	15	29	48.28%
5	4	21	25	16.00%
Total	126	84	210	60.00% $\chi^2 = 29.03$

TABLE 4b

Nasality Ratings	*Identified as /u/*	*Not Identified as /u/*	*Total*	*Percentage Identified as /u/*
1	38	9	47	80.85%
2	16	13	29	55.17%
3	12	27	39	30.77%
4	15	45	60	25.00%
5	7	28	35	20.00%
Total	88	122	210	41.90% $\chi^2 = 47.03$

that "phonatory detail" may differ from normal in the presence of oral-nasal coupling; and Fletcher (1977) has suggested that voice onset time maturation may be affected by congenital cleft palate. In light of that, it would seem important to continue the search for possible relationships between nasality and the acoustic characteristics of the glottal source.

The present findings regarding listener reliability for rating nasality also raise a question about the relative importance of vowel formant changes as acoustic cues to nasality. House and Stevens (1956) and others have suggested that the primary acoustic basis for the perception of nasality may be changes in vowel formant frequency, intensity, and bandwidth that occur as a consequence of oral-nasal coupling. If it can be assumed that the formant effects of coupling are similar for both voiced and whispered test samples, it is difficult to explain why the listeners did not attain highly reliable nasality judgments for the whispered vowels. It seems possible that the formant-coupling effects associated with the whispered vowels did not provide sufficient cues to permit the listeners to make optimally reliable nasality judgments.

The ratings of vowel nasality for the voiced test samples suggested that increases in oral-nasal orifice area do not necessarily result in increased vowel nasality. For the one subject studied at least, oral-nasal coupling increases were sometimes accompanied by significant vowel nasality decreases. McDonald and Koepp-Baker (1951) have hypothesized that there is a "critical point" in the degree of velar closure, a point where the characteristic normal balance is established between oral and nasal resonance. The present findings for voiced /i/ and voiced /u/ seemed more consistent with a concept of "critical points" regarding oral-nasal coupling. That is, there was more than one magnitude of coupling where nasality was diminished even though it was not necessarily normal. It will be recalled, for example, that the lowest nasality ratings for the voiced test vowels were obtained when there was no measurable orifice area and, presumably, no oral-nasal coupling, CC I, and at the 28.27 mm^2 coupling condition, CC III.

In the same regard, oral-nasal orifice area increases did not seem to be well correlated with a decrease in correct vowel identifications. For the voiced /i/ test samples, the percentage of correct identifications did not change appreciably until the orifice area was relatively large, CC VI and CC VII. For the voiced /u/ test samples, however, the percentage of correct identifications varied from coupling condition to coupling condition.

The statistical analyses also showed that the most nasal, voiced vowel samples were, in general, those that were most difficult to identify. That finding is consistent with those of previous investigators who have reported that nasalized vowel productions are less intelligible. Additionally, the present findings suggest to us a possible explanation for that relationship. The data show that the voiced test samples produced with zero or 28.27 mm^2 of opening (CC I and CC III) were more often correctly identified and were significantly less nasal than vowels produced with openings of either 12.57 mm^2 or 50.26 mm^2, CC II and CC IV. That finding might be explained as a consequence of misarticulation. It did not appear, however, that our subject misarticulated both test vowels at the 12.57 mm^2 and 50.26 mm^2 orifice areas but correctly articulated both vowels at zero and 28.27 mm^2. It seems likely that some coupling areas were associated with a major vowel resonance distortion while others were associated with a comparatively minor distortion. For those coupling conditions where vowel distortion was major, there was a consequent decrease in the number of correct identifications and an increase in vowel nasality.

The data from this study suggest that, at least in some cases, one should not expect a simple quasilinear relationship between the size of the orifice and either the nasality or identity of vowel productions. For the one subject of this study, the resonance distortion that apparently occurred as a consequence of coupling did not systematically increase as orifice area increased. It also appears from the study that relatively small orifice area changes may have a considerable impact on vowel identification and nasality. This is not to imply, however, that a specific velopharyngeal orifice area would have the same perceptual impact for different individuals. On the contrary, we would expect variation in such effects for reasons we have discussed earlier (Watterson and Emanuel, 1981).

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