Rethinking Nasalance and Nasal Emission

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There are a number of physiological problems that can result in speech that can be classified as abnormally nasal, where this term refers to abnormal operation of the structures that separate the oral chamber from the nasal passageways aerodynamically and acoustically (speech associated with Velopharyngeal Insufficiency or VPI). Important among these problems are deafness and a cleft palate or repaired cleft. Though the literature contains numerous attempts to evaluate VPI perceptually (Henningson, et al. 2008), there are also many attempts to evaluate and correct VPI using objective instrumental methods. We focus here on measuring **nasal airflow** in pressure consonants and quantifying n**asal resonance** problems, or hypernasality, in vowels and vowel-like consonants. The latter is also commonly referred to as nasalization. Lastly, we consider the **weak voice syndrome** that often accompanies a history of VPI (Trost-Caradamone JE, et al. 2006), presumably a learned behavior that is picked up as an individual having significant nasal escape of air in pressure consonants attempts to reduce such air escape by speaking with a reduced subglottal pressure. Of the two major dimensions of VPI, namely nasal airflow in consonants and nasal resonance in vowels, nasal air escape in pressure consonants is the more important problem in the speech of individuals with a cleft palate or a repaired cleft. Conversely, nasal resonance in vowels is the more important problem in the speech of the deaf, with or without a cochlear implant, since the degree of hearing in such cases is often insufficient to distinguish a nasalized vowel from the same vowel produced without nasality. On the other hand, proprioception is usually sufficient for a hearing impaired speaker to monitor, and if necessary correct, the production of pressure consonants.

Nasal Emission

Baken and Orlikoff (2000) accept the definition of **Nasal Emission** as the escape of air through the nasal passages when the speaker is attempting to produce a speech sound requiring significant intraoral breath pressure, such as plosives or most fricatives. We will refer to such speech sounds as the **pressure consonants**. According to Baken and Orlikoff, and we agree, “nasal emission is a fairly straightforward concept, not subject to much debate. Nasal Emission can be readily measured and displayed by means of a pneumotachograph (a system for measuring volume air flow) at the nose.” Though there is a flow of voiced airflow through the nose during a nasalized vowel, or nasal consonant, the term Nasal Emission is generally meant to refer to the effect of VPI on pressure consonants, and is not associated with vowels or nasal consonants.

Though nasal emission is easily detected and measured by means of a pneumotachograph at the nose, and there a number of commercially available systems for doing this, an inexpensive and convenient way to detect the presence of nasal emission is to look for fogging of a mirror held under the nostrils (the so-called Glatzel mirror technique).

If nasal emission is associated with some degree of turbulence at the point at which the airflow escapes into the nasal passageway, it is often referred to as Audible Nasal Emission. However, we will not be concerned here with the audibility or inaudibility of nasal emission, only its magnitude.

The NEM System

Examples of nasal emission will be shown here as recorded using the NEM system from Glottal Enterprises. The NEM System measures and displays the nasal emission of airflow by means of a wire-screen pneumotachograph mask enclosing the nose. The system simultaneously monitors and displays the speech acoustic energy as recorded from a microphone in the electronics enclosure mounted on the handle.

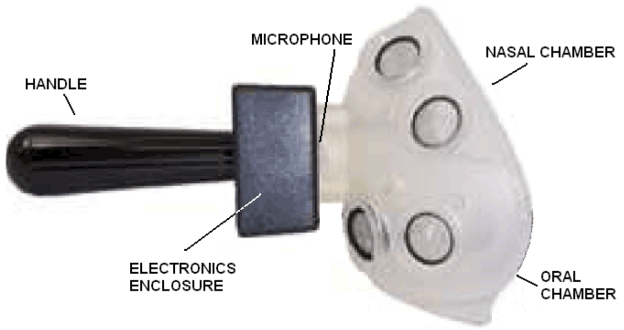

FIGURE 1. Dual chamber mask and mask handle used in the NEM system for recording and displaying nasal emission.

In the NEM software, airflow and sound level are displayed simultaneously as a function of time in a two-color chart. An example is shown if Figure 2.

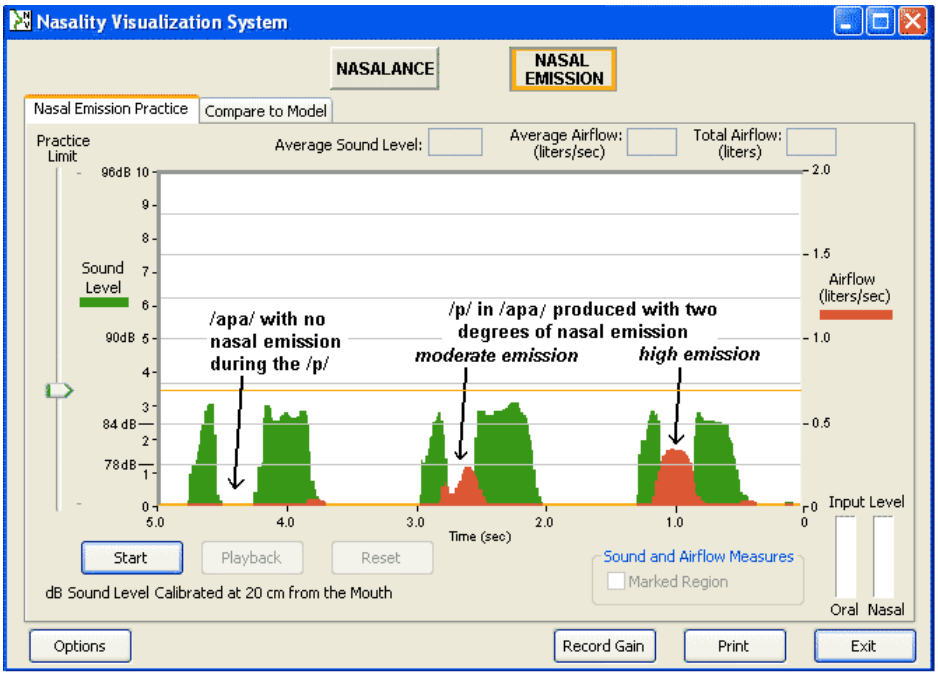

FIGURE 2. The bi-syllable /apa/ spoken with three levels of nasal emission by a phonetically trained male adult speaker. Areas in red show the level of airflow in the consonants, while the green areas show the sound level in the vowels.

> Note: Nasal Emission **does not directly reflect the area of the velopharyngeal opening.** Systems for estimating opening area more closely also record the oral pressure and compute an estimate of area from a combination of airflow and pressure. However such systems tend to be complex and expensive. For most clinical situations, airflow alone may suffice, especially if augmented by a measure of vocal effort, as in Fig. 2.

Norms for Nasal Emission – Values for nasal emission that separate normal productions and those with VPI are easy to determine from the literature cited by Baken and Orlikoff (Tables 11-4 and 11-5). In a normal production of a pressure consonant, there is little or no nasal emission. Taking into account the possibility of measurement errors, we could say that values below approximately 30 ml/s can be considered normal for adults for typical levels of voice effort (and subglottal pressure). Peak airflows above about 100ml/s during the consonant appear to indicate some degree of impairment (Baken and Orlikoff Table 11-5). The fact that there is no nasal emission in normal speech is easy to verify. Figure 3 shows an NEM recording of the sentence 'Peter piper picked peppers' and two repetitions of sa sa sa by a male adult with normal speech.

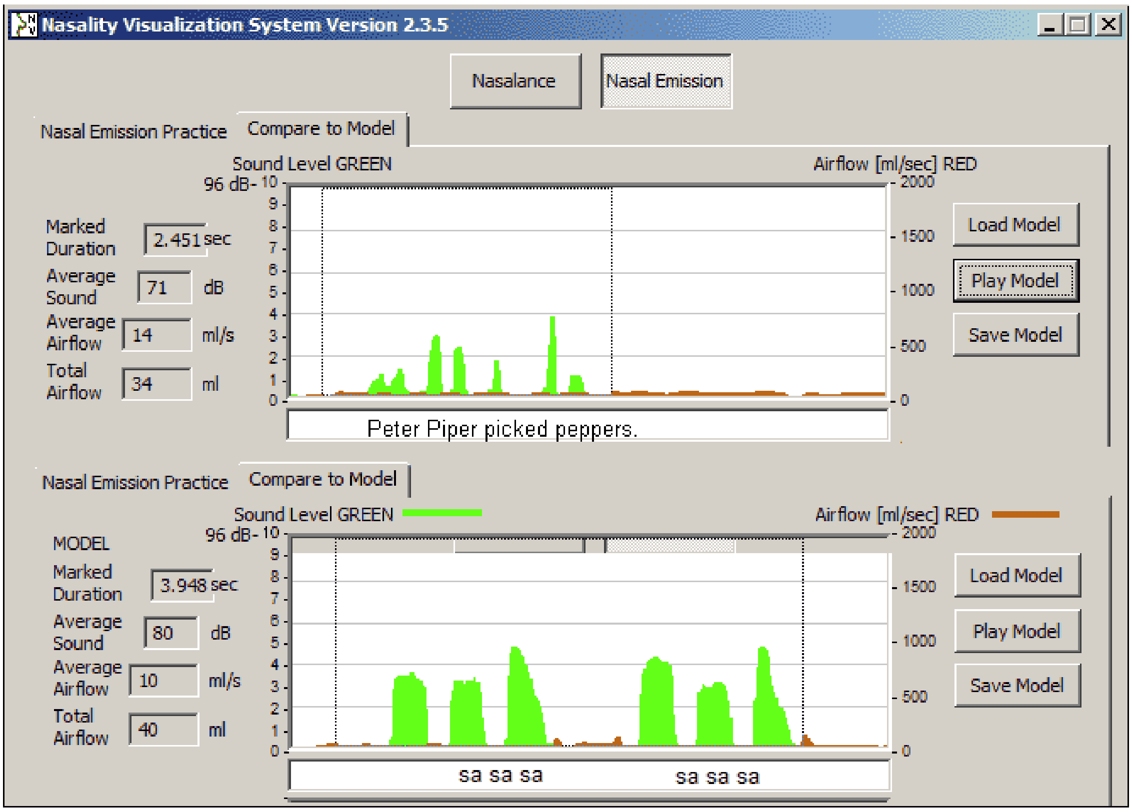

FIGURE 3. Examples showing that there is no appreciable nasal emission during pressure consonants in normal speech.

Note that there is no nasal emission recorded during any of the pressure consonants in the sentence or syllable sequences. The slight indications of nasal emission in the sa sa sa repetitions occur in the pause between the /sa/ sequences and at the termination of the final vowel and not during any of the six productions of /s/. The heights of the green areas, indicating the sound pressure level in the vowels, indicate that the speech volume was at a typical conversational level in both cases.

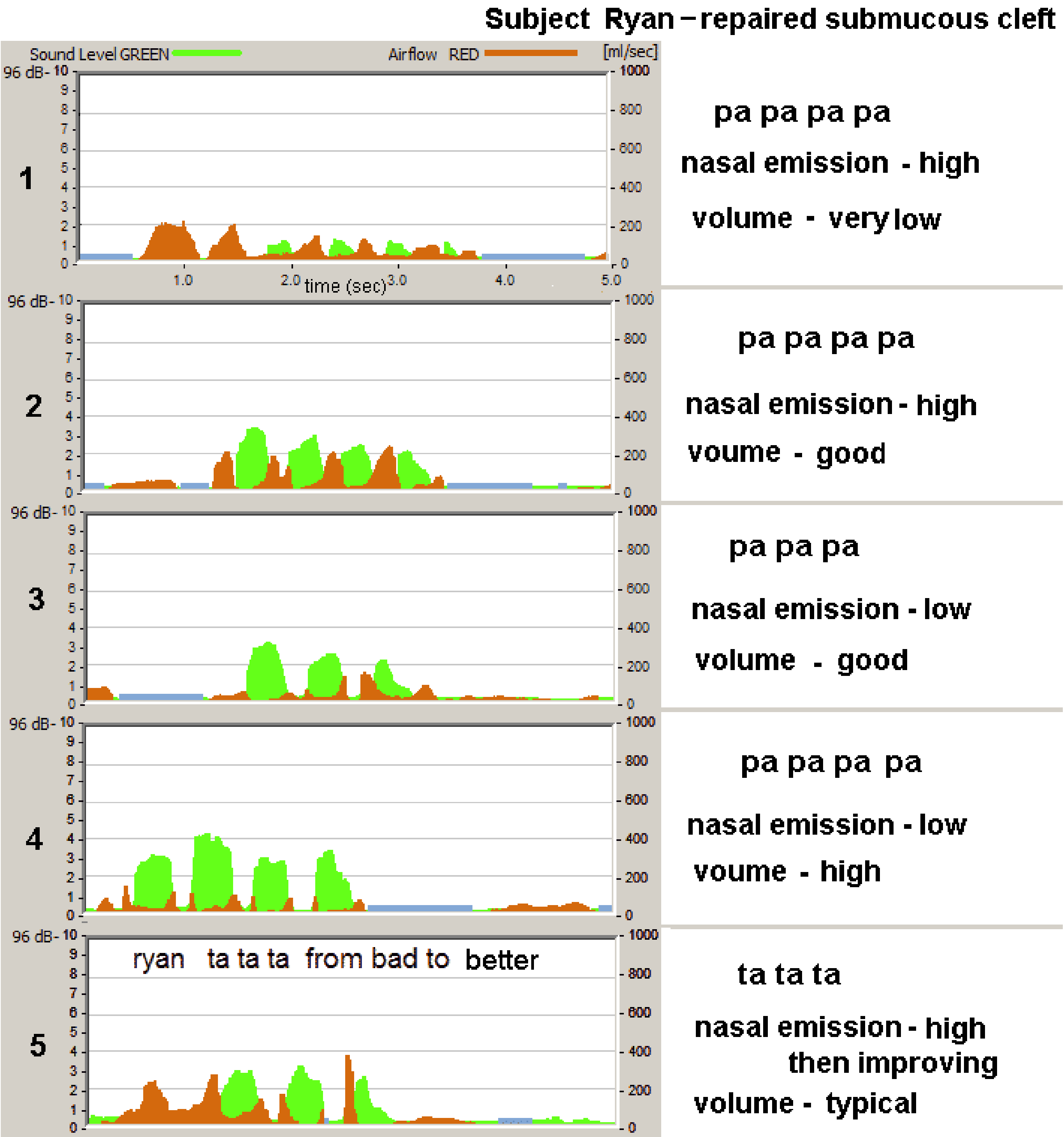

FIGURE 4. Compiled examples from the testing for nasal emission of a teen-age boy having a repaired submucous cleft.

The examples of repetitions of the syllable /pa/, going from 1 to 4, show a progressive reduction of nasal emission along with an increase in vocal effort. Example 5 shows the subject starting a sequence of ta syllables with considerable nasal emission, which decreases progressively in the second and third syllable.

Nasalance

Nasal resonance, or hypernasality, is more difficult to measure and quantify than is nasal emission, but is commonly believed to be somewhat quantified by the objective measurement called Nasalance.

Nasalance is defined as a ratio of the nasally emitted acoustic energy (N) in vowels to the sum of nasally emitted acoustic energy and the orally emitted energy (O), usually expressed as a percentage 100x (N/N+O).

In summary, nasalance measures the effect of VPI on vowels and vowel-like consonants (such as the sonorants /l/ or /r/). Since nasalance is measured from acoustic energy associated with vowels, it is not relevant to quantifying the nasal escape of air in pressure consonants (nasal emission).

The **Nasality Visualization System** from Glottal Enterprises (and an associated product **Dualview**) can measure both of these aspects of nasality, nasal emission and nasalance. [Systems that measure only nasalance, such as the Kay-Pentax version of the nasometer, measure only hypernasality in vowels. That system tells the user nothing about nasal emission.] The component of the Nasality Visualization System that measures nasalance is the NAS system.

With an appropriate handle (not shown), the NAS system can be used with the dual-chamber CV mask shown in Figure 1. The screen pictures of nasalance shown here were taken using a separator handle with a partition that is held against the upper lip and holds the two microphones and electronics. This handle is shown in Figure 5.

FIGURE 5. Separator handle for recording nasalance.

Measurement of Average Nasalance

Until recently, testing for a subject's level of nasalance has been commonly performed using one or more of the following types of test material (Categories 1 through 3) originally suggested by Fletcher and his associates approximately 40 years ago (Fletcher, et al. 1974):

Category 1. Sentences or phrases that are rich in nasal consonants. For example the "Nasally biased" sentences proposed by Fletcher, (see Baken and Orlikoff Table 11.2) and the sentences suggested in the user manual for the Kay-Pentax version of the Nasometer.

Category 2. Sentences or phrases that are rich in pressure consonants but have no nasal consonants. For example, the Zoo Passage described by Baken and Orlikoff and elsewhere.

Category 3. Sentences or phrases that are phonetically balanced as far as frequency of occurrence. For example, the well-known Rainbow Passage for English.

More recently there has been an interest in using sentences or phrases that have no nasal consonants or pressure consonants, as Hello, how are you? or Where are we? or Here we are. or I hear her. In a recent

Research Note, Zajac has referred to such productions as 'low-pressure sentences', and also mentions the English sentences (a) We were away. (b) Why were you away? (c) We were really low. and (d) We were away all year. (Zajac, 2013) We will refer to such phases and sentences as being in **Category 4**.

It is suggested by many in the literature and in the manual for the Kay-Pentax version of the nasometer that by establishing norms in the first three categories, it is possible to identify nasality problems objectively, and separate normal from abnormal speech. Let us examine each category after first defining coarticulation**.**

Understanding Coarticulation

To understand the use of Nasalance in estimating VPI, one must appreciate the role of coarticulation in speech, especially in determining nasality. The velar and pharyngeal movements that determine nasalization are not rapid (except maybe in highly trained voice users). As a result, the state of the velum and pharynx in a particular speech sound, whether it be a vowel, pressure consonant or nasal consonant, can strongly influence the state of the velum and pharynx in adjoining speech sounds. This is termed coarticulation.

NVS unique features – The examples of nasalance below were recorded using the NAS system for measuring and displaying nasalance from Glottal Enterprises, which is part of the Nasality Visualization System. To understand the graphs of nasalance shown here, it should be understood that the NAS system has two unique features that differentiate nasalance charts from those produced by devices from other manufacturers. These features can be selected by clicking on the appropriate control panel icons shown in Figure 6.

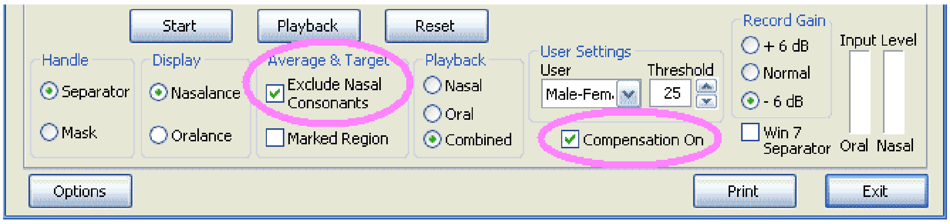

FIGURE 6. NAS system control panel with two exclusive features circled

Feature 1. The capability for excluding from an average value computation the nasalance values during nasal consonants (though not from values associated with coarticulation with such consonants). Since the velum is lowered and the oral passageway closed during a nasal consonant, the acoustic energy radiated will be all or almost all nasal, and therefore the nasalance will be close to 100% (generally above 90%). These high values of nasalance will be attained in normal speech and are not indicative of hypernasality. Including them in average value computations meant to explicate hypernasality does not make sense.

Feature 2. The capability for compensating for, in the values of nasalance displayed, much of the acoustic crossover between the oral and nasal channels. (This feature is covered by a US Patent) Activating this feature makes the nasalance in non-nasal speech closer to the theoretically expected value of zero, and the nasalance in nasal consonants closer to the theoretically expected value of 100%.

In addition, the NAS system has the capability for visually differentiating values of nasalance computed during a nasal consonant by displaying such values in another color, as in the productions of /m/ or /n/ in Figure 7. We will see examples of this in sentences or phrases in the various categories.

Category 1. Sentences or phrases that are rich in nasal consonants, as in Figure 7, obtained using a Separator Handle. (A similar result could be expected using a Mask Handle.)

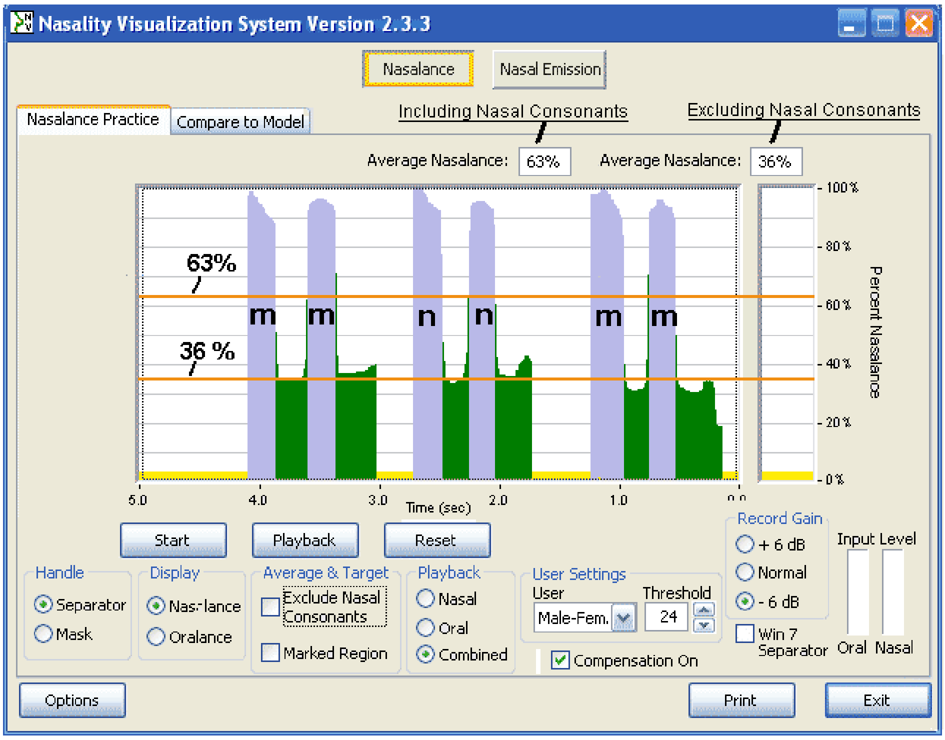

FIGURE 7. Estimating the improvement in measurement efficiency obtained by excluding nasal consonants when averaging.

In Fig. 7, the nasalance averaged over the entire chart was 63%. However, if the feature "Exclude Nasal Consonants" was selected, the average nasalance displayed was 36% (lower horizontal line), which can be seen to be a much better representation of the average value during the vowels (green areas). (Crossover compensation was used in both cases.)

Figure 8 shows a display of nasalance from a Nasality Visualization System as recorded from a normal-speaking phonetically trained adult male subject saying /ma ma ma ma ma ma/, using a separator handle. The first three syllables were pronounced with an attempt to produce a minimal nasalization of the vowels, while the final three syllables were pronounced with an attempt to produce a maximum nasalization of the vowels. The object was to see if the NVS feature of excluding the nasal consonants from the computation of average nasalance could bring a greater separation between the nasalance values for the minimally nasalized syllables (44% and 18%) and maximally nasalized vowels (60% and 30 %).

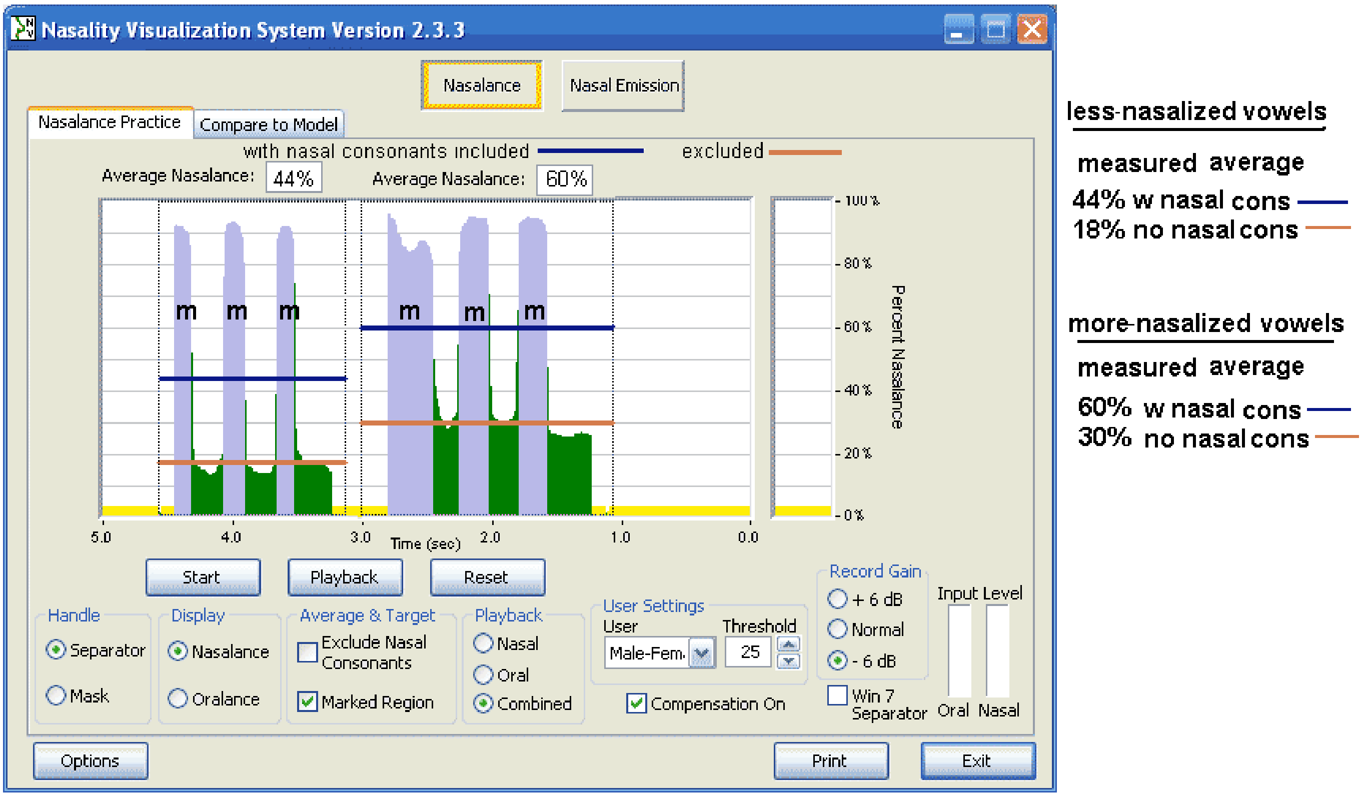

FIGURE 8. Minimally nasalized and highly nasalized vowels in a nasal consonant context, testing the effect of excluding the nasal consonants in the averaging.

When including nasal consonants in the average, the ratio of average nasalance values for the highly nasalized to minimally nasalized vowels is 60/44 = 1.36. When the nasal consonants are omitted from the average calculation, the ratio is 30/18 = 1.67. Thus the differentiation between the highly nasalized and minimally nasalized changed from changed from 1.36 to 1.67. The differentiation ratio increased by 0.31 for an improvement of 0.31/1.36, or 23%.

A caveat for singers: Some singers would like to keep vowels denasalized, even in a nasal consonant environment. With concentration and practice, such singers may be able to produce low nasalance values in a sentence with lots of nasal consonants. Some examples from a non-singer attempting to emulate the nasalance pattern of a singer are in Figure 9.

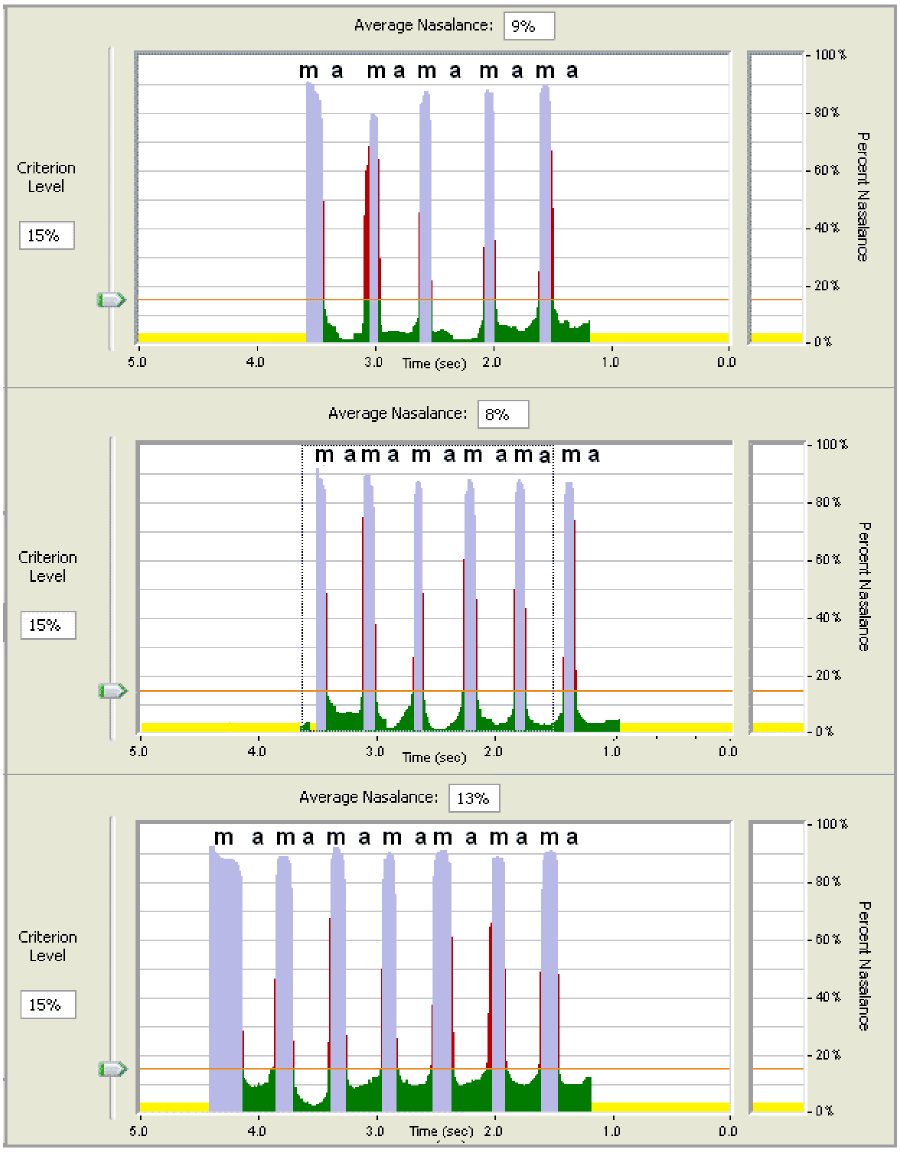

FIGURE 9 Reducing coarticulation effects from nasal consonants.

In Figure 9 one can see the effort made by this speaker to close the velum in the intervals between the nasal consonants. The nasalance values of close to 90% during the nasal consonants indicate that the subject appeared to succeed in lowering the velum and closing the oral pathway during the consonants, though maybe not completely in some instances.

Thus the feedback from this display may be useful in the training of singers.

Category 2. Phrases that are rich in pressure consonants but have no nasal consonants are illustrated in Figure 10, in which a normal speaker spoke the nonsense sequence ‘papa baba sasa’. As explained in the caption, the consonants are indicated by a yellow stripe at the baseline, the color displayed in the absence of voiced energy.

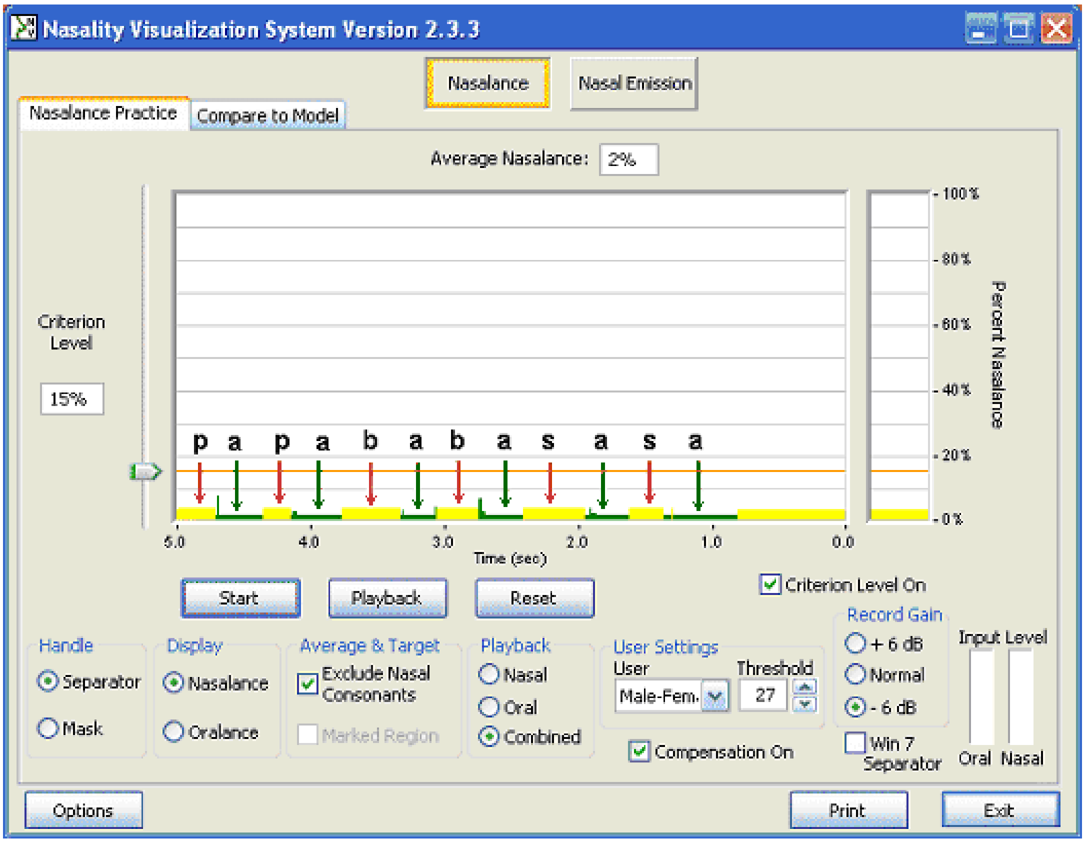

FIGURE 10. Vowels between the pressure consonants /p/, /b/, and /s/, showing a minimum of nasalance (2% average for the vowel /a/). The yellow bars indicate that the voiced energy in the oral and nasal channels at that instant was below a preset threshold and no nasalance measurement was possible. Thus these yellow bars mark the /p/ /b/ and /s/ consonants and a period of silence after the final vowel.

If pressure consonants in a sentence are produced with a good velopharyngeal closure (no nasal emission), coarticulation effects are likely to result in a good velopharyngeal closure in the neighboring vowels and a correspondingly low vowel nasalance. Thus sentences or phrases in Category 2 will generally, but not necessarily, have the lowest nasalance. Sentences or phrases in Category 2 should be considered as a training vehicle for learning to close the velum during vowels, and as a test vehicle to see if a subject has the physiological capability for effecting a velopharyngeal closure in a vowel or as the first step in training velar closure during vowels.

Nasalance will also vary with the nature of the vowel being pronounced, as is well documented in the literature cited by Baken and Orlikoff (Table 11-3). As illustrated in Figure 11, in normal speech, the vowels that have no significant oral constriction forward of the velum, such as /a/ / æ/ /e/ /ɛ/ and /ɔ/, have a similar nasalance for a given degree of nasalization, and that is near zero in the context of pressure consonants. The vowel /i/ (as in "peat") has the highest level of nasalance for a given degree of nasalization, at least in its English pronunciation.

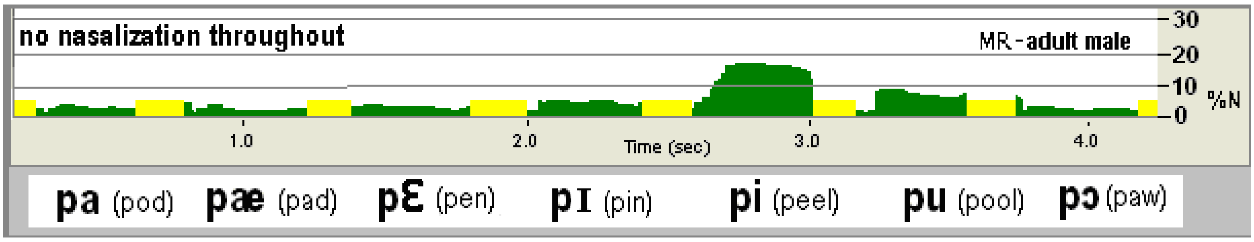

FIGURE 11. Nasalance variation among the non-diphthong vowels of English following the pressure consonant /p/. Speaker is an adult male having no hypernasality.

Though other vowels may exhibit more nasalance than the /a/ vowel, the pressure consonant environment will usually result in the minimum for that vowel (again see Table 11-3 in Baken and Orlikoff).

Note that the variation with vowel value may also result in variations between languages and between dialects of English.

Category 3. Sentences or phrases that are phonetically balanced. Such phrases and sentences contain segments during which the vowel nasalance is being increased by coarticulation from nasal consonants, a factor not related to VPI, and segments during which coarticulation from pressure consonants may be reducing the nasalance. In addition, if the nasalance analysis program used does not have the capacity to exclude nasalance values from the nasal consonants themselves, as does the Glottal Enterprises program, the average nasalance will be further increased by this extraneous factor. This is illustrated in Figure 7 above.

Category 4. Sentences or phrases that have no nasal consonants or pressure consonants

However if a person with nasality problems exhibits a low nasalance in Category 2 sentences (having only pressure consonants), it will not necessarily mean that this person's speech without pressure consonants will not be nasal. The ultimate test of a speaker's ability to speak or sing without nasalization of the vowels is the ability to produce low nasalance in sentences in which there are no nasal consonants or pressure consonants, such as the sentences "How are you? " or Where are we? in English (Category 4).

In Figure 12, a Category 4 sentence is shown spoken intensionally with 3 degrees of nasalization, by a phonetically trained normal-speaking male adult speaker.

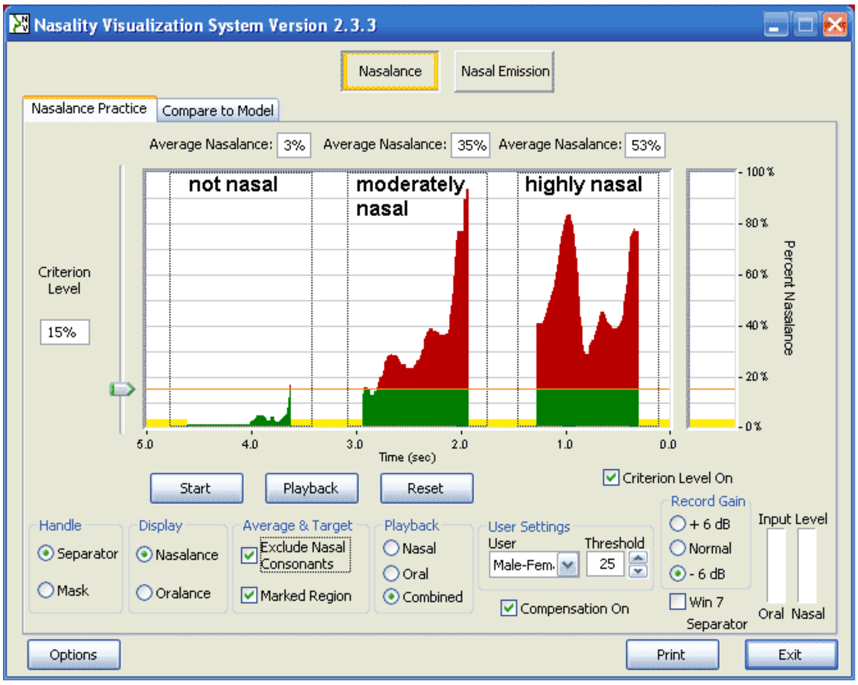

FIGURE 12. The sentence How are you?, in Category 4, spoken by a normal speaking trained linguist with 3 degrees of nasalization. Sentences were spoken separately and compiled graphically.

Nasalance can be expected to correlate most highly with the perception of nasality for sentences in Category 4, and they make the best test of a speaker's ability to control the velum without the help of pressure consonants to aid in the closure. The criterion level of 15% in Figure 12 is a suggestion for separating vowel segments that do not sound nasal (colored entirely green) from those that exhibit significant nasality (colored red above the 15% criterion level in the figure). It would be interesting and informative to test this level suggestion experimentally.

Caution: In measuring nasalance it should be kept in mind what this measure is not:

Nasalance **does not directly reflect the subjective level of nasal resonance.** There are a number of reasons for this. One is that nasalance varies with the vowel. Nasalance also is strongly affected by nasal consonant coarticulation, whereas nasal resonance is not. It is as if the listener's perception expects the increased velopharyngeal opening near a nasal consonant and ignores it when judging nasality. Perceived nasal resonance is also affected by the acoustics of the anterior nasal passages. Nasalance is not. In fact, partially blocking the nares will increase the perception of nasality and for this reason is commonly used as a test for VPI. However, blocking the anterior nares will tend to decrease the nasalance, since it reduces the passage of acoustic energy through the nose.

There are other mechanical and procedural problems in attempting to correlate nasalance with perceived nasal resonance. For example, a separation partition resting on the upper lip will register different values of nasalance depending on the positioning of the separator. This is true for all makes of nasometer. (The mask handle separator available from Glottal Enterprises shows much less of this effect. Also, perceived nasal resonance depends somewhat on voice level and quality. Nasalance values in general do not vary with voice level and quality, though the acoustic filtering of the nasal passageways could conceivably cause the spectral qualities of the voice to interact with nasalance.

Norms for Nasalance – Unlike as is the case for nasal emission, it is difficult to establish 'normal' values for nasalance in any natural speech task, given the various factors that can affect the readings, especially the co-articulatory effects described above and the variations with the vowel being spoken. Clinicians are well-advised to keep these effects in mind when treating patients, and not look for a magic procedure that will use nasalance measurements to separate a normal voice from one with VPI. On the other hand, nasalance can be quite valuable clinically in measuring and displaying intrasubject variations, since in intrasubject measurements most of the confounding variables are not present. For example, nasalance can be used for measuring the effect of surgery or therapy. Also, nasalance displays can be useful for biofeedback for patients learning to hear their own nasality or to reduce their nasality. When using nasalance in intrasubject measurements, a guiding principle is that for a given linguistic context, voice level, etc. the nasalance will invariably increase when the area of the velopharyngeal passageway increases, and vice-versa.

However, a speech task with an easily defined norm for nasalance can be constructed if the confounding variables of coarticulation or vowel value are restricted. In Figure 12, the vowel has been restricted to a single vowel in order to determine the possible effects of coarticulation with a male adult deaf speaker having two cochlear implants. Concerning the results shown in the figure, I t is of possible interest for the purpose of speech training that this speaker shows more nasalance in the context of unvoiced bilabial and alveolar stops than with voiced stops, but has no nasalance in either the voiced or unvoiced velar stops.

In the context of low pressure consonants (lalalala-example10), the subject was able to keep a good velopharyngeal closure in the first 6 syllables, however lost this ability progressively in the succeeding syllables. Again, this result may have some implications in speech training. A normal-hearing speaker would be expected to keep a good velopharyngeal closure throughout.

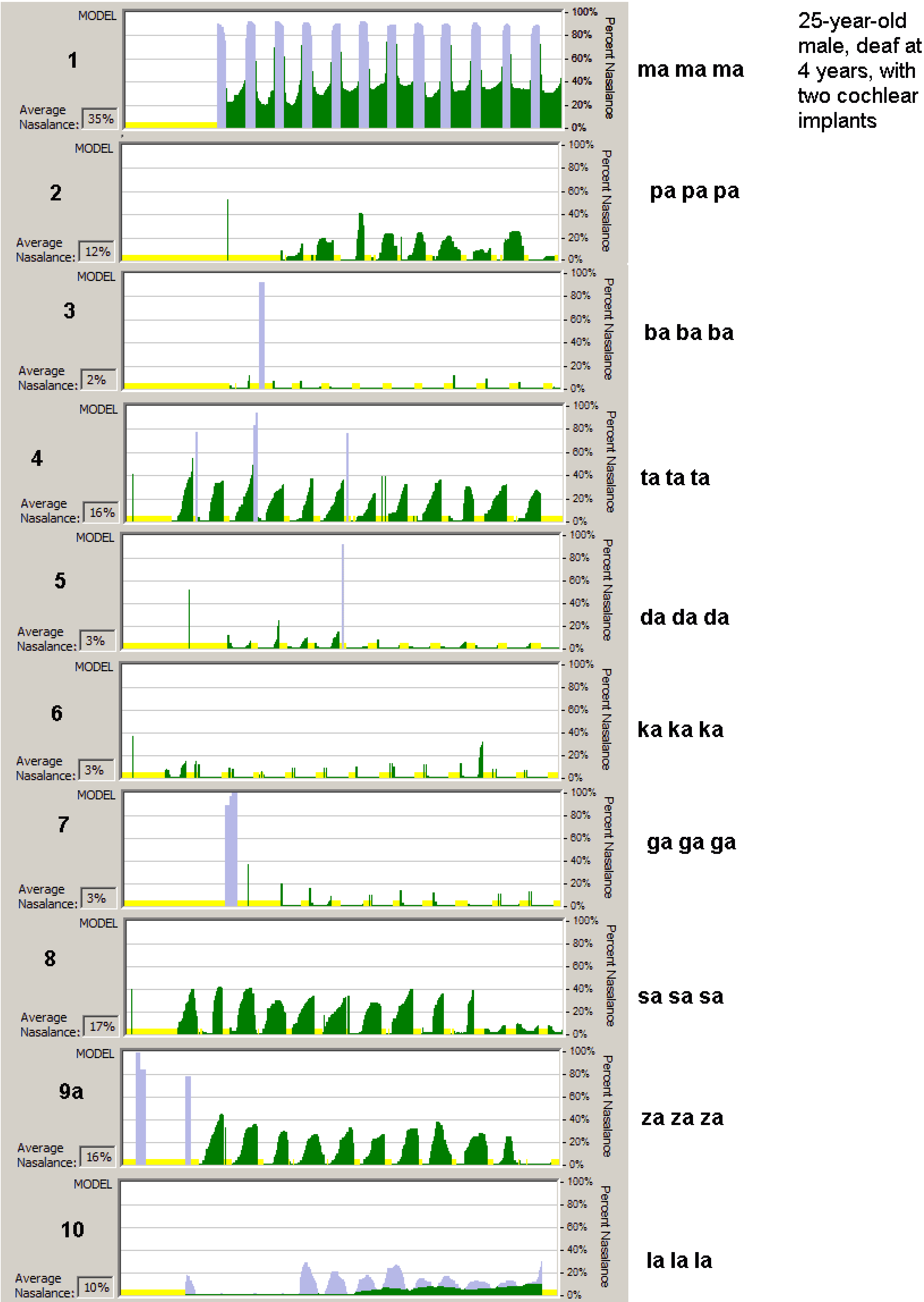

FIGURE 13. Nasalance for a deaf speaker with bilateral cochlear implants, with the vowel restricted to /a/ in order to study the effect of the consonant context prior to speech training.

As explained above, the NAS system can be set to grey out the nasality values that occur during the nasal consonants, and are not related to VPI. Thus, in Figure 13, the consonants are greyed out in the first repeated syllable phrase in which the consonant was a nasal (chart number 1). However, in a repeated consonant-vowel sequence in which the consonant is a voiced low pressure consonant other than a nasal (/l/ in the case of lalalala, number 10), increases in the nasalance unrelated to VPI are caused by the oral constrictions in the consonants.

However, in a recent innovation, the NAS system from Glottal Enterprises has the unique capacity to grey out the increases in nasalance that are caused by the oral constrictions in a repeated syllable sequence in which the consonant is a low pressure consonant (lalala). This greying out of the consonants makes the variation in vowel nasalance more clearly observed.

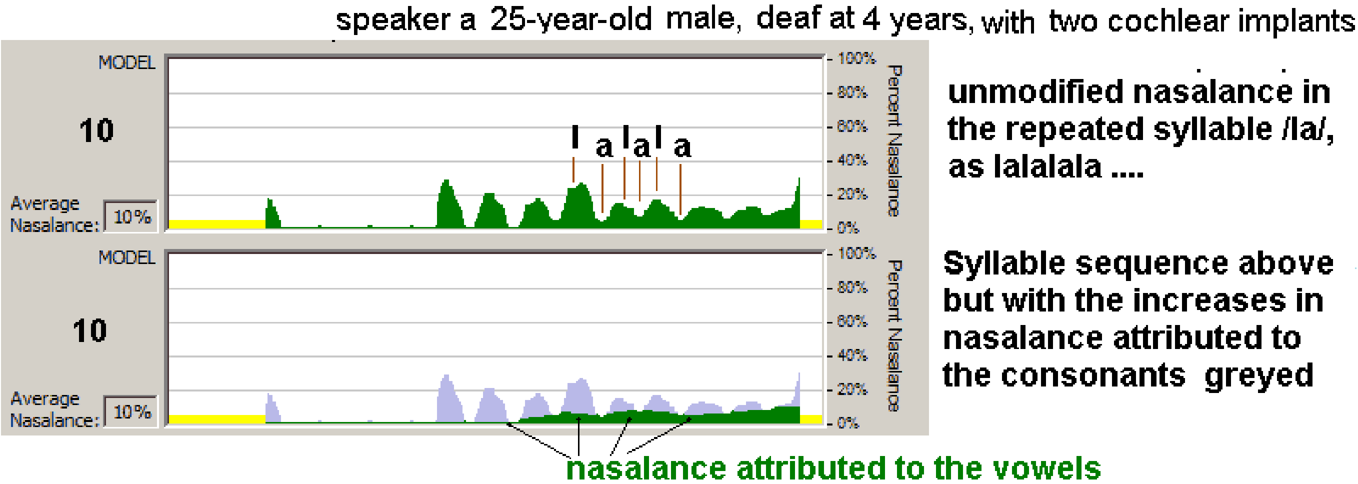

FIGURE 14. Display of lalala in NEM system explained.

In Figure 14, the unmodified nasalance in the sequence /lalalala/ is shown at the center, and after the greying out of the consonants in the bottom-most chart. The green area in the bottom chart follows and makes more visible the variation in the vowel nasalance from syllable to syllable.

Vocal Effort

As mentioned above, VPI is related to vocal effort in a complex manner, especially in the case of speakers having a cleft palate or repaired cleft. Thus analysis of the speech associated with VPI should include a measure of the vocal effort used. There are two options for this. In the option illustrated in Figure 15, the vocal effort is indicated by the sound pressure level in the vowels, shown in green on the charts. The speaker in this case was a 10 year old male child being treated for a submucous cleft. In these recordings he showed considerable nasal emission (red) during the production of /s/, whether he spoke at a low or high vocal effort. In other similar recordings, it has been found that the SPL during the vowels, as reflected in the height of the green areas in the nasal emission chart, gave a reasonable and useful indication of vocal effort that appeared to explain variations in variations in Nasal emission.

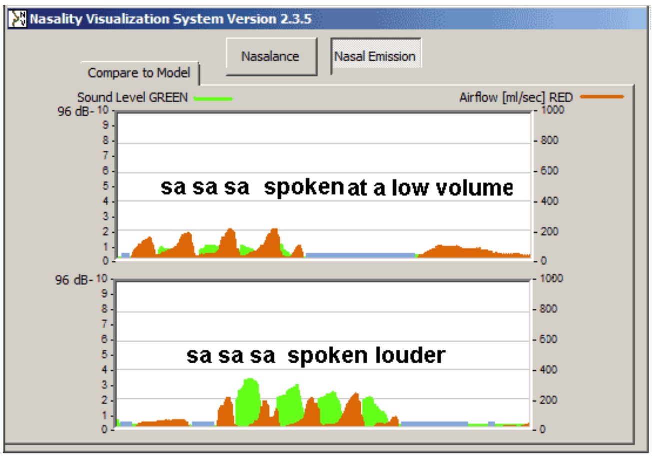

FIGURE 15. Display of vocal effort in the NEM system, as reflected in the SPL during the vowels.

The second option for monitoring vocal effort is to measure the approximate level of subglottal pressure during the utterance. Until recently, the difficulty in doing this non-invasively has made this option impractical, and therefore speech pathologists rarely considered the option. However, advances in technology have recently made available a hand-held device for providing a real-time approximation to the subglottal pressure. One version of such a device is shown in Figure 16. (Though designed for speech without VPI, it is likely that protocols can be devised for speech with VPI.)

FIGURE 16. Device for providing a real-time approximation to subglottal pressure during speech.

CONCLUSIONS

In a 2008 report, Henningson, et al. state that "perceptual evaluation remains the gold standard for evaluating (cleft palate) speech, as well as the most commonly used method". However, for over 40 years, researchers have been attempting to develop quantitative instrumental techniques to support and in some cases replace perceptual evaluation. The primary candidates have been nasopharyngoscopy, nasal emission of airflow in pressure consonants, the nasalance of vowels, and measures of vocal effort such as SPL. During the past two or three decades, advances in technology, such as miniature pressure transducers, electret microphones and inexpensive powerful personal computers that can run complex analysis and display programs in real-time, have brought improvements in devices available to the speech pathologist. Unfortunately, advances in methodology have not grown apace. For example, measurements of nasalance are still primarily made using protocols suggested by Fletcher and his associates 40 years ago (Fletcher, et al. 1974), as if these were set in stone and not just good faith suggestions.

It is argued here that, unlike the case for nasal emission, because of the multitude of confounding factors affecting a reading of nasalance, norms that effectively separate normal and defective speech are difficult if not impossible to develop using the outdated protocols suggested by Fletcher, and that unless other protocols having less variance are developed, nasalance should be restricted to intrasubject comparisons.

In the figures above we have illustrated alternative treatment of nasal consonants, both in the software and in the protocol used. We have found repeated monosyllables useful both in testing and speech training, and in measuring nasalance, we have found that restricting the vowel (as to the vowel /a/) to eliminate the variability not attributed to VPI that occurs with continuous natural speech. We also suggest that the sentences and phrases containing only low pressure non-nasal consonants be considered for testing and speech training, and that systems for displaying nasalance include a capacity for differentiating between the nasalance in the consonants and that in the vowels, as in Figures 13 and 14.

Finally, we can argue that systems for convenient and affordable measurement and display of subglottal pressure will be increasingly available, and that Speech Pathologists should become sensitive to where this component of vocal effort is important in speech diagnosis and treatment.

References

Baken, RJ and Orlikoff, RF, *Clinical Measurement of Speech and Voice 2e*, Singular, Thompson, San Diego. (2000)

Fletcher, S; Frost, I; Frost, S (1974). "Quantitative and graphic analysis of prosthetic treatment for 'nasalance' in speech". *The Journal of Prosthetic Dentistry* **32** (3): 284–291.

Zajac DJ, Nasalance of Children with Repaired Cleft Palate, *Amer. J. of Speech-Language Pathology* 22, 572-576, Aug. 2013.

Henningson G, Kuehn DP, Sell D, Sweeney T, Trost-Caradamone JE, and Whitehill TL, Universal Parameters for Reporting Speech Outcomes in Individuals With Cleft Palate, *Cleft Palate-Craniofacial Journa, Vol.45, Jan. 2008, 1-16.*

Peterson-Falzone SJ, Trost-Caradamone JE, Karnell MJ, and Hardin-Jones MA, *The Clinician's Guide to Treating Cleft Palate Speech*, Mosby-Elsevier (2006)