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Unsteady Nasalance Traces Among Sustained Vowels in Typical Adult Speakers: Prevalence & Potential Causes

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Abstract

Background. Vowels are a commonly used stimulus for evaluating speech resonance because hypernasality is best detected in vowel sounds. It was observed that steady-state sustained vowels show considerable within sample nasalance variance, although nasalance is expected to be stable for this speech target.

Purpose. The purpose of the study was to ascertain the prevalence of variability among normal speakers in steady state vowel nasalance traces and to determine the variables that predict variability.

Methods: Sixty-one participants aged 18 through 30 years were recruited. All participants were lifelong residents of the lower peninsula of Michigan with normal hearing sensitivity and no history of cleft palate. Nasalance was measured using the KayPentax Nasometer II 6450 for nasometry paragraphs, sentences, repeated CV syllables, and sustained vowels presented in random order. Variability in nasalance was evaluated for 1411 steady state vowel productions. Presence of variability was identified using standard deviation around mean nasalance and nasalance distance (maximum nasalance – minimum nasalance). All nasalance measures were transformed to rationalized arcsine units (RAU) to allow for statistical analyses of percentage data. Variables considered included individual speaker, gender, trial, vowel produced, speaker fundamental frequency, laryngeal periodicity, and signal intensity.

Results: Nearly all (92%) samples had a standard deviation around mean nasalance greater than 5%, showing greater variance than expected. Half of all vowels produced had a within sample minimum to maximum nasalance distance of at least 19% or greater, also demonstrating larger than expected variance. No significant relationship was found between within sample variation and trial, fundamental, frequency, periodicity, or gender. However, speaker, vowel, and vocal intensity were significantly related to likelihood of variability of nasalance within steady state vowel productions.

Discussion: Variation in nasalance is common in a sample of 61 healthy adult volunteers, with half of all vowels produced with a nasalance distance of 19% or greater. It is expected that variation would be more likely in clinical populations of children and those with velopharyngeal or neuromotor dysfunction. Instability of nasalance traces within steady state speech production raises concerns about interpretation of nasalance measures in clinical and research settings.

Conclusion: Sustained vowels should be considered an unreliable stimuli for measuring nasalance. Further research is needed to understand the reason for unstable nasalance in sustained vowel productions.

Background

During normal speech production, sound generated by the vocal folds in the larynx resonates in vocal tract spaces. For speech to be produced correctly, a combination of sound, airflow, and air pressure within the vocal tract is directed to both the oral and nasal cavities (Kummer, 2008). Sound produced by the larynx is modified as it travels through these spaces by the enhancement of certain frequencies as articulators shift (Kummer, 2008).

Resonance Disorders

Resonance disorders are a class of speech disorders that most often focus on perceived differences in the balance of sound, airflow, and air pressure between the oral and nasal cavities. Any obstruction in the vocal tract can also disturb oral-nasal balance and create a resonance disorder (Kummer, 2008). Hypernasality is a resonance disorder that occurs when excess sound enters the nasal cavity during speech (Kummer, 2008). Hypernasality is perceived most during vowel production. Hyponasality occurs when there is a reduction of sound entering the nasal cavity, and affects nasal consonants such as /m/, /n/, and /ŋ/ and the surrounding vowels (Kummer, 2008).

Nasalance

Nasalance is a ratio of nasal-to-total (nasal+oral) sound energy, multiplied by 100 and reported as percent nasalance (Watterson, Lewis, & Deutsch, 1998). Nasalance is typically measured during the production of vowels, glides, and liquids (Watterson, Lewis, & Deutsch, 1998). Nasalance is used as a quantitative measure to identify and assess resonance disorders (Watterson et al., 1998). Phonation, articulatory precision, age, fundamental frequency, rate, dialect, anxiety of speaker, and insufficient function of physiological structures are all thought to impact nasality or have been found to correlate with nasalance (Watterson, Lewis, Allord, Sulprizio, & O'Neill, 2007). Researchers have suggested that gender differences may be more evident in certain linguistic regions (Seaver, Dalston, Leeper, & Adams, 1991). However, other studies have found that factors that were previously thought to influence nasalance, such as gender, do not have statistical significance (Litzaw & Dalston, 1992).

Measuring Nasalance

Nasalance can be measured using the KayPentax Nasometer II 6400/6450, a commercially available system that is a commonly used method for nasalance measures (Kummer, Clark, Redle, Thomsen, & Billmire). The Nasometer is used to assess speech resonance and identifies normal and abnormal nasal resonance (Watterson, Lewis, & Tami, 2005).

Quantitative Interpretation of Resonance

There are multiple methods used to interpret nasalance measures to ascertain if a speaker's resonance is normal or abnormal. These include the use of cut-off or threshold values, boundaries set by standard deviation ranges of 1, 1.5, or 2 standard deviations, nasalance distance and ratio, and perceptual interpretation (Bressmann, Whitehill, Zeilhofer, & Horch, 2005; Imatomi, 2005; Kummer, 2005; Vallino-Napoli, 1997).

A cut-off or threshold value compares a speaker's nasalance to other speakers on a continuum (Kummer, 2008). For oral stimuli, if nasalance falls under a certain threshold value, a speaker's nasalance is categorized as normal and is abnormal if it exceeds that value (Kummer, 2008). However, Kummer (2008) stated that the use of threshold values can be arbitrary, as nasalance scores and speech characteristics are not directly correlated; nasalance does not directly correlate well with other measures of velopharyngeal function, but instead indicates whether or not a speaker falls within a specified range. As such, clinicians must understand that threshold values are not correlated with an exact measure of resonance, but rather serve as a point of comparison to normative data (Kummer, 2008). Therefore, these scores do not serve as a definitive measure of normality or abnormality, but instead allow the clinician to interpret a client's nasalance score in context with others in order to make a judgment about the existence of hyper/hyponasality (Kummer, 2008). This creates uncertainty about what can be considered "typical" or "atypical," as a provided cut-off value can be subjective (Kummer, 2008).

Additionally, there is difficulty with interpretation of nasalance scores on a normal curve distribution, related to the restricted range of percentages. Several commonly used reading passages typically yield either very high or very low mean nasalance, creating a non-normal distribution as the means approach 0% or 100% (Kummer, 2008). Other researchers have used standard deviation of a nasalance score to determine the presence of abnormal resonance. However, when Vallino-Napoli (1997) explored the utility of standard deviation of mean nasalance using three standardized reading passages, it was found that standard deviation could not be used to differentiate speakers by severity. The standard deviation measure was only useful in categorizing speakers into broad distinctions of either normal or abnormal (Vallino-Napoli, 1997).

The use of standard deviation is also problematic because of the restriction of range when mean scores approach the 0% and 100% boundaries. These floor and ceiling effects also create problems with statistical comparisons. Studebaker (1985) proposed a data manipulation to make such data more suitable for statistical analysis, called the Rationalized Arcsine Unit (RAU). This allows for statistical management of data that falls within the 0% to 15% and 85% to 100% region of a normal curve to be considered by accounting for these boundaries (Studebaker, 1985). Although this data manipulation is helpful in considering variance, it does not completely eradicate the limitations of the use of standard deviation as a method to interpret nasalance scores as a division. As indicated by Vallino-Napoli (1997), standard deviation does not provide a precise enough measure to make specific judgments about the severity of nasalance, only gross judgments.

A third method used to interpret nasalance scores is the use of nasalance distance and nasalance ratio measures (Bressmann et al., 2000). This method is useful for understanding the variability within a trace. Bressmann & colleagues (2000) have proposed the use of these measures in order to differentiate nasalance traces that show significant variability from stable traces. Nasalance distance describes the range between maximum and minimum nasalance in speech (maximum nasalance – minimum nasalance), while, similarly, the nasalance ratio (minimum nasalance/maximum nasalance) creates a proportion of the minimum to maximum nasalance (Bressmann et al., 2000). These two measures serve as a valuable measurement tool for the clinician, as they allow for each speaker to serve as his or her own reference, as opposed to other speakers (Bressmann et al., 2000).

Speakers naturally vary from one another due to differences in variables such as dialect or rate of speech; using the nasalance distance and ratio measures overcomes this problem by providing a measure with which to compare the speaker to him or herself

(Bressmann et al., 2000). Furthermore, in allowing each client or subject to serve as his or her own reference, the clinician is able to ascertain the speaker's minimum and maximum nasalance and establish what is "normal" for that speaker (Bressmann et al., 2000). Used in conjunction with normative nasalance data, these measures provide a fuller view of a speaker's nasalance and thus determine the presence of a resonance disorder (Bressmann et al., 2000). These measures are valuable in differentiate between normal and abnormal speakers, as a larger nasalance ratio or distance would be indicative of abnormal resonance, and would still be referred to the normative data to compare individual speaker variability to other speakers.

Qualitative Assessment of Resonance

Perceptual assessment is a qualitative method used to determine a measure of resonance (Imatomi, 2005). Perceptual assessment of resonance is constrained by difficulties of subjective scaling methods. Imatomi (2005) showed that ratings of resonance by trained listeners (both experienced speech-language pathologists and students) are hard to procure in a standardized manner or may be unstable if voice quality deviations are present. For example, the presence of hypernasality or a breathy voice source tends to skew ratings by speech-language pathologists, increasing the hypernasality rating score for speakers with slightly hypernasal speech and decreasing the rating of hypernasalisty for speakers who had moderately or severely hypernasal speech (Imatomi, 2005).

Vowels

Sustained vowel production would be an ideal stimulus when evaluating nasalance in a clinical setting, especially when working with children who have articulation, phonologic, or motor speech disorders. This is because vowels are easily produced by a variety of clients, and do not require rapid coordinated movements of the vocal tract (Lewis & Quint, 2000). Nasalance varies across vowels, with high vowels such as /i/ typically yielding much higher nasalance scores than low vowels such as /a/ (Lewis & Quint, 2000).

Normative data for nasalance scores of typically produced vowels in other studies indicates that there is great variance in nasalance measures among groups. A study assessing Ugandan speakers of English shows that the mean nasalance score for /a/ is 11.7%, but has a standard deviation across speakers of 8.6% (Luyten, D'haeseleer, Hodges, Galiwango, Budolfsen, Vermeersch, & Van Lierde, 2012). Mean nasalance scores for /i/ and /u/ are similarly variable, with nasalance scores of 24.1% and 17.4 % respectively and a standard deviation of 11.1% for both (Luyten et al., 2012). Repeated syllables and paragraphs tend to be less variable across speakers than vowels among English-speaking Ugandan speakers (Luyten et al., 2012). Similarly, the norms published by Kay-Pentax show greater variance for sustained vowels than for repeated syllables or paragraphs (MacKay & Kummer, 2005). The manufacturer suggests that the variance for sustained vowels can be within plus or minus two standard deviations and still be considered to be within the "normal" range. On the other hand, both the syllable repetition and paragraphs are expected to fall within 1 standard deviation of normative means (MacKay & Kummer, 2005). For example, a prolonged /a/ has a mean nasalance of 6%, with a standard deviation of 3% across speakers. Prolonged /i/ has a sample mean of 19% with a standard deviation of 9% (MacKay & Kummer, 2005). When compared to both repeated syllables and paragraphs, which use a cut-off score that does not exceed one standard deviation, more population variance is observed for sustained vowels than for other types of stimuli (MacKay & Kummer, 2005). Means provided by Kay Pentax are summarized in Table 1.

Purpose

In a study assessing the normative nasalance for typical adult speakers, we observed that many nasalance traces of steady state vowels showed considerable variability in the nasalance trace within different trials, as well as considerable variability within individual trials. Steady state vowel production is expected to yield a stable nasalance trace because no changes in velopharyngeal valve function should occur during a sustained vowel in a typical speaker. This study was designed to evaluate these observations and address the following research questions:

1. What is the prevalence of variability among normal speakers in steady state vowel nasalance traces?
2. What variables are associated with nasalance variability in sustained vowel production (e.g., vowel, speaker, speaker's gender, trial, fundamental frequency, vocal intensity)?

Materials

The KayPentax Nasometer II 6450 was used to obtain nasalance measures for each speech production. Audio files were saved for each stimulus produced and mean nasalance was hand recorded for each stimulus. The Nasometer, held to the participant's face with headgear, has two microphones that capture oral and nasal energy. Investigators checked the faceplate leveling and placement to ensure consistency across trials and readjusted as necessary throughout the protocol.

Oral and nasal signals captured by the microphones were sent to the computer, where KayPentax software calculated the ratio of nasal-to-total energy every 8 milliseconds used to calculate mean nasalance for each sample. The software also generates a visual nasalance trace.

Each participant produced vowels that were modelled by an investigator with the cue "say and hold the vowel /i/ as in 'bee' until I tell you to stop." Each participant also read repeated syllables, sentences, and paragraphs from cue cards.

Analyses

To determine the relationship between nasalance distance and other factors, multilevel regression models were used. These models accounted for the correlations among observations within participants, lab visits, and samples within visits.

Methods

Participants

Participants age 18 through 30 who had lived in the lower peninsula of Michigan their whole lives were invited to participate. Participants included 24 men and 34 women. The purpose, including the voluntary nature of participation in the study, was explained together with review of the informed consent form approved by the Human Subjects Institutional Review Board at Western Michigan University.

Participants completed auditory threshold testing at 500, 1000, 2000, and 4,000 Hz. To be included in the study, participants were required to have hearing thresholds of 25 dB hearing loss or better across all frequencies. Demographics collected included self-identified age, gender, and race, speech therapy history, and history of cleft palate. Subjects were 61 typical adult speakers, ages 18-30 years, with no history of cleft palate, resonance disorders, other speech disorders, or hearing loss.

Participants wore Nasometer headgear that placed a horizontal plate against their upper lip to separate their mouth and nose. The Nasometer was recalibrated daily. Facing away from the computer screen, in order to avoid visual feedback, participants read paragraphs, sentences, and produced a series of 14 repeated syllables. They also sustained six vowels for a minimum of 3 seconds each. These vowels were /i/, /e/, /æ/, /u/, /o/, and /a/. The order of speech stimulus type was randomized and stimuli within each class were also randomized. The entire protocol was repeated three times.

Researchers worked in pairs, one recording the mean nasalance values for each speech sample, the other administering directions to the participant. Speech samples were saved by participant code, which each participant was assigned. After all data were collected, the mean nasalance from each participant was recorded in a database. All data were double entered and checked for reliability with any data entry errors identified and corrected.

Data were organized based on several measures. First, data were sorted by standard deviation in order to determine which vowels were stable and not stable, as seen in Table 1. Data were then organized according to Bressmann & colleagues (2000) two measures, nasalance distance and nasalance ratio. Data were sorted based on the nasalance ratio (minimum nasal percentage divided by maximum nasal percentage). Data were also assessed by nasalance distance, which describes the range between maximum and minimum nasalance in speech (maximum nasalance-minimum nasalance). Both these methods sorted data based on their within-vowel variability, allowing us to understand the relationship between nasalance distance, nasalance ratio, and variability.

Data were then divided into percentiles in order to identify the tails of the distributions of nasalance stability and variance. Data was interpreted using Rationalized Arcsine Unit (RAU), a method that alters data to make it suitable for parametric statistical analysis. Studebaker's RAU method corrects for the limits imposed by the boundaries of 0% and 100% and allows for the incorporation of variance considerations for lower or upper level data within 0-15% and 85-100%. An example of both a stable trace and a non-stable trace is shown in Figure 1.

Results

Prevalence of Within Trial Variance

Steady state vowels are expected to yield stable nasalance within an individual trial. However, an examination of within trial standard deviation (S.D.) around mean nasalance scores identified 92% of samples had a S.D. greater than 5%. Nearly all nasalance traces, therefore, showed greater than expected variance. Furthermore, median nasalance distance, or the difference between maximum and minimum nasalance, was found to cluster around 19% nasalance, as seen in Figure 2. In other words, half of all vowels produced had a nasalance distance of at least 19% or greater.

Variables Associated with Variance in Nasalance

Analyses using standard deviation around mean nasalance showed that no significant correlation exists between trial, fundamental frequency, periodicity, and gender. However, Root Mean Square (RMS) intensity and participant identity were significantly related. Furthermore, mean nasalance and RMS intensity were also significantly related. The regression model used to predict nasalance distance based on trial, lab visit, vowel, and gender was significant. Post hoc comparisons revealed that /e/ and /æ/ (front vowels) had greater nasalance distances than /u/ (back vowel).

Nasalance distance tended to be consistent within participants, as participants who exhibited large distances in one vowel, trial, or lab visit were more likely to exhibit large distances in other measurements. The residual variance of 21% can be attributed to the individual participant, as the residual variance component associated with participants was 30 out of a total variance of 144.

Lab visit and trial were not predicative of nasalance distance. Given this finding, multiple observations from either multiple trials and/or lab visits can be averaged in order to ascertain a more stable estimate of nasalance distance and account for the variance of individual nasalance scores.

Typically, unstable nasalance, or high within-sample variability, points to neuromotor or velopharyngeal dysfunction. However, because half of 1411 steady state vowels produced by subjects had a nasalance distance of 19% or greater, there is too great a rate of change in nasalance to be indicative of a neuromotor or velopharyngeal dysfunction, especially as the population from which data was collected was a normal population screened for any sort of speech disorders.

Based on the significant associations between nasalance and RMS amplitude, it could be suggested that one should interpret nasalance measurements with caution unless RMS amplitude is controlled in normative data when collecting data from a patient or research subject. It appears that once RMS amplitude is controlled, nasalance measures could be expected to be more consistent for each individual's trials.

Discussion

Half of all 1411 steady state vowels produced by the typical adult speakers in our study had a within sample nasalance distance of at least 19% or greater. This much variance cannot be attributed to velopharyngeal or neuromotor dysfunction in a sample of healthy adult volunteers. It is expected that clinical populations would exhibit even greater variance than a normative population. Therefore, it is important that the difficulties with obtaining a stable sustained vowel trace are understood and accounted for prior to their use in clinical settings.

The instability of nasalance measures causes potential difficulty when considering the use of nasometry as an outcome endpoint in evidence-based practice. If the only evidence or data before and after a certain intervention are nasometry measures, the observed instability of these measures makes it more difficult to demonstrate that the intervention provided any difference.

Unsteady nasalance traces must be accounted for when collecting data in clinical settings, whether through adjusting normative data or controlling RMS amplitude to create a more stable, valid measurement of nasalance distance. Vowel selection has an impact on stability; /i/, /u/, and /a/ yield the most stable measures.

When assessing nasalance clinically, it is expected that vowels /e/ and /æ/ will have less stable within-trial variance, as these vowels were associated with greater nasalance distance. Therefore, large amounts of variance in these vowels should not necessarily be cause for alarm in a clinical population and should be compared with other, more stable vowels prior to making any decisions about clinical management. These vowels could also be averaged with other traces of the same vowel to provide a more accurate nasalance score.

Through the course of this study, it was discovered that although unsteady nasalance is significantly associated with individual participant, vowel, and RMS signal intensity, it is not related to gender, trial, periodicity, fundamental frequency, or lab visit. Steps should be taken in clinical settings to control variables that are known to have an impact on nasalance. For example, if one of an individual client's traces shows variance, it is likely that he or she will have subsequent trials demonstrating wide variance. It is important to flag speakers who tend to demonstrate variability in vowel production from the beginning, and take steps to minimize this effect, such as averaging traces. Furthermore, it is suggested that RMS signal intensity is controlled during data collection. Through the course of our study, we discovered that an increase in RMS intensity results in an decrease in nasalance distance. In other words, increased vocal intensity yields more stable nasalance. Controlling RMS intensity should be implemented into basic Nasometer protocol in the future and should be a focus of future research. Further research should also center on variables that are thought to potentially impact nasalance scores but are still unknown, such as phonation, articulatory precision, age, sex, fundamental frequency, rate, dialect, and speaker anxiety.

Conclusion

Sustained vowels must be interpreted with caution. The Kay-Pentax nasometry software allows the examiner to select a portion of a sample for analysis, so it is possible to select the most stable portion of a sustained vowel for analysis. This would allow the examiner to exclude the end of the vowel production if there is a drop in nasalance, for example. A single nasalance trace for a sustained vowel can yield dramatically different nasalance values within the sample. Thus, the examiner could unintentionally skew the findings depending on which portion of the speech sample is selected for analysis. Clinical documentation should include observations of variance within the sample and a description of the basis on which any within-vowel sample selection is conducted. Selecting one value over another can be detrimental to the client, as it may not reflect an accurate assessment of the client's speech resonance. If measures of sustained vowels appear substantively different from other units of speech (e.g., sentences), the measures of nasalance for vowels should be evaluated with caution. Until further research is conducted, nasalance measures for sustained vowels should not be used as the sole measure for clinical decisions about management of resonance disorders.

Overall, the utility of sustained vowels as a valid and reliable measure of nasalance is questionable. In a population of typical adult speakers, nasalance measured through sustained vowel production is not a dependable indicator of speech resonance. Therefore, measures of nasalance using sustained vowels should be avoided and should not be used as a sole determinant in clinical decisions. Although in other areas of variability, a solution is to average nasalance across multiple trials (Winters, 2012), the findings of the current study suggest that when variance is observed within a speaker, that speaker is likely to demonstrate variance across speech samples. Further investigation about the degree of nasalance variance in steady state vowel production should be conducted in clinical populations.

In conclusion, although the KayPentax Nasometer II 6400/6450 provides important quantifiable data that can have utility in the diagnosis of various resonance disorders, it is important that the limitations of nasalance measures are understood. Due to the wide variance and unsteady nature of nasalance traces in sustained vowels, and the variables that potentially impact nasalance distance within steady state vowel productions, it is suggested that nasalance should be used in tandem with perceptual measures and instrumental assessment methods.

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Tables

Figures and Tables

Prolonged Sounds	Norm	SD
Prolonged /a/	6	3
Prolonged /i/	19	9
Prolonged /s/	0	0
Prolonged /m/	93	3

Acceptable score: Threshold +/- 2 Standard Deviations from the mean

Reading Passages	16	5
Bilabial Plosives	16	5
Sibilant Fricatives	10	4

Table 1. KayPentax Manufacturer norms. The tables above represent the mean nasalance scores and mean SDs found in different passages used in the SNAP Test-R. The reading passages show less variance than the prolonged sounds, which allow for +/-2 standard deviations from the mean. No other component of the SNAP Test-R allows for such wide variance (MacKay & Kummer, 2005).

Subject	% of SD<5	% of SD>5
101	83.33%	16.67%
102	88.89%	11.11%
103	94.44%	5.56%
104	88.24%	11.76%
105	88.89%	11.11%
201	38.89%	61.11%
202	94.44%	5.56%
203	83.33%	16.67%
204	50%	50%
205	75%	25%

Table 2. Standard Deviation by subject. Above, an example of percentage of trials that had standard deviation less than and greater than 5 in trials for both males and females. Some subjects had at least one trial that had a standard deviation greater than 5, while some had multiple trials greater than 5. Clearly, there is variability present in individual trials.

Figures

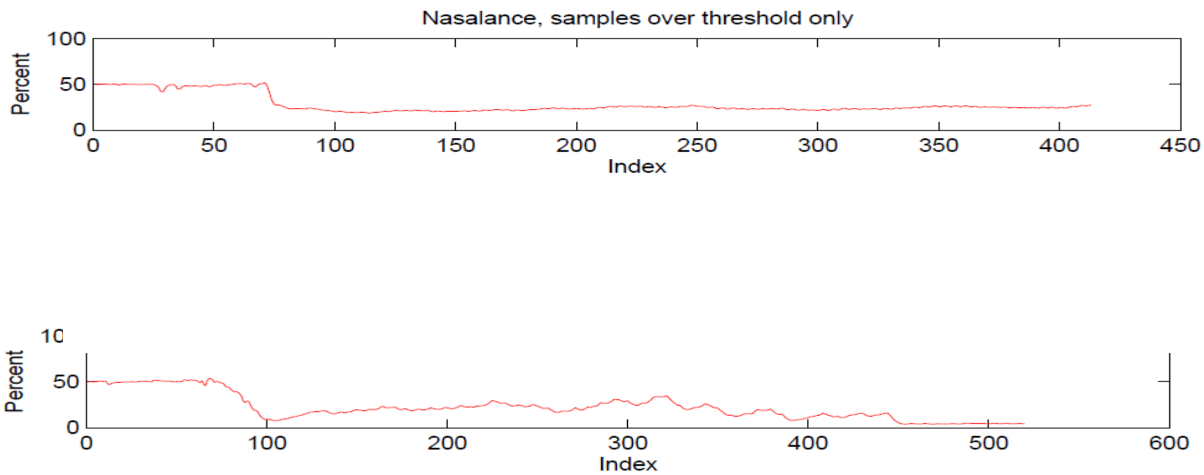

Figure 1. Stable and unstable nasalance traces. Above are nasalance traces for the vowel /æ/. The top trace shows a stable nasalance measure, with a mean of 23 and a nasalance ratio of .68. The bottom trace shows a high within-production variance, with a mean of 17 and a nasalance ratio of .11. The nasalance ratio was one of several methods, including percentiles and nasalance distance, utilized to organize traces into stable or unstable trace categories.

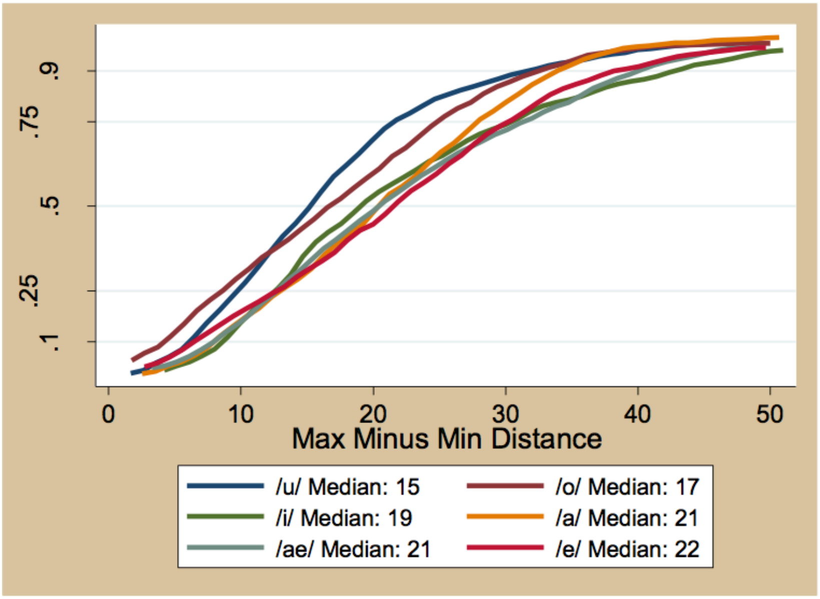

Figure 2. Cumulative distribution of nasalance distance by vowel. Nasalance distance is a measure of minimum nasalance subtracted from maximum nasalance by an individual. Here, median nasalance distance gathers around 19%, meaning that half of all vowels produced from our sample had a nasalance distance of at least 19% or greater, demonstrating great variability in a normal population.