# TONAR Calibration: A Brief Note

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*Measurements were made of the frequency response characteristics of the microphone-separator components of TONAR II instrumentation.* The results of our calibration studies revealed 1) appreciable non-uniformity in frequency response of the two microphones, 2) a considerable degree of mismatch in frequency response between the microphones and, 3) dynamic interactions among microphone, separator cavity, and talker cavity resonant characteristics. Findings are discussed in terms of their implications regarding the validity of *TONAR II based nasalance* ratio measures.

Excessive nasalization or hypernasality is acknowledged to be a speech disturbance associated with velopharyngeal inadequacy. In recent years, Fletcher and his associates have developed TONAR as an instrumental approach to the measurement of nasality. (See complete list of references.)

Briefly, TONAR II is a system that " . . . makes use of separated oral and nasal signals to quantitize nasality" (Fletcher and Bishop, 1970). The principal purpose of this system is to enable the calculation of ratios that reflect the relative acoustic output emitted from the nose versus the mouth. Separation of sound emitted from the nose and mouth during speech is accomplished by two lead chambers designed to conform with general external facial contours. Individual microphones suspended in fiberglass packing are contained in both the oral and the nasal chambers of the sound separator. Speech signals obtained in this microphone-sound separator system are used to derive a numerical acoustic ratio score, expressed as "nasalance percentage." These resultant measures are purported to reflect the relative ratio of acoustic energy within selected frequency passbands emitted from the nose and mouth during speech.

We recently purchased a sound separator-microphone assembly portion of the TONAR II system. In our facility, we routinely run calibration studies on newly acquired equipment to determine whether the instrumentation is working properly. Since TONAR II is used to calculate acoustic energy ratios between oral and nasal signals, initial calibration studies were conducted to determine the frequency responses of the microphones in the oral and nasal chambers. Specific attention was directed to determining how well the two microphones were matched and how flat the responses of the microphones were over the frequency range important to speech measurement.

The testing array used to assess microphone response is illustrated in Figure 1. Under these conditions, the compressor loop provided a control voltage to the oscillator and was used to assure that the intensity of the sound field remained constant at all frequencies across the range being sampled. The compressor loop compensated for any deficiencies in the speaker and power amplifiers.

The results of our microphone testing under free-field response conditions are shown in Figure 2. The two microphones were removed from the chambers, and the microphone frequency responses were determined using a B & K model 4212 Hearing Aid Box. These data reveal that a) the response of both the oral and the nasal microphones is *not* uniform over a frequency range of importance in speech measurement and b) the two microphones provided were not closely matched, particularly above 2000 Hz. Although this initial form of evaluation was accomplished under free-field response conditions, it must be understood that the TONAR microphones are not used in this fashion to calculate na-

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salance ratios or percentages. Rather, the individual microphones are suspended in fiberglass packing and housed within the oral and nasal chambers of the sound separator to obtain nasalance measurements. The results of our microphone testing under these conditions, i.e., suspended in fiberglass and housed within the separator chambers, are shown in Figure 3. These data clearly reveal that, under these more realistic conditions, a) the response of both the oral and nasal microphones is considerably more non-uniform over a frequency range of importance in speech measurement, b) the responses of the two microphones were less closely matched than in the free-field condition, particularly within certain frequency regions (e.g., at about 2000 Hz there was a 19 dB difference in microphone

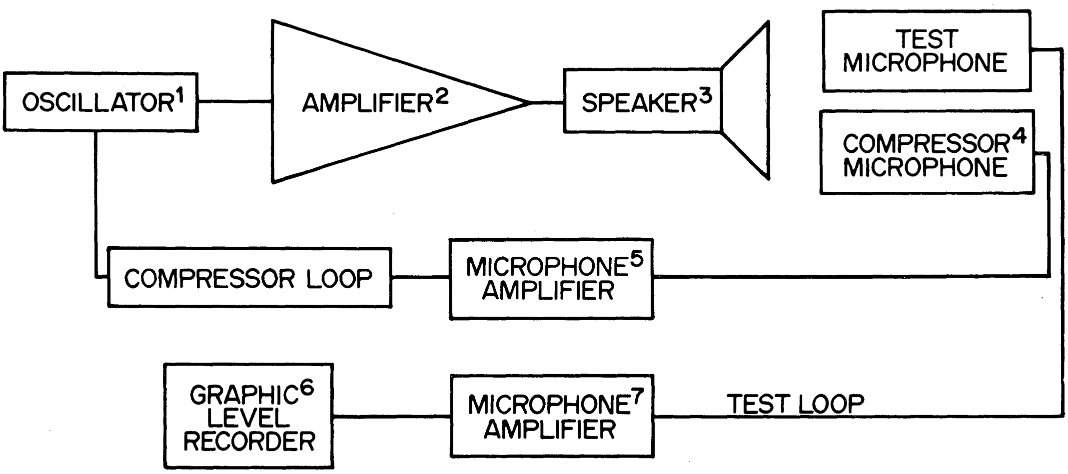


FIGURE 1. Microphone Response Test Array.

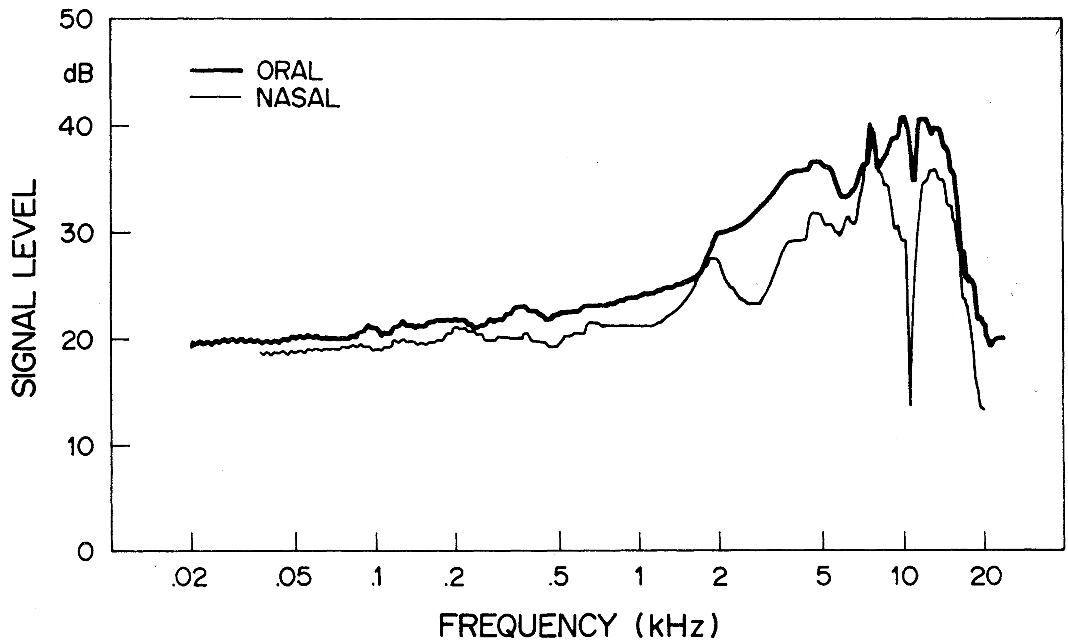


FIGURE 2. Free-field Frequency Responses of Microphones.

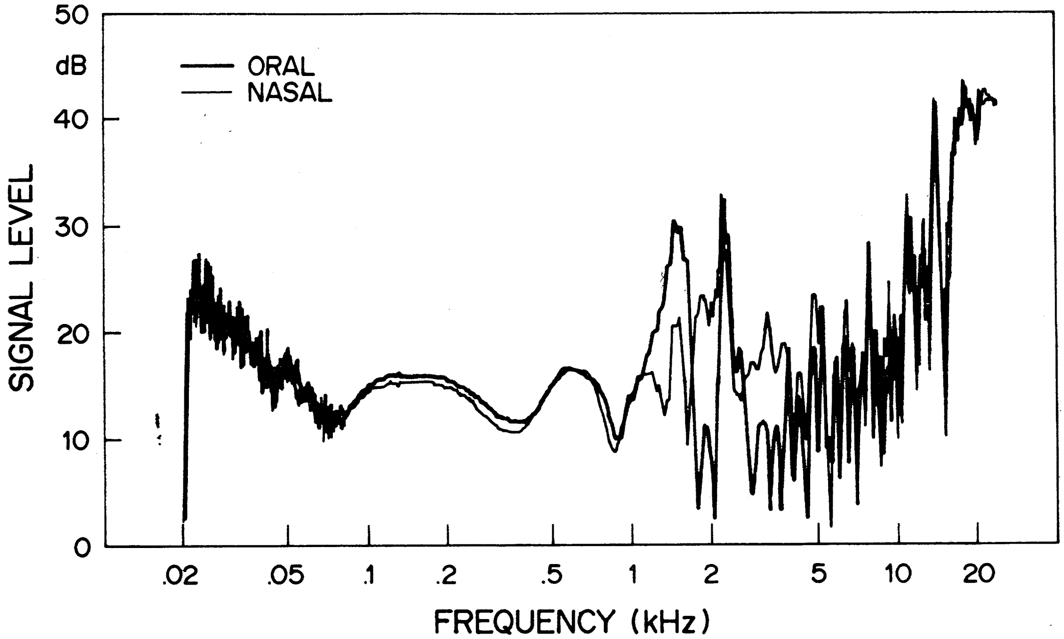


FIGURE 3. Frequency Responses of Microphones Placed in Separator.

responses), and c) the response curves revealed dynamic interactions between microphone and separator cavity resonant characteristics.

We have no way of knowing the degree to which our observations reflect the general status of microphone-separator characteristics supplied to clinicians and scientists already using TONAR II equipment or of additional equipment currently being held by the manufacturer. However, the results of our calibration studies are disturbing and would appear to have serious implications. Ratios of oral versus nasal acoustic energy calculated on the basis of the instrumentation provided to us by the manufacturer certainly would be suspect. The observed non-uniformity of separator/microphone response lead us to question what is meant by signal levels measured in either the oral or the nasal chamber.

An important issue raised by these observations concerns what is meant by average level of either the oral or the nasal signal sampled over a given time interval using TONAR II. To our knowledge, Fletcher and his colleagues have not discussed a) precisely how signal levels of individual channels were calculated or b) whether signal level calculations were preprocessed or adjusted to account for the individual channel non-uniformity and/or mismatch between channel responses. Our results clearly reveal a strong interaction between microphone response and separator cavity properties. Moreover, the data presented here also show that the properties of each cavity of the separator are different and that, consequently, a differential effect is exerted upon each of the channel responses included in the measurement system.

A complicating matter concerns the fact that, when measurements are made with TONAR II, there is an additional form of interaction when the subject places his face snuggly against the separator as speech is produced. Under these circumstances, channel response must, in part, also reflect interactions between talkers and separator cavities. The speaker-separator cavity interactions (particularly for the oral channel) clearly vary in a dynamic fashion over time as a function of articulatory maneuvers. The differential role of speaker-cavity interactions versus velopharyngeal port effects on nasalance ratio calculations are, in our opinion, also unknown, although they are of critical clinical and theoretical importance.

Published reports of measurements obtained with TONAR II have not included information of the type delineated here. Until additional information of this type is offered, we recommend that 1) persons purchasing or already using TONAR II conduct and share the results of calibration studies and 2) conclusions regarding the validity or appropriateness of TONAR II based nasalance ratios be tempered and reevaluated in light of these distressing, though acknowledgably limited, recent observations.

Fletcher (1976) has written that, "... many instrumental approaches have been used to measure facets of speech production that appear related to perceived nasality. The goals in this work were to reduce the complexities of the measurement procedures and at the same time derive scores that have more universal utility. A new instrument, TONAR II, developed during the past two decades is particularly promising in this regard."

On an instrumental level, our initial experiences with microphone calibration of TONAR II raise questions as to whether the measurement complexity and universal utility goal attributes have been compromised rather than attained.

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# Response to Article on TONAR Calibration/(Weinberg, Noll and Donohue)

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This is a response to the article by Bernd Weinberg and his collaborators concerning the characteristics of the microphone assembly in the TONAR II sound separator. I appreciate the opportunity to react to their findings.

Perhaps the best way to begin my response would be to review briefly the rationale behind the current version of the TONAR instrumentation. In preparing the specifications for TONAR II, our major concern was with contrasting oral and nasal signals in the frequency domain surrounding 500 Hz. Our studies with the prototype instrument had suggested that this is the region where closest agreement exists between listener judgments of nasality and the acoustical characteristics of oral versus nasal sounds. This finding was not surprising since other studies on this topic had tended to point in that direction.

From somewhat different orientations both House and Stevens (*JSHD*, 21:218-, 1956) and Delattre (*Phonetica*, 2:108-, 1958) had suggested that acoustic changes in the region of the first formant would likely serve as the principal cue for perceived nasality. Hattori et al (*JASA*, 30:267-, 1958) identified an antiresonance in the oral signal at about 500 Hz in all Japanese vowels they studied when a nasal sidebranch was added. Andrews (ASHA conv., 1967) observed a change in the third harmonic (420 Hz) of the vowels /i/ and /u/ when nasal coupling was introduced via a speech prosthesis with a variable aperature bulb between the soft palate and pharyngeal wall of a normal speaker. This change correlated highly (r = 0.86) with listener ratings of perceived nasality. Lindqvist and Sundberg (STL-OPSR, 1972, pp. 13-) found that when the frontal and nasal sinuses were included as shunting cavities in a twin-tube model of the nasal tract, the acoustic response curve peaked in the region of 400–600 Hz. Finally, in my studies of the relation between perceived nasality and TONAR II measures of nasal resonance, I found that as listeners improved in their perception of nasality, as reflected in increasingly homogenious ratings, their scores moved toward increasingly close agreement with the nasalance scores from TONAR II. All of these observations thus suggest that the most important region of the speech spectrum regarding nasal versus oral resonance is likely in the range specified for TONAR II. Now let's reexamine their data with that orientation in mind.

First of all, it should be pointed out that the incoming signals are band limited with 4-pole Butterworth filters to 350–650 Hz *before* the ratio is calculated; therefore the frequency components outside this range are substantially reduced in intensity. Also, since the voice spectra usually show a low frequency emphasis, the mismatch noted in the higher frequencies in microphone characteristics would be further deemphasized. The frequency responses of both microphones were found to be essentially linear to about 1500 Hz. This is well above the 350–650 range specified from our empirical studies for the calculation of "nasalance." (It might be well to add at this point that for other speech analyses use of the sound separator is not required. That is, if contrasting characteristics of oral and nasal signals are not needed, a single microphone can be used. These data could be obtained in free field condition using any high quality microphone. The recorded material could then be fed through TONAR II for a variety of acoustic analyses.) The second point that their observations appear to reveal is that in the sound separator the responses of the oral and nasal microphones would meet a ± 3 dB standard for uniformity across a frequency range from 80 Hz to near 800 Hz. Thus, in the region of primary importance for the calculation of nasalance (i.e. the 350–650 Hz range) current standards for microphone uniformity would be met although the response pattern may not be as flat as one might hope for in an ideal world. Finally, within the critical frequency range, and extending somewhat on each side of it, the microphone responses in the sound separator environment were rather closely matched. I would agree with their suggestion that if measures were compared for frequencies much beyond that range, the data would be divergent. This indicates that the manufacturers met the criteria specified but may not meet those desired by other persons for a different application.

All in all, it seems to me that their data would be consistent with the present procedure of contrasting nasal and oral signals using dual band-pass filters at a common frequency of 500 Hz and a 3 dB band width of 300 Hz. All of the normative data concerning nasalance in speech as well as the comparisons reported between perceived nasality and instrumental measures of nasalance were obtained using those criteria.

In view of the above, such statements as that on page 158 that use of TONAR II would not allow one to collect data "over a frequency range of importance in speech measurement" is rather surprising. Perhaps such statements should be "tempered and reevaluated" in light of the criteria applied for nasalance observations.

Finally, I appreciate their input and the suggestion that persons using the instrument share the results of calibration studies. I would certainly agree that much more must be learned. Improvements can then follow. It does seem to me, however, that a pretty good start has been made and that it is likely in the right direction. Of course, I will admit that I might be a bit biased in that regard.