Distributional Analyses of An Index of Nasal Coupling (HONC) In Simulated Hypernasal Speech

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Distributional characteristics of an index of nasal coupling, HONC, were investigated using simulated hypernasal speech produced by ten female adults. The results showed that the HONC index could differentiate between the normal and hypernasal speech as well as between the normal reading of two passages, one devoid of nasal consonants, and the other with nasal consonants contained at the natural frequency of occurrence in English. Two alternative methods of obtaining the HONC index were also studied and are discussed.

KEY WORDS: nasal coupling, hypernasality, adults, Horii Oral Nasal Coupling Index (HONC)

Recently, Horii (1980a; 1980b) proposed the use of a ratio of nasal accelerometric amplitude to voice amplitude as an index of nasal coupling. The ratio was called HONC—the *H*orii *O*ral *N*asal *C*oupling index. In essence, the method is an extension of an accelerometric technique of nasality detection described by Stevens et al. (1975). In their method, an extremely light-weight (1.8 grams) sensitive miniature accelerometer (BBN piezoelectric 501) was placed on the external surface of the nose. During speech, the output level of the accelerometer changed dynamically, producing high amplitude signals at nasalized segments and low amplitude signals at nonnasalized segments of speech. The accelerometric signal, plotted in decibels as a function of time, was called the "nasalization function."

Noting wide individual differences in the magnitude of nasal tissue vibration and the effects of vocal intensity on nasalization functions, Horii suggested the use of a nasal-to-voice amplitude ratio, where the nasal amplitude level was derived from a nasal accelerometer and the voice amplitude level was derived from either a regular microphone or a throat microphone/accelerometer (Horii, 1980a; 1980b; Horii and Lang, 1980; Taylor and Horii, 1980). The levels of the nasal and voice amplitude signals during fully-nasalized sustained [m] productions were used as the reference. More specifically, the ratio was defined as HONC = K $A_{rms}(n)/A_{rms}(v)$, where $A_{rms}(n)$ is the root-mean-square amplitude of the nasal accelerometer signal; $A_{rms}(v)$ is the root-mean-square amplitude of the voice signal; and k is a correction factor which makes HONC equal to unity during sustained [m] production. That is, k is the ratio of $A_{rms}(v)$ to $A_{rms}(n)$ during [m]. HONC can be expressed as a fraction, as a percentage by multiplying it by 100, or in dB. HONC in dB is equivalently the difference between the nasal and voice amplitude levels in dB. Use of a ratio such as HONC has been suggested by Stevens et al. (1976) and, in fact, has been employed by Garber and Moller (1979) and Bull et al., (1979) quite independent of the present authors. Specific descriptions of their procedures, however, have not been given, and no quantitative data are available in the literature.

There appear to be two alternative methods of obtaining the voice amplitude level. One is via a throat microphone or accelerometer, and the other by a regular microphone pick-up of air-borne voice signals. There are advantages and disadvantages to each method (Horii, 1980b). One prominent disadvantage

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of the throat microphone or accelerometer is related to postural change and vertical movements of the larynx which tend to introduce artifacts into the output signals. Through trial and error, it was found that placing the microphone immediately above the sternal notch, rather than on the thyroid laminae, appeared to be most stable. The throat accelerometer's advantage lies in the fact that its output levels are more linear with the nasal accelerometer output levels than are the airborne voice levels. The availability of airborne voice recordings, however, permits further acoustic and perceptual analyses of the voice. Thus, use of a regular microphone in obtaining voice amplitude is an attractive option. Before a decision is made as to which method is preferable, however, it is necessary to compare the results from the two alternative methods. Hence, the purpose of the present investigation was two-fold. The first objective was to investigate distributional characteristics of the HONC index associated with connected speech, and particularly, the index's sensitivity to distinctions between normal and hypernasal speech. The second objective was to compare the two alternative methods of calculating the index.

Method

Subjects and Speech Materials. Ten young female adults with a mean age of 23.3 years and normal speech and hearing served as subjects. They were enrolled in a graduate course in speech and hearing science. One week prior to the experiment, the subjects were provided with two reading passages and were instructed to practice reading each aloud with moderate and severe degrees of hypernasality. The two passages were the Zoo passage (Fletcher, 1978), which was devoid of nasal consonants, and the first paragraph of the Rainbow passage (Fairbanks, 1960). The two passages were as follows:

"ZOO" PASSAGE

"Look at this book with us. It's a story about a zoo. That is where bears go. Today it's very cold out of doors, but we see a cloud overhead that's a pretty, white fluffy shape. We hear straw covers the floor of cages to keep the chill away; yet a deer walks through the trees with her head high. They feed seeds to birds so they're able to fly."

"RAINBOW" PASSAGE

"When the sunlight strikes raindrops in the air, they act like a prism and form a rainbow. The rainbow is a division of white light into many beautiful colors. These take the shape of a long round arch, with its path high above, and its two ends apparently beyond the horizon. There is, according to legend, a boiling pot of gold at one end. People look, but no one ever finds it. When a man looks for something beyond his reach, his friends say he is looking for the pot of gold at the end of the rainbow."

Recording Procedures. The subject was seated in an IAC booth and was fitted with a headband which supported a quarter-inch condenser microphone (Sony TCM50). The microphone was positioned approximately 12 cm in front of the lips. A miniature accelerometer (BBN piezoelectric 501) was placed on the nose, slightly above the alae, with double-sided adhesive tape. Another miniature accelerometer was placed slightly above the sternal notch with the same type of adhesive tape. The nasal accelerometer and microphone signals were amplified and recorded on a dual-channel tape recorder (Teac 1200S). The same nasal accelerometer signal and the throat accelerometer signals were recorded on a second dual-channel tape recorder (Ampex 351). While the subject produced sustained [m] and vowels, the recording levels were adjusted to insure proper recording conditions, that is, to prevent excessive overdriving as well as underdriving.

Following practice and recording-level adjustments, each subject read the first paragraph of the Rainbow passage in a normal manner and then a Zoo passage once normally, once with a moderate amount of hypernasality, and once with a severe amount of hypernasality. The order of these four reading tasks was randomized from subject to subject. In addition, prior to the reading of each passage, the subject was asked to produce a sustained [m].

Ratings of the Hypernasality. While each speaker recorded the prescribed passages, the other subjects listened to the oral reading through a loudspeaker in the sound field of an adjacent room. The listeners were provided with a scoring sheet and were asked to rate the speech productions on a five-point scale. A rating of one represented a normal reading, and a rating of five represented severe hypernasality. The intent of this perceptual task was to verify that the intended hypernasal readings were, in fact, judged to be hypernasal. Mean ratings of the three Zoo passage conditions were subsequently used to obtain a Spearman rank-order correlation coefficient between this perceptual measure and the physical measure provided by the HONC.

HONC MEASUREMENTS. The recorded signals were played back and digitized for computer analysis of the HONC distributions. The digitization procedures are illustrated in Figure 1. As seen in the figure, the nasal and the throat or voice signals were amplified, fullwave-rectified, and smoothed with a time constant of approximately 30 msec. The signals were then further amplified, quantized, and stored on a magnetic tape using a CDC 1700 computer. The analog-to-digital conversion was made via a 16-bit converter at a sampling rate of 100 times per second for each channel.

The digital tape was subsequently analyzed by a computer program which required three passes. In the first pass, the program simply produced the graphic level tracings of the sampled data so that the noise levels of the two channels could be determined by the experimenter. The tracings also allowed visual inspection of the signals to assure that no peak-clipping or overdriving conditions had occurred in the digitization process. The second pass was applied only to the sustained [m] productions, and the program calculated values of correction factor k to be used for analysis of the connected speech. The third pass, using the noise level information and values of the correction factor k obtained by the first two passes, produced HONC results in terms of distribution histograms of (1) the adjusted nasal accelerometer amplitude levels in dB, (2) the air-borne voice or throat accelerometer amplitude levels in dB, (3) the difference between the nasal and voice amplitude levels in dB, (4) the HONC ratio in percentage, and (5) a cumulative relative frequency ogive for each histogram mentioned above. The above information was obtained for each reading by each subject.

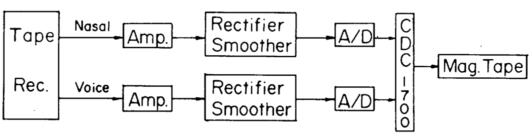

FIGURE 1. A block diagram illustrating digitization procedures.

Results

Results of HONC analysis are summarized in Table 1. In this table, means and standard deviations of the ten mean HONC values in dB obtained from the readings of the Rainbow and the Zoo passage are shown for the two methods of ratio calculation, the nasal accelerometer-to-air-borne voice amplitude ratio and the nasal-to-throat accelerometer amplitude ratio. The table shows that, on the average, the HONC values obtained by the two methods are comparable and that the simulated hypernasal readings of the Zoo passage were associated with progressively higher mean HONC values. A two-factor (2 methods × 4 readings) analysis of variance (Winer, 1971), in fact, showed a nonsignificant difference between the two methods and significant differences among the four readings. Post hoc analysis by Newman Keuls tests indicated that mean HONC values of all four readings were statistically different from each other. The mean HONC values of the normally-read Zoo passage were approximately 6 dB less than those of the normally-read Rainbow passage. The mean HONC values of the simulated hypernasal readings of the Zoo passage resulted in much greater mean HONC values than those of the Rainbow passage. The standard deviation values of the mean HONC scores indicated that there was substantial overlap of the mean HONC values of the moderately and severely hypernasal speech.

Results of the perceptual analysis showed that the mean ratings for the normal, moderately, and severely hypernasal readings were 1.93, 3.25, and 4.65, respectively. The Spearman rank-order correlation coefficient calculated between ranks of the mean HONC in dB and ranks of the hypernasal rating was 0.81. The coefficient value, although clearly significant statistically, might have been greater, had we used a more sensitive listening paradigm such as a paired-comparison method. In the present perceptual data, there were a number of ties in ranks especially at the two ends of scale, ratings of one and five. More rigorous perceptual experiments are currently being undertaken as part of a larger

TABLE 1. Means and Standard Deviations of the Mean HONC in dB for the Rainbow and Zoo Passage Readings Using the Two Methods of Determining Voice Amplitude, i.e., the Nasal to Air-Borne Voice Amplitude Ratio Versus the Nasal to Throat Accelerometric Amplitude Ratio

	Rainbow	*Zoo*		
	Normal	*Normal*	*Moderate*	*Severe*
Nasal/Voice				
Mean HONC	−16.2	−22.4	−11.7	−6.9
Standard Dev.	1.5	2.1	3.0	2.7
Nasal/Throat				
Mean HONC	−17.2	−22.8	−11.9	−7.6
Standard Dev.	2.6	2.7	3.9	2.4

project on instrumental methods of measuring nasality.

The mean HONC is only one of many potential statistical descriptions of the HONC distributional characteristics. Further insight may be gained by examining HONC distributions directly. Figure 2 summarizes the results of cumulative relative frequency ogives for HONC in dB derived from the normal readings and the severely hypernasal readings of the Zoo passage produced by the ten subjects. It is seen that the ogives for the normal reading clustered together and were clearly distinguishable from the hypernasal conditions. There were large individual variations in the ogives in the latter condition, possibly indicating that some subjects were more successful than others in simulating severe hypernasality. From the figure, it can be seen that the median HONC values (the 50% cumulative frequency) for the normal reading of the Zoo passage ranged from approximately −18 dB to less than −26 dB HONC. Similarly, the third quartile HONC (the 75 percent cumulative frequency) occurred between −16 and −22 dB HONC. For the severely hypernasal readings, the median HONC ranged from approximately −2 dB to −9 dB, while the third quartile HONC ranged from about 0 to −6 dB. The figure also shows that some ogives did not reach 100 percent at 0 dB HONC, indicative the occurrences of HONC values above 0 dB. The primary cause for such values was the fact that the average nasal amplitude levels of steady sustained [m] were not usually the maximum value. More often than not, the initial attack segments showed higher nasal amplitude levels. It was not surprising, therefore, that there were certain HONC values above 0 dB, especially when the utterance included nasal consonants. Simulated hypernasal speech apparently introduced many nasalized transients in the speech of some of the subjects. A secondary cause may be some nonlinearity in growth and decay characteristics between the nasal and the voice signals.

Average cumulative frequency ogives of HONC are presented in Figure 3, where results pooled for all subjects are given for each of the passage readings. The cumulative ogives in this figure were generated by taking the average of the ten ogives at HONC values of between −30 dB and 0 dB with a 1 dB increment. The figure characterizes the typical distributional characteristics of HONC associated with each condition, which might not be obvious in the mean HONC data in Table 1. It should also be kept in mind that, in this figure, individual variations are not indicated. As stated earlier, the variations were sizable for the simulated hypernasal conditions. Like the mean HONC, the average ogives in this figure show progressively greater nasal coupling starting from the Zoo passage normal reading, continuing to the Rainbow passage, and then to the moderately and severely hypernasal readings of the Zoo passage.

Discussion

The results of this study show that the distributional approach to the HONC index is a promising technique for assessing the magnitude of nasal coupling. In addition, use of the sustained [m] as the reference appeared to be successful in normalizing the accelerometer signals, which, otherwise, tended to vary considerably from individual to individual.

The Zoo passage, constructed by Fletcher (1978) for the specific purpose of assessing nasality, was indeed quite different from the Rainbow passage in terms of HONC distributional characteristics. Under simulated hy-

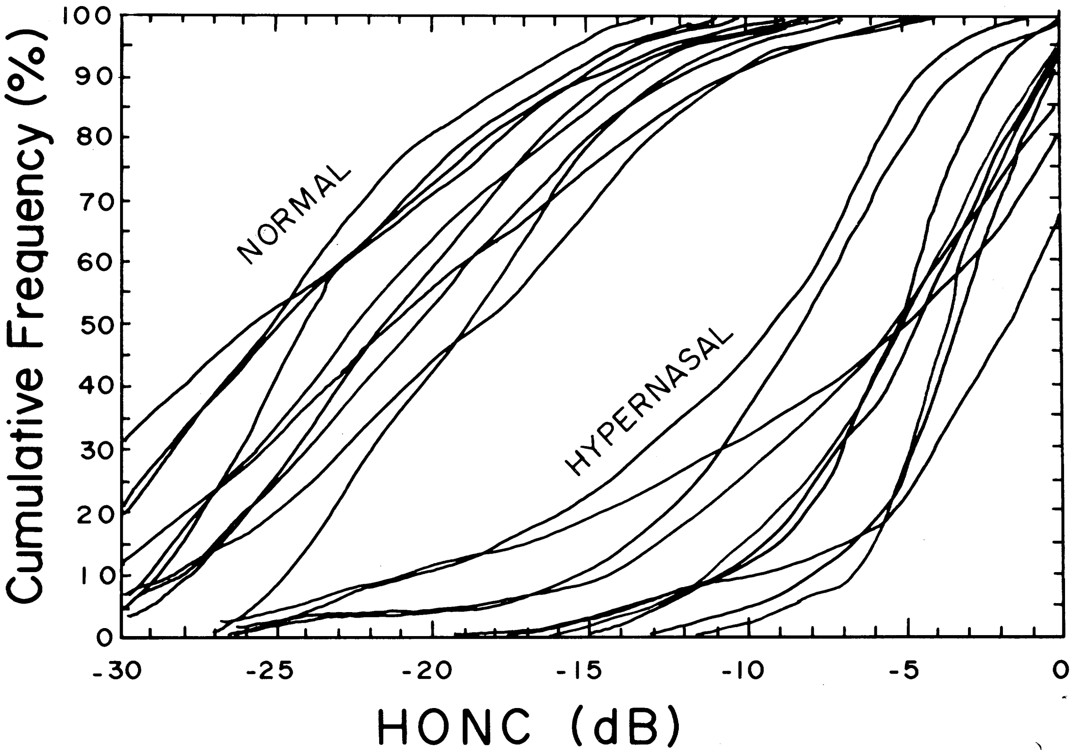

FIGURE 2. Cumulative relative frequency ogives as a function of HONC in dB derived from normal readings and severely hypernasal readings of the Zoo passage by the ten subjects.

pernasal conditions, however, the HONC distributions for the Zoo passage showed more nasal coupling than those of the normally-read Rainbow passage. These results clearly indicate that the HONC method is a viable candidate for noninvasive if indirect instrumental method for assessing variations in velopharyngeal closure.

There have been a number of essentially noninvasive instrumental techniques for testing velopharyngeal competency. These include (1) flow and pressure methods such as manometric, spirometric, respirometric, anemometric and pneumotachometric techniques (Buncke, 1959; Barnes and Morris, 1967; Quigley et al., 1963; Warren and DuBois, 1964; Warren, 1979; Hixon et al., 1967); (2) acoustic methods (Weiss, 1954; Fletcher, 1970; Shelton et al., 1967); (3) nasal vibration detection techniques such as the stethoscope, contact microphone, and accelerometric methods (Hultzen, 1942; Mease, 1961; Leeper, 1966), and (4) other techniques such as the ZIPPO method (Zemlin and Berry, 1969; Plattner et al., and Horii, 1980). Warren's method for calculating the size of the orifice using the hydro-kinetic equation (Warren and DuBoise, 1964) and his simplified oral-nasal pressure measurement device, Perci (Warren, 1979), and Fletcher's TONAR (Fletcher, 1972) are examples of fairly elaborate instrumental approaches to nasality assessment. There are advantages and disadvantages to each of these methods. A preferred instrumental method should satisfy certain criteria. It should (1) be reliable and valid, (2) be capable of analyzing connected speech as well as isolated sustained productions of speech sounds, (3) interfere as little as possible with the normal processes of respiration, phonation, and articulation and with auditory, tactile, and kinesthetic feedback, and (4) be physically and psychologically noninvasive or essentially so. From a clinical standpoint, the method should be easy to use, provide immediate results, cost little, and be portable. The miniature accelerometric approach, at its present stage of development, requires further investigation and development to satisfy these criteria. This is particularly true of validity, which can be approached through correlations between HONC results and rigorous

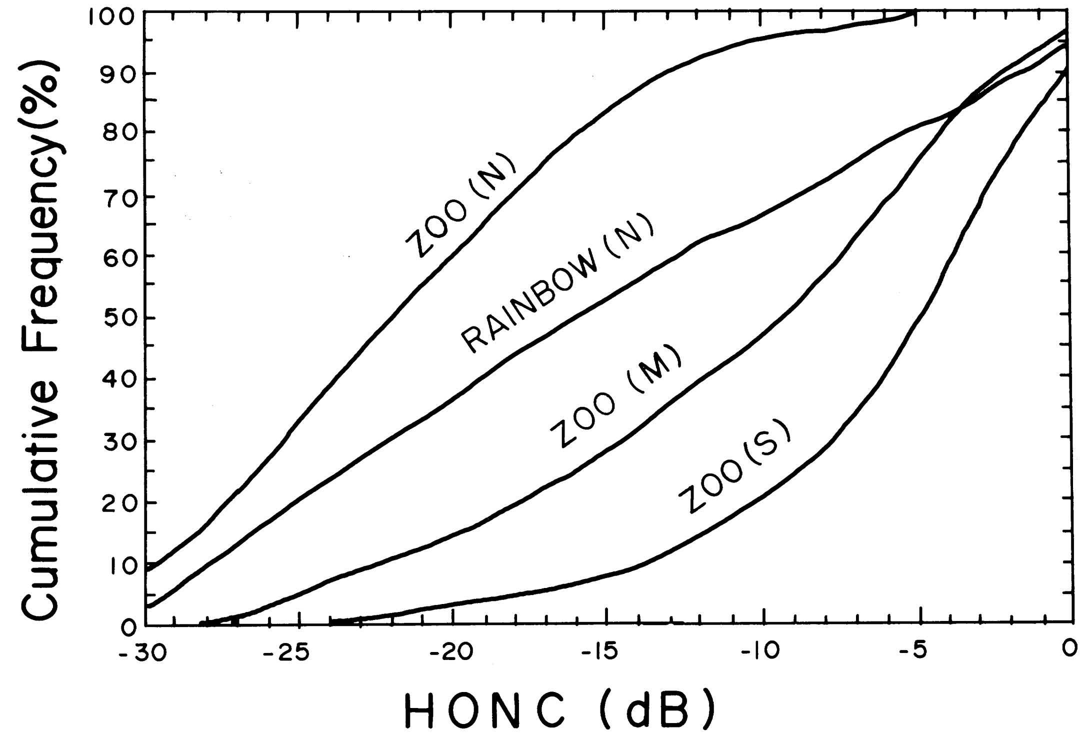

FIGURE 3. Average cumulative frequency ogives as a function of HONC in dB for the Zoo passage read normally and with moderate and severe degrees of hypernasality. An average ogive for the normally-read Rainbow passage is also shown for comparison.

perceptual analyses of the hypernasality in speech samples. To this end, a number of experiments are currently being undertaken including carefully constructed perceptual analyses of the voices used in this study. To date, the method appears to be promising when compared to other noninvasive instrumental techniques. These comparisons should, of course, be carried out formally in the future.

The two alternative methods of calculating HONC, namely, the ratio of the nasal accelerometric amplitude to the air-borne voice amplitude and the ratio of the nasal amplitude to the throat accelerometric amplitude appear to produce well correlated measures (Pearson product-moment correlation of 0.89), although specific values may be different. There are at least two reasons for the difference in absolute values as well as for the lower than expected correlation between the two methods. One reason is related to the fact that the speech segments analyzed were not identical. With the throat accelerometer signals, the segments analyzed were only voiced segments because unvoiced segments and pauses were treated as silence. On the other hand, with the air-borne voice signals, both voiced and unvoiced segments, except pauses, were analyzed as long as the intensity level was above the background noise level.

The second reason relates to the fact that the nasal accelerometer amplitude levels in dB are more linearly related to the throat accelerometer amplitude levels in dB than to the air-borne voice amplitude levels. The nonlinear relationship between the nasal accelerometer amplitude levels and the air-borne voice signals was noted by Stevens et al. (1976) and Garber and Moller (1979). Stevens et al. (1976) stated that the variation of the nasalization functions during the normal range of vocal intensity variations is on the order of a few decibels. Garber and Moller (1979) reported more specifically that there was a two-to-one power ratio between the voice and nasal accelerometer amplitudes. Such nonlinearity would certainly affect the HONC distributions derived from the nasal to air-borne voice amplitude ratio and result in absolute differences in HONC values.

The recording of an air-borne voice signal is attractive because of its wide applicability for use in acoustic and perceptual analyses. In contrast, the signal from the throat accelerometric is highly unintelligible and, of course, is present only during voiced segments of speech. Thus, the ratio between the nasal accelerometric value and voice amplitude may be recommended as the method of choice for a variety of clinical and research applications.

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