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# Overall Nasalance versus Trimmed Selection of Stable Syllable Repetition

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**Abstract**

**Objective:** To evaluate the difference between nasalance measured using overall nasalance for the full set of syllable repetitions in a speech sample contrasted with syllable repetitions selected (trimmed) from the overall sample.

**Method:** Participants included 24 males and 34 females between 18 and 30 years of age who participated in a normative study of nasalance in Michigan's lower peninsula. Participants produced 14 syllable stimuli. Each syllable sequence was repeated at least 8 times. Three trials of each repetition were recorded together with other speech stimuli. Overall nasalance was calculated for each syllable repetition sequence (whole) and compared with the mean nasalance across 5 selected (trimmed) syllables. Syllable selection was conducted using MATLAB (Mathworks, 2011) to identify syllable onset and to select syllables 2-6 in the repetition sequence.

**Results:** Analyses indicate that the mean difference between overall and trimmed nasalance was centered around 0 with a broad variance distribution and a range of EDITEDIT. A multilevel multivariable regression ($X^2(3, N=2110) = 32.79, p<0.0005$) associated with mean differences include consonant manner class (stops, sibilants, nasals) and vowel (/i/ versus /a/) with significant differences observed for oral consonants, but not nasal consonants.

**Conclusion:** Nasalance measures are statistically different when overall sample is compared with selected syllables. In most cases, differences are small and thus not clinically significant. In a few cases, however, differences were substantial and could yield clinically relevant differences. Further research is needed to define clinical significance and to explore best trimming practices.

*Keywords:* speech resonance, nasalance, syllable repetition, speech-language pathology, nasometry, cleft palate, reliability

# Overall Nasalance and Trimmed Selection of Stable Syllable Repetition

English speech production relies upon an array of approximately 44 phonemes (Reithaug, 2002). Phonemes are distinct sounds produced through speech and are categorized as vowels and consonant sounds that carry unique information with each phoneme represented by a symbol in The International Phonetic Alphabet (International Phonetic Association, 2005).

Consonant sounds are produced with oral resonance, except for a few consonants that are produced by allowing energy transfer to the nasal cavity. The "nasal" manner of articulation is largely attributable to the physical adjustments of the velopharyngeal valve which opens to allow speech sounds to resonate in the nasal cavity. When the soft palate closes together with the pharynx, the nasal cavity is separated from the vocal tract and oral speech sounds are produced (Figure 1, University of Lausanne, 2011).

Nasal resonance is most often evaluated perceptually. Various methods for quantifying speech resonance have been developed and the least invasive of these is nasometry. Nasometry yields a metric, known as nasalance, which indicates the proportion of one's speech sound energy that is nasal versus oral. Nasalance is measured by having the participant wear a specialized baffle plate that isolates nasal and oral acoustic energy. This plate is often mounted using a headgear to allow for hands-free measurement.

Nasalance is typically expressed as a percentage that is calculated from the nasal/oral acoustic ratio, which can be expressed by the equation:

$$Nasalance\ \% = \frac{An}{(Am+An)} * 100, \qquad (1)$$

where $A_n$ denotes nasal acoustic energy and $A_m$ indicates oral acoustic energy. The value obtained from this calculation is often considered to be an objective quantification of a speech attribute (Fletcher, Sooudi, & Frost, 1974).

Nasometry was initially developed in order to meet the needs of medical and dental professionals to evaluate changes in speech as a result of prosthetic interventions (Fletcher, Sooudi, & Frost, 1974). It has since evolved into a diagnostic tool that is utilized by speech-language pathologists in diagnostics and research related to dysfunctions of speech production, speech after cleft palate repair, as well as motor speech disorders. As a diagnostic tool, normative data are needed so clinical samples can be compared to determine whether nasalance in speech is within normal limits (Dutka Souza, Pegoraro Krook, Williams, & Magalhaes, 2005; Sweeney, Sell, & O'Regan, 2004).

Technological innovations such as Fletcher's Tonar II system and its more modern adaptations have also been shown to be empirically superior to observation alone, even when experienced judges such as speech-language pathologists and plastic surgeons are utilized (Dalston & Warren, 1986). Despite nasalance's conceptual simplicity, there are a variety of models, interface settings, and calibration defaults. These can engender differences in measured nasalance.

The geographic region from which the test sample was selected also plays a significant role in the nasalance values obtained. When divided into four regions – Mid-Western, Mid-Atlantic, Southern, and Ontario – researchers found significant variances between each region in the cases of nasal sentences, the "rainbow passage," and the "zoo passage," (Appendix B: ) (Seaver, Dalston, Leeper, & Adams, 1991).Therefore, a new set of normative data must be established for each distinct population before norm-referenced score interpretations can be offered. Variation between regions may also occur, as demonstrated by the demarcations within maps displayed in Atlas of North American English: Phonetics, Phonology, and Sound Change (Figure 2) (Labov, Ash, & Boberg, 2005). Without consistent equipment norms and the corrective measurements that can be taken when normative data are available, experiments that utilize nasalance values lack reliability and external validity.

A further threat to reliability is an apparent lack of clarity in practice patterns between clinicians to measure nasalance across the overall sample or to select the most stable portion of the sample. While standard nasalance software offers the functionality to trim samples manually (reference Kay manual), there is no clear consensus on when or if this function is necessary or the impact that it has on the nasalance measures. Some view the inclusion of internal sample anomalies as a necessary part of a clinical evaluation (for example, instability could be indicative of a motor speech production disorder), while others view them as negligible incongruities from the pertinent sample data (e.g. anomalies associated with data collection and measurement).

Selecting a portion of the speech sample is particularly relevant when evaluating nasalance for sustained vowels and syllable repetitions in contrast to sentences or paragraphs, which are often treated as a whole sample. Although trimming of the speech sample is built into the KayPentax Nasometry system, little research has been conducted to determine the impact of such trimming methods on nasalance scores, and no specific clinical guidelines have been published to guide how or when speech-language pathologists should trim particular samples. Clinicians may find it difficult to find evidence-based criteria for accepting the nasalance measures for the overall spoken sample versus trimming representative portions of a sample for analyses. The purpose of this study was to determine if trimming the nasalance trace yields statistically or clinically different results from nasalance measures for the whole sample.

# Methods

## Participants and Setting

The study protocol was reviewed and approved by the Western Michigan University Human Subjects Institutional Review Board. To be included in the study, participants were required to be between the age of 18 and 30 years and have lived in the lower peninsula of Michigan for their entire lives. Once enrolled, participants were required to pass a hearing screening at 25dB HL across 4 frequencies (500, 1000, 2000, and 4000 Hz). N participants enrolled and N did not pass the hearing screening criteria and one participant indicated a history of cleft palate and was also excluded from the current analysis.

Fifty-eight adults (24 men and 34 women) completed the study. Mean age was 20.5 years (SD: 2.7 years). Of the 58 participants, none were enrolled in active speech therapy (eight had previously received speech therapy), two had been told by others that they might have hearing loss, four reported current colds or allergies, but were asymptomatic, and all were white in race. Participants attended a one-hour experimental session in a research laboratory environment.

[move the Data Collection and Procedure to here]

## Instrumentation

A hearing evaluation was conducted to establish thresholds in both right and left ears to ensure audibility at a minimum presentation level of 25 decibels (dB HTL) across 500, 1000, 2000, and 4000 Hertz (Hz). This evaluation was conducted using a Grason-Stadler Instruments

(GSI) 61 Clinical Audiometer with TDH-50 supra-aural headphones. Hearing threshold levels were recorded for all frequencies tested for both right and left ears.

**Hardware**. Nasalance measures and multichannel wav file recordings were obtained using the Nasometer II 6450 (KayPENTAX, 2010). The baffle plate was attached to the participant with a headgear that allowed a hands-free and consistent microphone placement across trials (see Figure 3). Microphones are mounted on each side of the plate to capture of nasal and oral speech sound energy. These microphones each feed a signal to a laptop computer, and the Nasometer II software calculates a ratio of nasal energy to the sum of oral and nasal energy and expresses this measure as a percent nasalance score. Wav files for each stimulus were saved for later analyses.

**Software**. For this study, Nasalance was calculated using a custom MATLAB routine that operated on stored WAV files stored by the Nasometer II. Software was developed to identify syllable onset, select the 2$^{nd}$ through 6$^{th}$ syllable repetition (shown in Figure 4), and calculated mean nasalance across the 5 selected syllables. Nasalance data were imported into Stata (StataCorp, 2013) for descriptive and inferential analyses.

**Data Collection and Procedure**

Participants completed a demographics form (Appendix A: Forms) to identify their age, gender, self-identified race using United States Census definitions, history of cleft lip or palate, history of receiving speech therapy, and self-reported indicators of hearing trouble.

Participants then completed pure tone threshold testing using the procedures described in “Instrumentation.” Participants who met the hearing screening requirement for inclusion were then fitted with the nasometry faceplate and headgear. The participant sat so the computer monitor was not visible, and was asked to say, read, or repeat

A. Paragraphs – 4 paragraphs

B. Sentences – 5 sentences

C. Sustained vowels (minimum of 3 seconds per vowel) – 6 vowels

D. Syllable repetition – 14 syllables (Appendix B: ):

Presentation order for paragraphs, sentences, and vowels were randomized, but syllable repetition always occurred last. Presentation order of each speech task within each language-level category was also randomized. Participants were asked to produce repeated syllables (e.g., /papa/) a minimum of 8 syllable repetitions. Each task was repeated 3 times.

The custom MATLAB (Mathworks, 2011) function automated the identification of syllable onset and selection of 5 consecutive repetitions (syllables 2-6) within each sample, reducing inconsistency between participants and clinicians when trimming samples; Figure 4 exemplifies a typical situation in which this practice may be implemented. This study utilizes this method in comparison/contrast with the practice of taking the overall nasalance output given by the software – in this case, the Nasometer II 6450 – in an effort to estimate differences between trimmed and overall nasalance.

**Data Analysis**

Following MATLAB parsing, data from both trimmed and untrimmed samples were exported into a spreadsheet. Nasalance given as percent nasalance was converted into rationalized arcsine units (rau) to overcome boundary limits of a 0 to 100% scale and allow for more robust statistical comparisons, particularly for data nearing the upper and lower 15% of the scale so

$$R = 1.46\left(31.83098861\left(\arcsin\left(\sqrt{\frac{X}{N+1}}\right) + \arcsin\left(\sqrt{\frac{(X+1}{N+1}}\right)\right) - 50\right) + 50, \qquad (2)$$

where R is the result expressed in rationalized arcsine units, X indicates “the number of samples observed to be positive (or negative) with respect to the characteristic tested,” and N is the total sample (Studebaker, 1985). Conversion to rau was calculated in Stata, and the data, in rau, were compared using a maximum-likelihood multivariate regression model controlling for repeated trials.

## Results

Comparison of the Nasometer 6450 system nasalance outputs were correlated with overall nasalance calculated using the MATLAB software and yielded a correlation of $r=0.999$ (Figures 5 and 6). This finding verified that overall nasalance, as calculated by MATLAB, could be considered equivalent to the data generated using the KayPentax Nasometry system software.

Differences in nasalance between trimmed and the overall sample centered around 0 rau with a range of -30 rau to +18 rau across all independent observations. Comparisons of trimmed syllables 2 through 6 with the overall nasalance for the sample was conducted using a maximum-likelihood multivariable regression analysis approach controlling for consonant class. This comparison yielded a significant difference between these measurement approaches (Wald $X^2(3, N=2110) = 32.79$, $p<0.0005$).

Significant differences were found for stops ($p=.002$) and fricatives ($p < .001$) and both showed the same direction of change with trimmed samples having lower nasalance. Syllables with nasal consonants yielded change in the opposite direction with an increase in nasalance associated with trimming, but this change was not statistically significantly different ($p=.123$). Syllables with nasal consonants have differences that vary upwards by 0.15 rau, stops declining by 0.27 rau, and fricatives declining by 0.43 rau, on average, and p-values < 0.0005, as can be seen in Table 1. The 95% confidence interval of these consonant classes are [-0.0394, 0.3303] rau, [-0.4479, -0.0985] rau, and [0-.6149, -0.2435] rau, respectively. A comparison of observed differences by vowel height is shown in Figure 7.

## Discussion

The results of this study show that nasalance sample trimming yields statistical differences when compared with nasalance obtained from the overall sample. Specifically, trimming results in decrease in estimates of nasalance for syllables with stops and fricatives. Clinical significance is more difficult to determine, with great variation depending on subject matter as well as an inherent difficult in quantifying what some consider to be a subjective matter (Jacobson & Truax, 1991; Reed, Lynn, & Meade, 2003). There is no definitive consensus for preexisting criteria to determine whether a change would be substantial enough to influence clinical classification as typical or atypical. For instance, fricatives show a slight decrease (-.43 rau). Since nasometry measures are reported in whole numbers, fractions of a percent differences are unlikely to alter clinical interpretation. However, some authors rely on a “cut-off” value to classify speakers as having normal or abnormal resonance. As speakers near these thresholds, slight changes in nasalance could impact clinical determinations. .

**Implications**. These findings provide evidence that clinicians and researchers should specify measurement methods when reporting nasalance values in clinical or research reports. Trimmed data omits portions of speech samples that may or may not reflect the speaker’s typical speech. One may argue that samples should be trimmed to ensure that the speech sample represents the speaker’s most consistent effort; however, it can also be argued that how a speaker produces the whole sample is of clinical interest because irregularities at speech onset or offset may indicate dysfunction. In either case, the time and, therefore, cost required in implementing trimming procedures may be considerations.

The results of this study are based on speech samples taken from typical adult speakers from one geographic region. Additional studies should include speech of children and clinical populations of interest to evaluate the capacity of the MATLAB software to identify syllable onset in less stable speech samples and to assess the impact of trimming on these samples. The effect of trimming may be underestimated in adults with relatively stable speech patterns. These participants were instructed to stop syllable repetitions, most often after recording had been stopped. This is in contrast to clinical sample collection in which the recording often extends through the end of the client's production. It is observed that speakers may exhibit excess nasal energy bursts at the onset and natural offset for speech, thus it is likely that the findings of the current study underestimate the impact of trimming the sample, particularly for syllables produced with oral consonant sounds.

The findings of this study suggest that trimmed nasalance samples are statistically significantly different when compared with results measured using the overall speech sample. Future studies should be conducted to determine whether these observed differences are clinically significant, particularly in clinical populations. Future research should also address specific procedures for trimming speech samples to measure samples that are best representative of the speaker's speech.

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## Tables

| **Consonant Category** | **Marginal Mean** | **Standard Error** | **z** | **P>\|z\|** | **95% Conf. Interval** | |
|---|---|---|---|---|---|---|
| Nasals | 0.1455 | 0.0943 | 1.54 | .123 | -0.0394 | 0.3303 |
| Stops | -0.2732 | 0.0891 | -3.07 | .002 | -0.4479 | -0.0985 |
| Fricatives | -0.4292 | 0.0947 | -4.53 | < .001 | -0.6149 | -0.2435 |

**Table 1. Marginal mean difference between trimmed and whole nasalance by consonant class in syllable repetition tasks.**

## Figures

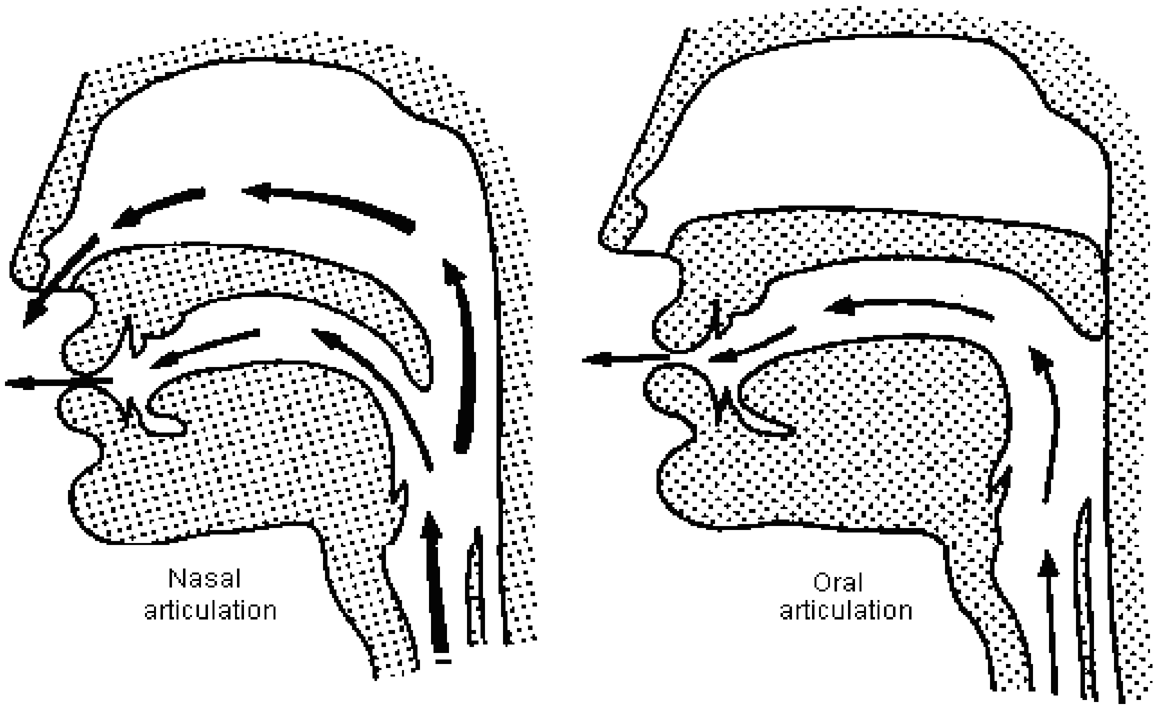


**Figure 1. Depiction of directional power output in nasal articulation (left) and oral articulation (right) (University of Lausanne, 2011).**

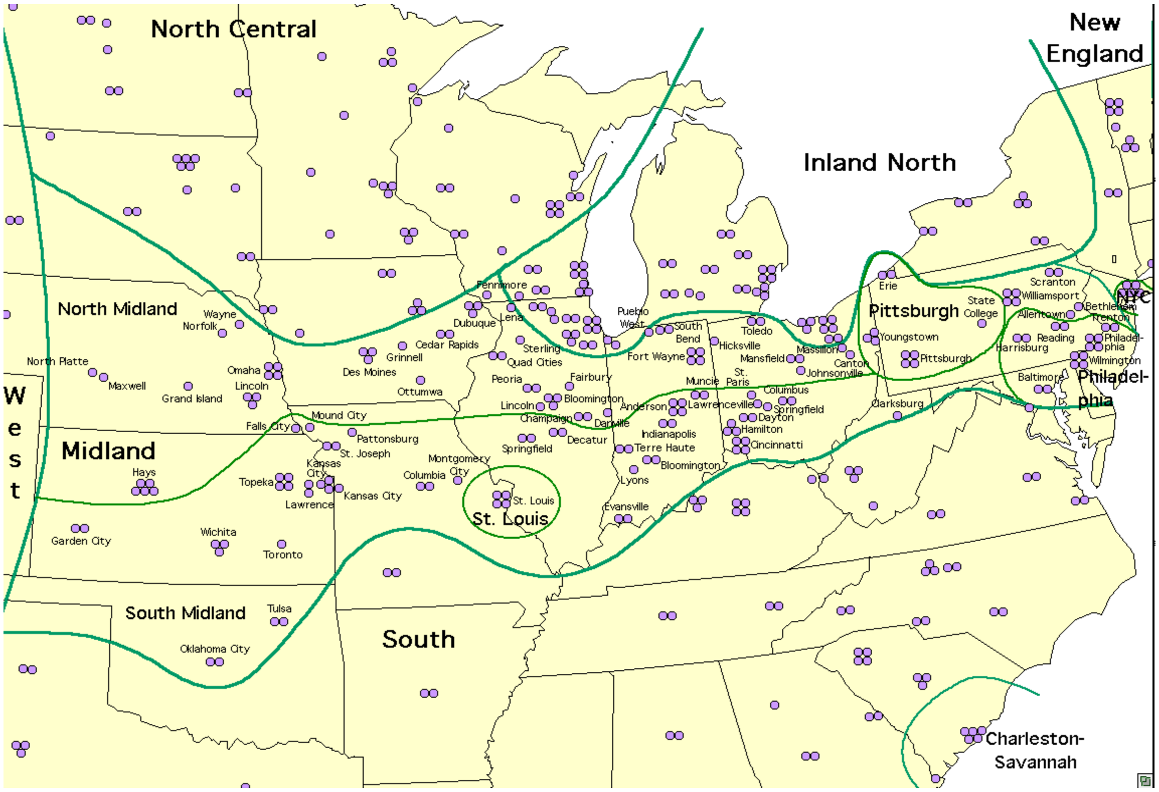


**Figure 2. Map of Inland North regional dialect for North America (Labov, Ash, & Boberg, 2005).**

**Figure 3. Nasometer II 6450 headset with plastic seal in typical configuration above upper lip on male participant.**

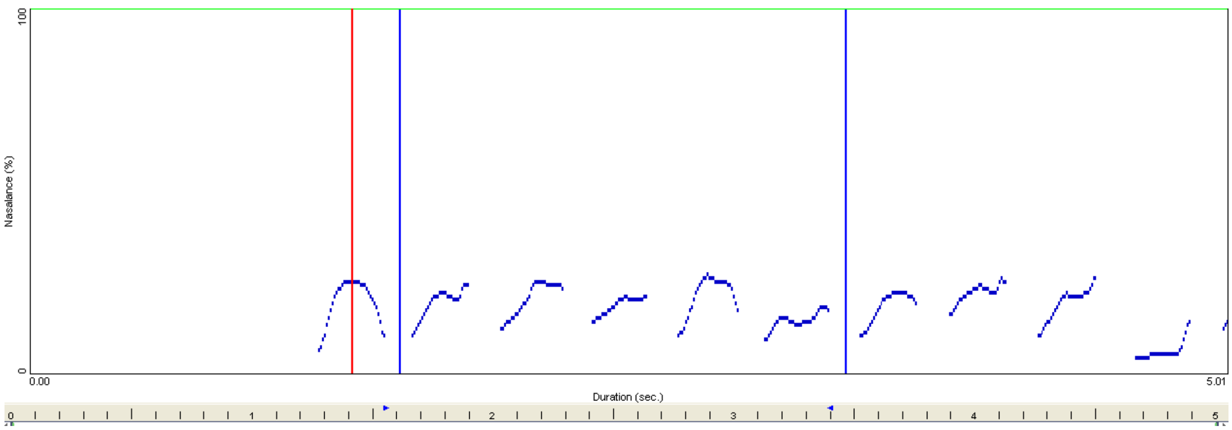


**Figure 4. Example of a MATLAB-style trim of stable syllable repetitions 2-6, denoted by blue bars, while omitting syllable 1, which appears to be a burst, indicated by the red bar, as well as the end of the sample, which appears to taper (KayPENTAX, 2010).**

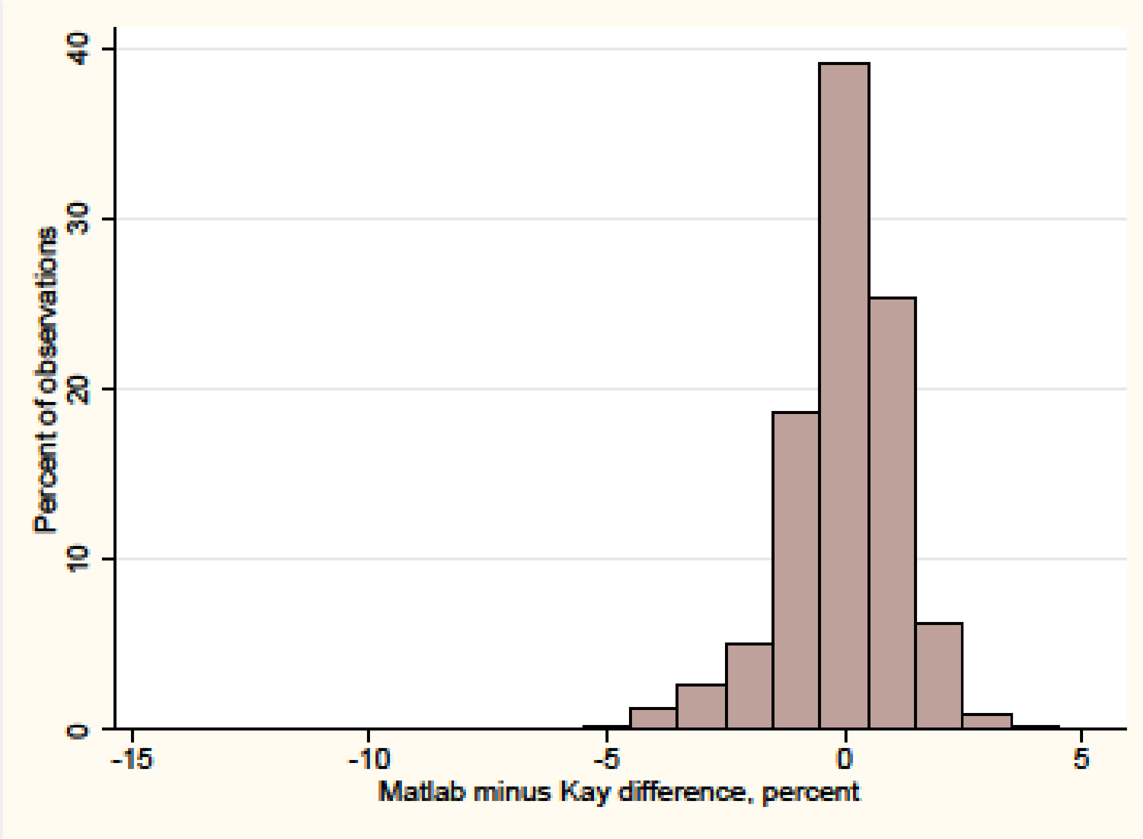


**Figure 5. Frequency histogram of MATLAB nasalance differences minus Kay nasalance differences, expressed in raw percentages.**

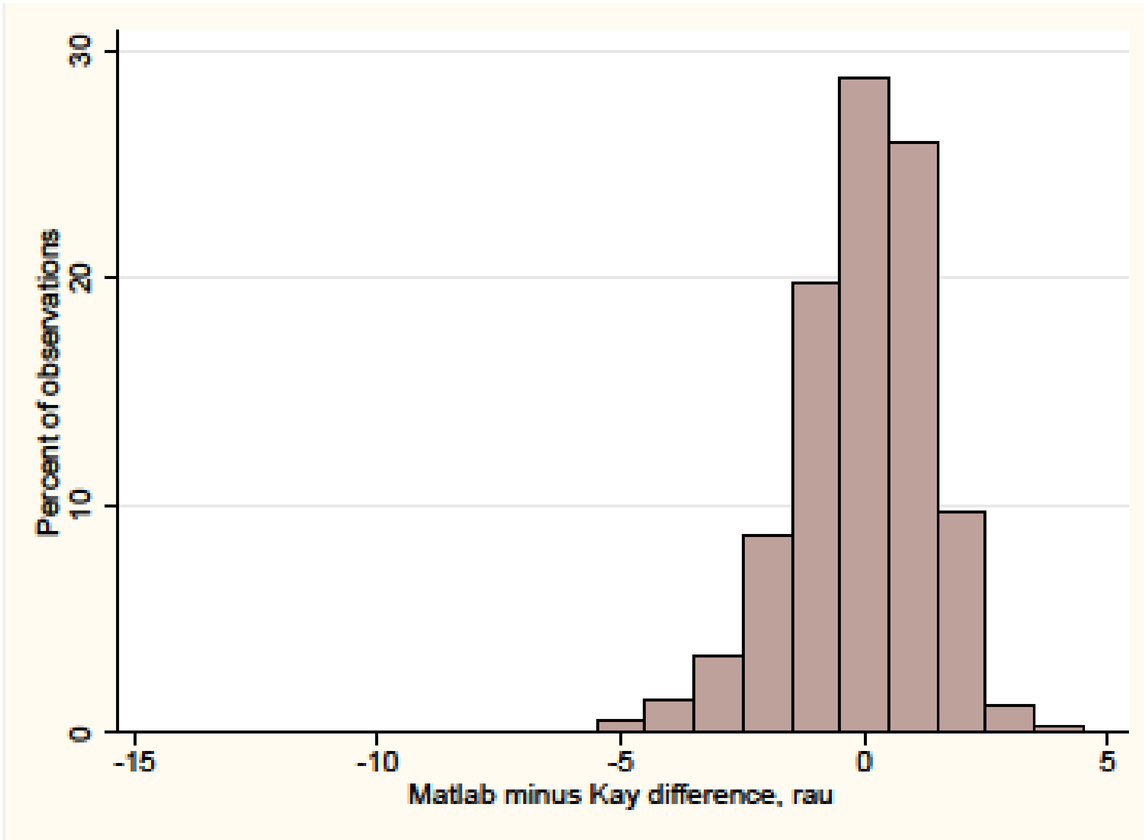


**Figure 6. Frequency histogram of MATLAB nasalance differences minus Kay nasalance differences, expressed in rationalized arcsine units (raus).**

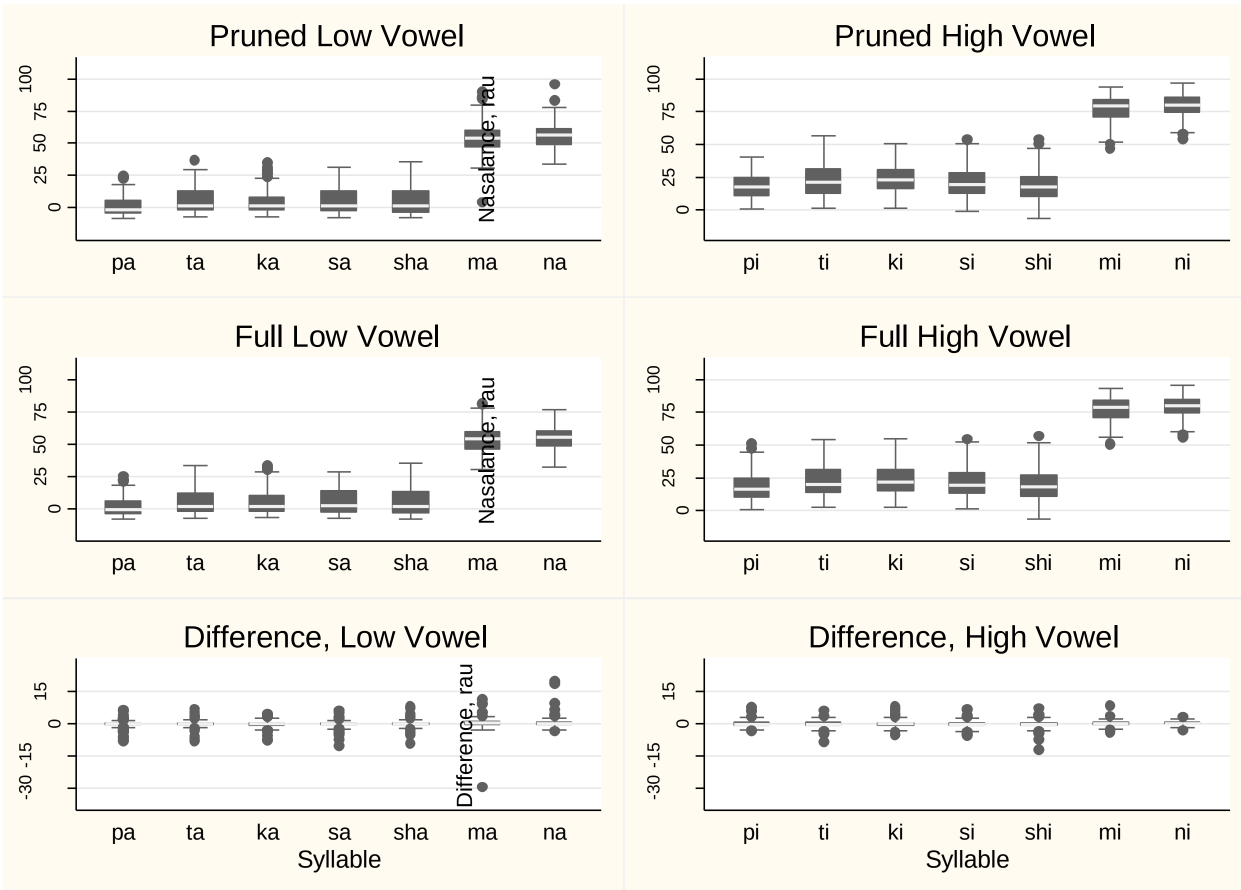


**Figure 7. Combined boxplots of trimmed versus full low and high vowels with resulting differences measured in raus and listed by syllable show range between -30 and +18 rau with interquartile range depicted by whiskers.**

# Appendix A: Forms

## Hearing Form

Record the participant's threshold in dB for each frequency

| **Ear** | **500** | **1000** | **2000** | **4000** |
|---|---|---|---|---|
| Right [Red] | | | | |
| Left [Blue] | | | | |

***If any threshold is > 25 dB discontinue testing, thank the participant for their time and interest and provide a summary sheet of referral sites where they can obtain a comprehensive audiologic assessment.*

## Demographics Form

**Subject I.D. ___________________________**

**Gender:** ☐ Male ☐ Female

**Age: ______________**

**Race/Ethnicity (*See Census 2010 Descriptions Reverse)*:**

☐ White ☐ Black/African American

☐ American Indian/Alaskan Native ☐ Asian

☐ Native Hawaiian/Pacific Islander ☐ Hispanic/Latino Origin

☐ Other Race/Ethnicity

**Have you ever had speech therapy?** ☐ Yes ☐ No

**If yes, what for? ____________________________________________________________**

**Have you ever been told that you have a hearing loss?** ☐ Yes ☐ No

**Have you ever had a hearing aid?** ☐ Yes ☐ No

**Do you have a cold or allergies today?** ☐ Yes ☐ No

**If yes, do you have nasal congestion?** ☐ Yes ☐ No

**Definition of Race/Ethnicity Categories According to 2010 United States Census**

**"White"** refers to a person having origins in any of the original peoples of Europe, the Middle East, or North Africa. It includes people who indicated their race(s) as "White" or reported entries such as Irish, German, Italian, Lebanese, Arab, Moroccan, or Caucasian.

**"Black or African American"** refers to a person having origins in any of the Black racial groups of Africa. It includes people who indicated their race(s) as "Black, African Am., or Negro" or reported entries such as African American, Kenyan, Nigerian, or Haitian.

**"American Indian or Alaska Native"** refers to a person having origins in any of the original peoples of North and South America (including Central America) and who maintains tribal affiliation or community attachment. This category includes people who indicated their race(s) as

"American Indian or Alaska Native" or reported their enrolled or principal tribe, such as Navajo, Blackfeet, Inupiat, Yup'ik, or Central American Indian groups or South American Indian groups.

**"Asian"** refers to a person having origins in any of the original peoples of the Far East, Southeast Asia, or the Indian subcontinent, including, for example, Cambodia, China, India, Japan, Korea, Malaysia, Pakistan, the Philippine Islands, Thailand, and Vietnam. It includes people who indicated their race(s) as "Asian" or reported entries such as "Asian Indian," "Chinese," "Filipino," "Korean," "Japanese," "Vietnamese," and "Other Asian" or provided other detailed Asian responses.

**"Native Hawaiian or Other Pacific Islander"** refers to a person having origins in any of the original peoples of Hawaii, Guam, Samoa, or other Pacific Islands. It includes people who indicated their race(s) as "Pacific Islander" or reported entries such as "Native Hawaiian," "Guamanian or Chamorro," "Samoan," and "Other Pacific Islander" or provided other detailed Pacific Islander responses.

**"Hispanic or Latino"** refers to a person of Cuban, Mexican, Puerto Rican, South or Central American, or other Spanish culture or origin regardless of race.

**"Other Race"** includes all other responses not included in the White, Black or African American, American Indian or Alaska Native, Asian, and Native Hawaiian or Other Pacific Islander race categories described above. Respondents reporting entries such as multiracial, mixed, interracial, or a Hispanic or Latino group (for example, Mexican, Puerto Rican, Cuban, or Spanish) in response to the race question are included in this category.

**Appendix B: Speech Stimuli**

I. Three Paragraphs

A. The Rainbow Passage (11% nasal content)

When the sunlight strikes raindrops in the air, they act as 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. 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. (Fairbanks, 1960)

B. Nasal Sentences (35% nasal content) (read as one continuous sample)

Mama made some lemon jam. Ten men came in when Jane rang. Dan's gang changed my mind. Ben can't plan on a lengthy rain. Amanda came from Bounding, Maine.

C. The Zoo Passage (no nasal content)

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 that 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.

D. Sibilant Passage (no nasal content)

Suzy eats cereal or toast for breakfast. After that, she rides the bus to school. Suzy likes to sit with Sally. At school, the teacher gives Suzy's class a test. Suzy likes her school. She also likes her teacher.

II. Five Sentences

A. He had two rock lizards.

B. Bill sees the sleepy kid

C. Sue took the old blue shoes.

D. Bess has Ella's red cat.

E. Father got all four cards.

III. Sustained Vowels (minimum of 3 seconds per vowel)

A. /i/ "bee"

B. /e/ "bay"

C. /ae/ "bath"

D. /u/ "blue"

E. /o/ "boat"

F. /a/ "bah"

IV. Repeated Syllables

A. /papa/ /tata/ /kaka/ /sasa/ "shasha"

B. /pipi/ /titi/ /kiki/ /sisi/ "sheshe"

C. /mama/ /nana/ /mimi/ /nini/