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THE RELATIONSHIP BETWEEN SPEAKING RATE AND NASALANCE IN TYPICAL ADULT SPEAKERS

by

Rachel Whitney

A thesis submitted to the Graduate College
in partial fulfillment of the requirements
for the degree of Master of Arts
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THE RELATIONSHIP BETWEEN SPEAKING RATE AND NASALANCE IN TYPICAL ADULT SPEAKERS

Rachel Whitney, M.A.

Western Michigan University, 2014

Nasometry is a non-invasive tool frequently used to measure speech resonance in clinical populations. The instrument uses an acoustic recording system to derive a measure termed nasalance, which is an estimate of the relative amount of acoustic energy emitted from the nasal cavity. Nasometry protocols do not provide detailed instructions for speaking rate control during data collection. Studies attempting to establish a relationship between speaking rate and nasalance have yielded mixed results; therefore, it is important to identify the influence of speaking rate on nasalance in a variety of speaking tasks. If rate is found to influence nasalance values, protocols should be modified to minimize rate variation or report normative data stratified by speaking rate. This study examines the degree to which natural variations in speaking rate influences nasalance measures for syllable repetition and paragraph reading tasks. Participants in this study were fifty-six typical adult speakers, ranging in age from 18 to 29, who were part of a larger normative nasometry study. Participants had normal hearing and no history of cleft palate. Analysis focused on syllable repetitions and four standard paragraphs that varied in phonetic structure. Syllable repetition rates ranged from .88 to 5.56 syllables/second and paragraph speaking rates ranged from 1.79 to 5.46 syllables/second. Statistical analysis revealed that a faster speaking rate was associated with lower nasalance for oral syllables and higher nasalance for nasal syllables containing the vowel /a/, but not the vowel /i/. For paragraph reading, a faster speaking rate was associated with lower nasalance for those passages that only contain oral phonemes. These findings suggest that speaking rate can influence nasalance values and that clinical protocols for performing nasometry should control for speaking rate.

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Rachel Whitney

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INTRODUCTION

Speech production can be thought of as motor processes undertaken by the speaker to allow a physical approximation of a series of abstract linguistic structures (i.e., phonemes). Speech production is commonly characterized using the source-filter theory of speech production (Fant, 1960). The "source" refers to any of the sound generating systems within the speech production mechanism. This is often the larynx, which produced phonation, but also includes other articulatory contacts (e.g., the audible release burst associated with the plosives /p/ and /b/ or the generation of turbulence during the lingua-palatal approximation when producing the fricative /ʃ/). The "filter" refers to the airspace in the oral, nasal, pharyngeal, tracheal, and pulmonary cavities that act as a variable acoustic resonator. This complex system, collectively referred to as the vocal tract, can be thought of as a series of tubes and valves that can be varied by the speaker to alter the spectral characteristics of the sound source that passes through it. The velopharyngeal port is part of the filter system that acts as a valve that can adjust the acoustic and aerodynamic coupling between the nasal cavity and the rest of the vocal tract (Fant, 1960).

Speakers of Standard American English use 42 oral speech sounds, comprised of 15 vowels, 3 diphthongs, 21 oral consonants, and 3 nasal consonants. During production of oral phonemes, the velum and pharyngeal walls occlude the entrance to the nasal cavity to decouple the sound and air stream from the rest of the vocal tract. On the other hand, during nasal consonants production (i.e. /n/, /m/, and /ŋ/), the velopharyngeal port is open and the nasal cavity is coupled to the rest of the vocal tract. The coupling and decoupling of the oral and nasal cavities influences how the vocal tract resonates, and the resulting sound patterns that radiate from it. Listeners use the sound patterns to identify oral and nasal phonemes, and judge the overall oral-nasal resonance balance of speech signal. Therefore, oral-nasal resonance balance (referred hereafter as 'resonance') is an auditory-perceptual descriptor of speech that is assumed to be correlated with the degree of acoustic coupling between the nasal cavity and the rest of the vocal tract. Typical speech resonance lies on a continuum, with varying levels of oral nasal resonance being considered acceptable to listeners. A small amount of acoustic energy passing through the nasal cavity is typical during oral phoneme production in connected speech; however, excessive nasal acoustic energy, particularly heard across vowel sounds, is described as hypernasality. Hypernasality is most often associated with incomplete velopharyngeal closure. In contrast, hyponasality, or denasalized speech, describes abnormal resonance that arises from a reduction in sound being directed through the nasal cavity perceived by the listener. Denasalized speech is most prominently heard on the nasal phonemes /m, n, ŋ/ (Peterson-Falzone, Hardin-Jones, & Karnell, 2010). Abnormal resonance is associated with a variety of conditions including cleft palate and velopharyngeal insufficiency (Kummer, Clark, Redle, Thomsen, & Bilmire, 2012), nasal airway impairments (Dalston, Warren, & Dalston, 1991), hearing impairments (Fletcher, Mahfuzh, & Hendarmin, 1999), and motor speech disorders (Kummer et al., 2012).

Measures of Resonance

Clinically, resonance can be measured using auditory-perceptual rating scales, direct instrumental techniques, and indirect instrumental techniques. Auditory-perceptual rating scales rely on the clinician’s auditory impressions to rate the severity of the resonance disorder. Direct techniques allow the clinician to view the structures of the velopharynx during the assessment procedure and make qualitative (i.e. visual-perceptual) evaluations as to how the structure and function contribute to the perceived resonance. Visualization of the structures provides important information pertinent to treatment decisions. Indirect techniques do not provide a view of the velopharynx, but rather provide information that can be used to infer the structural configuration and function of the velopharyngeal port.

Auditory-Perceptual Assessment

Clinicians frequently use auditory-perceptual assessments to identify the type and severity of resonance disorders using five, seven, or nine point scales to rate hyper- and hyponasality. Auditory-perceptual assessments scales are considered to have a high degree of face validity for evaluating resonance; however, it is important to note that these ratings can vary among professionals (Peterson-Falzone, et al., 2010). Severity ratings and descriptors have been found to be more reliable than the numbers on the rating scale (Peterson-Falzone et al., 2010). Similar to other measures of behavior and physiology, it is preferable to use multiple assessment methods to obtain valid and reliable measures (Shadish, Cook, & Campbell, 2002).

Direct Assessment of the Velopharyngeal Port Structure and Function

Videonasendoscopy allows for visualization of the velopharyngeal port during speech using a small, flexible fiberoptic endoscope, with an attached camera and light source. The instrument can be passed through the nasal cavity to provide a view of the movements of the velum and pharyngeal walls from above. The patient is situated in an upright, seated position for this assessment. A topical anesthesia is applied through the nares to reduce discomfort during the endoscopic examination. The endoscope and camera require a disinfection procedure between each use.

Videofluoroscopy uses x-ray to visualize the structures of the velopharynx while the patient is producing speech. Barium sulfate is applied to the nasopharynx to outline the nasal surface of the velum as well as the pharyngeal walls. Conclusions about velopharyngeal function can be made from the images. The patient can be repositioned during videofluoroscopy, allowing the velopharyngeal valve to be viewed from multiple angles.

Magnetic resonance imaging (MRI) is an assessment technique that employs electromagnetic energy to image the soft tissues of the body. MRI provides information about anatomical differences and closure patterns visible on the images. This technique does not require radiation, and therefore is presumed to have fewer health risks as compared to other methods for producing images of the velopharyngeal port (Perry & Schenck, 2013).

There are disadvantages to utilizing direct techniques to evaluate resonance. These assessments each provide images that are interpreted by clinicians concerning type, size, and configuration of the velopharyngeal port (Peterson-Falzone et al., 2010). These procedures also require extensive training for speech-language pathologists to perform and interpret. These assessment measures also have less face validity as compared to auditory perceptual techniques, as often an incomplete closure pattern does not result in a perceptually unacceptable resonance pattern or larger velopharyngeal openings are not always associated with ratings of more severe hypernasality. Additionally, videonasendoscopy is invasive, and can be uncomfortable for some patients to tolerate. Videofluoroscopy involves the added risk of radiation exposure. MRIs are not appropriate for individuals with ferrous metal inside of their body (e.g., shrapnel, surgical screws, etc.), as the magnetic field can cause these metals to shift internally (Peterson-Falzone et al., 2010). MRI and videofluoroscopy must be performed in a radiology center, requiring coordination between the speech-language pathologist and the radiology department and resulting in additional cost to the patient. All these methods require considerable cooperation from patients who are often very young; thus tolerance of these procedures as well as consideration of risks also limits the utility of these techniques for ongoing diagnostic therapy or biofeedback. In addition, normative data, which lacks systematic rating methods, are limited for each of these methods of assessment of velopharyngeal function.

Indirect Techniques for Assessment of the Velopharyngeal Port

Aerodynamic measures can be made to estimate velopharyngeal port size during speech. Air resistance of the velopharyngeal port is measured using the pressure-flow technique, providing indirect information about velopharyngeal function during various speech tasks (Warren & DuBois, 1964). Catheters are placed in the oral and nasal cavities and connected to pressure and flow transducers. The values derived from the oral catheter provides information about the air pressure below the level of the velopharyngeal port, while pressure derived from the nasal catheters or nasal mask provide information about the pressure and airflow after passing through the velopharyngeal port. Calculations can then be made comparing these three values, providing insight into the patency of the velopharyngeal port during specific speech movements.

There are some limitations to using aerodynamic measures. As a result, these measures should not be interpreted independently, but rather in conjunction with auditory-perceptual evaluations. Some individuals are able to compensate for incomplete velopharyngeal closure, resulting in speech that is considered acceptable to the listener; however, under aerodynamic evaluation, these individuals would be identified as someone with inadequate velopharyngeal function. Additionally, attributes of the measurement tubes (e.g., length, curvature, internal diameter) and can confound the results of aerodynamic measurements. Müller and Brown (1980) found that results of orifice area using aerodynamic assessment vary when shape of the port, but not velopharyngeal gap size, are manipulated. The authors also reported that the shape of the entry and exit of the port could also affect the estimation of orifice area. Other external factors can also influence aerodynamic measurements, such as bumping the tubing and obstructions of the tube system from mucous.

Nasometry, the most widely used non-invasive, instrument to assess speech resonance (Kummer et al., 2012), is considered the “gold standard for the clinical diagnosis of resonance disorders” (Bressmann, 2004). Prior to the advent of computer technology for clinical use, Fletcher invented the Oral-Nasal Acoustic Ratio (TONAR) system to electronically chart the acoustic component of nasality, now referred to as nasalance (Fletcher & Bishop, 1970; KayPentax, 2013; Perry & Schenck, 2013). Several brands of computer-based diagnostic tools have evolved from the TONAR system, including the Nasometer from KayPentax, OroNasal System from Glottal Enterprises, and the NasalView from Tiger Electronics (Perry & Schenck, 2013). These devices are comprised of a separator plate, microphones, and a mask or headgear to attach the device to the patients face. The baffle plate rests above the patient's upper lip, situated parallel to the floor, to separate the acoustic energy radiating from the oral and nasal cavities. Microphones are attached to both sides of the separator plate for recording the 'nasal' and 'oral' acoustic signals.

The equation below describes how nasalance is calculated. Essentially, it is the ratio of the nasal sound energy to the total energy recorded by both microphones. To facilitate interpretation, it is expressed as a percentage. Low nasalance values are associated with vowels and oral consonants in typical speakers, as the velopharyngeal port is closed, forcing acoustic energy to escape through the oral cavity. High nasalance values are associated with the production of nasal consonants in typical speakers, as the majority of the acoustic energy escapes through the nasal cavity. In speech, the velopharyngeal port closes and opens as oral and nasal phonemes are produced. When oral and nasal phonemes are strung together in words or connected speech, the nasalance of the oral phonemes surrounding a nasal may be elevated, as the velopharyngeal port may not yet be completely closed during the production of the oral phonemes.

$$Nasalance = \frac{Nasal\ Acoustic\ Energy}{Oral\ Acoustic\ Energy + Nasal\ Acoustic\ Energy} \times 100$$

Factors that Affect Nasalance Values

There are several contributing factors that are known to affect nasalance measures. Over the years, several studies evaluating resonance with various assessment procedures (auditory-perceptual and visiual-perceptual assessments, aerodynamic assessment, nasometry) have noted influences of gender, age, dialect, fundamental frequency, vocal intensity, and speaking rate (Dwyer, Robb, O'Beirne, & Gilbert, 2009; Fletcher & Daly, 1976; Goberman, Selby, Gilbert, 2001; Hutchinson, Robinson, & Nerbonne, 1978; Mandulak & Zajac, 2009; Seaver, Dalston, Leeper, & Adams, 1991; Watterson, York, & McFarlane, 1994).

Some investigations of nasalance have reported no gender differences (Litzaw & Dalston, 1992), while other studies have found gender-specific variance in nasalance (Goberman et al., 2001; Seaver et al., 1991). Seaver and colleagues found that typical female speakers have higher nasalance values than males on passages loaded with nasal phonemes. Goberman et al. reported that males are perceived by investigators to speak with greater nasality than females when producing speech tasks loaded with oral phonemes; however nasometric values indicated that females exhibit greater nasalance values than males on “nasal” passages, consistent with Seaver and colleagues’ findings.

Hutchinson, Robinson, and Nerbonne (1978) examined nasalance in aging populations, specifically individuals 50 to 80 years old. Older subjects demonstrated higher than normal nasalance values when reading a passage that contains all oral phonemes (the “Zoo Passage”). This shift is attributed to the neurological changes associated with advancing age (Hutchinson et al., 1978). Awan (1998) examined the effects of development on nasalance in children and adolescents. Awan found that older adolescent males (age 13-14) had significantly higher nasalance than younger males (age 5-6 and age 7-8). It was also reported that older female adolescents (age 11-12 and 13-14) had significantly higher nasalance than younger females (age 5-6, 7-8, 9-10).

Dialect also seems to play some role in nasalance values. A study of nasalance in four regions of North America, the Mid-West United States, the Mid-Atlantic United States, the Southern United States, and Ontario, identified Mid-Atlantic speakers to have increased nasalance values on the all oral Zoo Passage and Rainbow Passage (a phonetically balanced passage) when compared with other dialect regions (Seaver et al., 1991).

Mandaluk and Zajac (2009) investigated the influence of fundamental frequency on nasalance with typically speaking adults. Participants produced prolonged vowels, /a/ and /i/, at targeted sound pressure levels and fundamental frequencies. The authors found that within limited sound pressure level ranges, small but significant variations in nasalance were associated with altered fundamental frequency.

Watterson, York, and McFarlane (1994) found that as vocal intensity increased, the measured nasalance values for the vowel increased. These authors also noted that individuals with a history of repaired cleft palate tend to speak with lower vocal intensity. Secondary to the vocal intensity findings, the authors postulated that individuals with a repaired cleft palate may speak at a slower rate in an effort to reduce the level of perceived nasality, though no formal evaluation of speaking rate was pursued.

Speaking Rate and Nasalance

Previous research has indicated possible relations between speaking rate and velopharyngeal function. For example, speaking rate has been found to be slower for individuals with a repaired cleft palate and a moderate to severe articulation disorder than those with a mild articulation disorder and non-cleft speakers (Bressmann & Sader, 2001). This is consistent with the findings from a study conducted by Lass and Noll (1970), which reported that participants with a repaired cleft palate had slower oral reading rates, higher frequencies and durations of pausing and higher degree of performance variability than the non-cleft control group. Speaking rate appears to influence various measures of resonance in the non-cleft population. Dwyer and colleagues (2009) investigated the effects of speaking rate on perceived hypernasality in individuals with hearing impairments. Results indicated that as speaking rate decreased, perceived hypernasality increased. Goberman et al. (2001) reported similar findings in a group of typical speakers.

Fletcher and Daly (1976) explored the relationship between speaking rate and nasalance in 50 hearing impaired and 64 normal hearing individuals. The hearing status of the normal hearing population was determined by a pure tone hearing screening of 250-4,000 Hz at 15 dB HTL. The participants of the study ranged in age from 7 to 25 years old, representing both pediatric and young adult populations. Using the Quan-Tech TONAR II system and three speech stimuli (the *Zoo Passage*, an isolated /a/, and the *Goldman-Fristoe Speech Articulation Test*), this study sought to examine the influence of natural variations of speaking rate on nasalance values. Though the authors were interested in identifying differences between hearing impaired and normal hearing populations, only the data from the non-hearing impaired group was found to be relevant to the current study. Results revealed that, for the reading passage, those normal hearing speakers with longer reading times (i.e. slower speaking rate) exhibited significantly higher nasalance values compared to the speakers with shorter reading times (i.e. faster speaking rates).

Gauster and colleagues (2010) explored the relationship between speaking rate and nasalance in typical adult speakers using the Nasometer II. Twenty-seven participants produced oral (“Buy Bobby a puppy”) and nasal sentences (“Mama made some lemon jam”) and “hamper” at four self-selected speaking rates (normal, fast, slow, and slowest). The researchers provided definitions to help the participants select the appropriate speech rate. Slow was defined as half the rate of normal speech, fast was defined as twice the speed of normal speech, and slowest was defined as the slowest possible rate at which intelligible speech can be produced. The stimuli were produced twice, once for nasalance measures and another for aerodynamic measures, with a randomized order of assessment for each participant. Results of this study suggested that nasalance values are not related to speaking rate, as variation in nasalance values for both oral and nasal stimuli did not differ significantly across rate conditions. However, the study used a relatively small speaker pool (N=27) and therefore may not have sufficient statistical power to discern actual differences across the conditions.

Achenbaugh (2012) extended the methods of the Gauster et al. (2010) work to a typically developing pediatric population, ranging in age from 4 years 1 month to 7 years 11 months. The authors used the same speech stimuli as the Gauster et al. study, but included age-appropriate visual cues to elicit the different speaking rates. Results revealed that higher nasalance values were associated with the fast production of the oral sentence and the slow production of the nasal sentence. Achenbaugh also reported that females produced higher nasalance values than males on the oral sentence task.

Tasko et al. (2013) evaluated the relationship between variations in speaking rate and nasalance in 58 typical speakers for repeated syllables of SNAP Test-R protocol using the Nasometer II system. Rate was not an experimental factor in this study. Instead, the study exploited the rather large range in speaking rate naturally produced by the relatively large speaker group. Speakers were divided into “fast rate” and “slow rate” groups using a median split approach. Results revealed that nasalance was significantly higher for the ”fast rate" group when producing nasal syllables. Though for oral syllable repetitions there were no statistically significant results, there was a trend towards lower nasalance values for the fast rate group.

Limitations of Previous Studies Examining Speech Rate and Nasalance

Previous studies examining the role of speech rate on nasalance suffer from a number of limitations. The Gauster et al. (2010) and Auchenbaugh (2012) studies employed speech stimuli that are not widely used with clinical populations. Fletcher and Daly (1976) utilized the *Zoo Passage*, a passage free of nasal phonemes. This passage alone may not fully represent a subject's speech during habitual speech. The Tasko and colleagues (2013) study examined repeated oral and nasal syllables. Though clinicians report use of the repeated syllable portion of the *SNAP Test-R* protocol when using nasometry with non-readers, these stimuli may result in greater variability in rate due to limited linguistic constraints. A longer, more phonemically balanced passage, such as the *Rainbow Passage*, may be more appropriate for use with literate clients to draw conclusions about habitual speech.

In the Fletcher and Daly (1976) and Tasko and colleagues (2013) studies, rate of speech was not controlled. As a result, no within subject measures were made, or only when significant rate changes were identified due to natural variation across the study group. The participants in the Gauster and colleagues (2010) study self-selected their modifications in speaking rate. Though self-selection for rate is not unprecedented, the rate modification could be achieved in a more systematic manner (i.e. using more rigidly defined rate modifications).

Lastly, these studies examined limited populations. Sample sizes were small for all of the studies, and each sample group lacked regional and dialectal variability. The homogeneity of these populations makes it difficult to generalize the results to other, larger, populations.

The Present Study

Previous research suggests a possible relationship between speaking rate and nasalance measures, as well as auditory-perceptual measures of resonance. The American Cleft Palate and Craniofacial Association (2009) has called for standardized and objective measures for all patients with resonance disorders and/or nasal air emissions to allow for inter-center outcomes comparisons. If speaking rate alters nasalance measures in typical speakers, then speaking rate may be a variable to consider in establishing standardized protocols for speech outcome. Considerable variation has been documented in habitual speaking rate of typical speakers (Bressmann & Sader, 2001). As syllable repetition tasks do not adhere to linguistic constraints (e.g., intelligibility requirements, pausing and phrasing, melodic contour of communication) that are required to convey a message, a potentially greater opportunity exists for variability in this task.

The purpose of this study is to identify if a relationship exists between natural variation in speaking rate and nasalance. To address this research question, we examined speaking rate at the paragraph level, with the *Rainbow Passage* (phonetically balanced), *Nasal Paragraph* (loaded with nasal phonemes), *Zoo Passage* (loaded with oral phonemes), and the *Sibilant Passage* (loaded with sibilants) and at the syllable level, with the repeated syllable tasks from *SNAP TEST-R* protocol.

METHODS

Participants

To be included in the study, participants were required to be between 18 and 30 years of age and lifelong residents in the lower peninsula of Michigan. All participants completed a hearing assessment and were required to have thresholds better than 25 dB HTL at 500, 1,000, 2,000, and 4,000 Hz bilaterally. This study received approval from the Human Subjects Institutional Review Board (Appendix A). Sixty volunteers (35 female, 25 male) were enrolled, ranging in age from 18 to 29 years old, with a mean age of 20.5 years and a median age of 19 years. Two participants did not meet the hearing requirement, and did not participate in the remainder of the study. One participant was used as a pilot participant. Since instructions and procedures were modified after data collection with the pilot participant, the participant's data were excluded. One participant reported having a submucous cleft palate and was not included in this data analysis. The final sample size included in this investigation was 56 (35 female, 21 male) participants.

Participants completed questionnaires providing current health status and background information (Appendix B). No participants were actively receiving speech therapy; however 14% reported a history of speech-language treatment. At the time of data collection, 2% reported congestion or allergies, although no participants presented with abnormal resonance as perceived by the investigative team.

Speech Stimuli

Four speaking tasks were included in this study: sustained vowels, syllable repetition, sentence readings, and paragraph readings. Participants sustained the vowels /a/, /e/, /ae/, /o/, /u/, and /i/ for approximately three seconds. Participants repeated 14 consonant-vowel syllables, standardized on the SNAP Test-R protocol, which provided opportunities to produce stops (/p, t, k/), fricatives (/s, ʃ/), and nasal (/m, n/) consonants paired with a low (/a/) and high (/i/) vowel (Kummer, 2005). The sentence stimuli used were five vowel-loaded sentences (Lewis, Watterson, & Quint, 2000). Four paragraphs were included as stimuli: the *Zoo Passage, the Rainbow Passage, the Sibilant Passage, and the Nasal Paragraph* (Appendix C). Stimuli were randomized across category (except the syllable task was always last) and within category using a Matlab-based random permutation function.

Instrumentation and Data Collection

All data were collected using two devices: the Nasometer II and a microphone-digital recorder setup. The Nasometer II was connected to a Dell Latitude E6500 laptop computer. The Nasometer II was calibrated each day according to the user's manual, prior to collecting data with participants. The Nasometer II records from the oral and nasal microphones into each channel of a stereo, uncompressed pcm file (sample frequency = 11.025 KHz; quantization = 16 bit). The signal was also band-pass filtered with corner frequencies of 300 Hz and 750 Hz.

High quality audio recordings were also collected using a dynamic external microphone (Shure SM58) was positioned approximately 30 cm from the participant's mouth and was attached to a Marantz PMD 660 Solid State Digital Recorder (sample frequency = 44.1 KHz; quantization = 16 bit). Following the recording on the Marantz system, sound files were transferred onto a Dell Vostro desktop computer to be spliced into task specific speech samples using Goldwave (2012) and saved as an uncompressed pcm file. Seven researchers were involved in the data collection process with a minimum of two researchers per data collection session. During data collection, one researcher was responsible for recording and saving the Nasometer recordings while another supplied the speech stimuli to the participant and monitored for headgear placement.

Data Processing and Measurement

Nasalance

The pcm files from the Nasometer system were read into Matlab (Mathworks, 2011). From these files, nasalance values were estimated using a custom Matlab program. This Matlab routine emulates the KayPentax approach and was developed to allow for large scale processing of signals. In a previous study, Peebles (2013) found that the nasalance estimates obtained using the Matlab software were highly correlated (r>.999) with results obtained from the Nasometer II. In other word, the Matlab results did not differ in central tendency from the results from the Nasometer II system.

Speech Rate

For the SNAP Test-R tasks, the duration of the syllable string, as well as the number of syllable produce, was determined using TF32, an acoustic analysis software (Milenkovic, 2009). The syllable count and the duration were then used to derive the speaking rate for that condition. A different method was used for determining speaking rate at the paragraph level. The custom Matlab routine that was used for determining nasalance also provides the duration of the sample for which nasalance values were determined. This duration was used to estimate the overall duration of the speech sample. This duration, combined with the number of syllables in the reading passage was used to derive the speaking rate for that condition.

Data Analysis

Nasalance is typically expressed as a percentage, which can be problematic for statistical analysis, particularly for data that are near the natural boundaries (near 0 or 100) of the scale. Therefore, a numeric transformation was necessary to prepare the data for appropriate statistical analysis (Stubdebaker, 1985). The data were transformed into rationalized arcsine units (rau) to achieve consistent variance across the percentage scale. This transformation is especially appropriate when percentage values approach the floor and ceiling (less than 15% and greater than 85%). The rau transformation resulted in extending the data range of from a minimum of -21 to a maximum of 121. The transformation left the middle of the distribution unaffected.

The Shapiro-Wilk Test was used to examine normality of speaking rate and rau-transformed nasalance. Within syllable stimuli, the assumption of normality was rejected. As a result, descriptive data will be reported using medians and quartiles rather than means and standard deviations.

A multi-level mixed-effects regression model was used to assess association between nasalance and speaking rate while controlling for covariates (i.e., speech stimuli, trial, and gender) and repeated (correlated) observations obtained within subjects. Between-subject factors were treated as fixed factors. Observations were considered nested within trials, and trials were considered nested within individual participants within this analytic model. Main and interaction effects were tested.

Overall model significance was evaluated using the Wald Chi-Square statistic with a criterion *p*-value of 0.05. Post-hoc comparisons of model coefficients were conducted using Bonferroni-adjusted or unadjusted *p*-values. All analyses were conducted using Stata software.

RESULTS

Descriptive Results

Speaking Rate

Table 1 shows the variability in speaking rate for each of the paragraph stimuli. Paragraph speaking rates ranged from 1.794 to 5.457 syllables per second. Table 2 shows the variability in speaking rate for each of the repeated syllable stimuli. Syllable repetition speaking rates ranged from .8801 to 5.557 syllables per second. Clearly, the range of speaking rate was much larger for the syllable repetition task as compared to paragraph reading.

Table 1. Minimum, maximum and quartiles of speaking rate (syllables/second) across all paragraph-level stimuli.

Stimuli	*Minimum*	*25%*	*50%*	*75%*	*Maximum*
Rainbow	2.826	4.017	4.310	4.699	5.457
Nasal	1.794	2.554	2.780	3.057	3.817
Zoo	2.691	3.515	3.788	4.151	5.084
Sibilant	2.750	3.481	3.745	4.008	5.144

Table 2. Minimum, maximum and quartiles of speaking rate (syllables/second) across all syllable-level stimuli.

Stimuli	*Minimum*	*25%*	*50%*	*75%*	*Maximum*
/pa/	0.880	1.849	2.460	3.202	4.908
/ta/	0.967	1.894	2.569	3.255	5.375
/ka/	0.991	1.880	2.467	3.244	5.557
/sa/	0.969	1.881	2.425	3.031	4.504
/ʃa/	0.960	1.850	2.412	3.052	4.278
/ma/	1.046	1.855	2.499	3.221	4.391
/na/	1.036	1.913	2.538	3.209	4.353
/pi/	1.048	1.852	2.581	3.324	5.270
/ti/	1.043	1.859	2.624	3.256	4.893
/ki/	1.042	1.851	2.506	3.189	4.889
/si/	1.015	1.816	2.516	3.104	4.750
/ʃi/	1.011	1.776	2.489	3.062	4.271
/mi/	1.064	1.923	2.622	3.389	5.198
/ni/	1.032	1.892	2.569	3.252	4.912

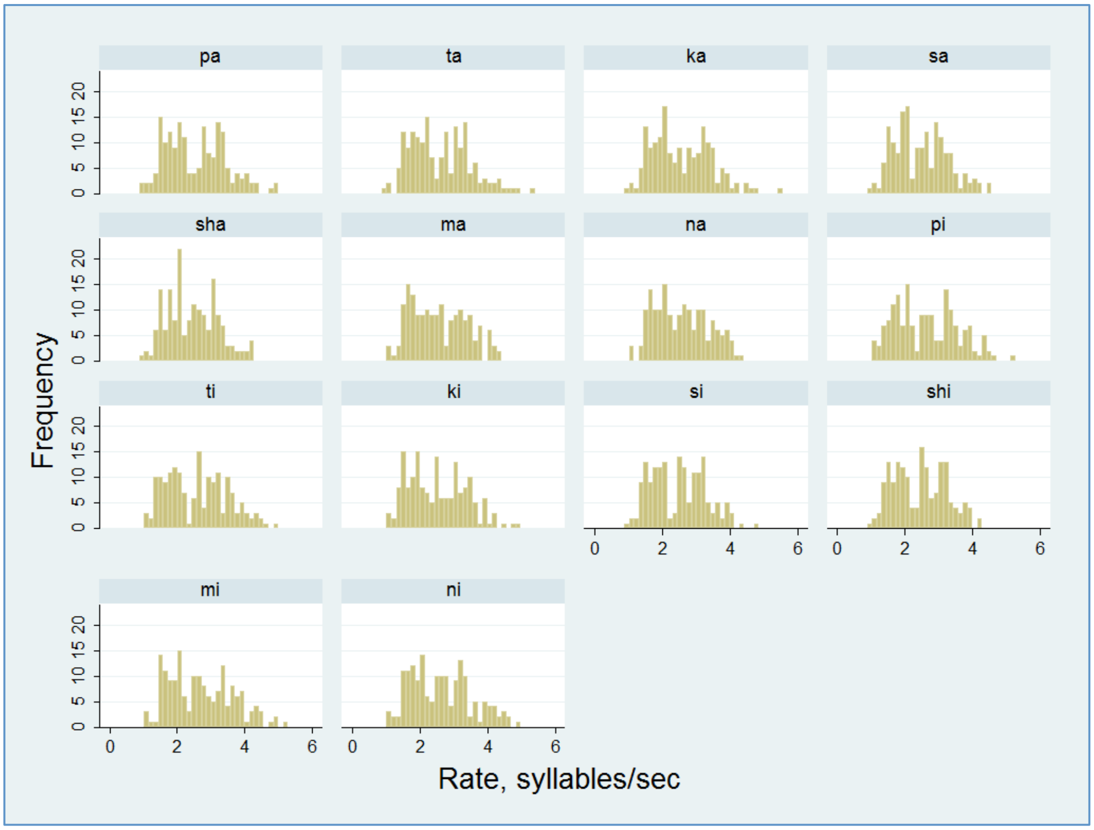

Figure 1. Frequency of occurrence histograms showing the distributional patterns of speaking rate (expressed in syllables/second) across all syllable-level stimuli.

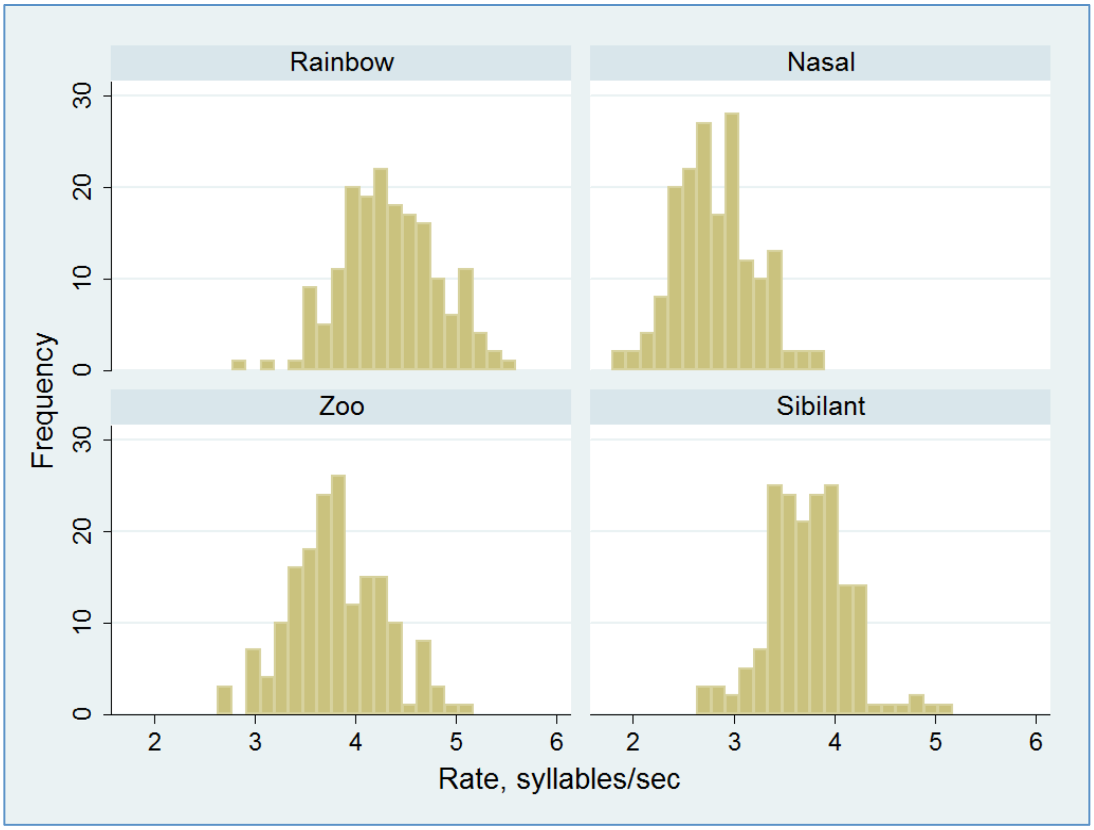

Figure 2. Frequency of occurrence histograms showing the distributional patterns of speaking rate (expressed in syllables/second) across all paragraph-level stimuli.

Frequency-of-occurrence histograms were created for each speaking stimulus to show dispersion of speaking rate. As was confirmed by the Shapiro-Wilk test, visual examination reveals that the data were not normally distributed for the repeated syllable tasks (see Figure 1) or the paragraph tasks (see Figure 2).

Due to the non-normal distribution of the data and to simplify statistical analysis, for each speech stimulus, the range of speaking rates was divided into three equally sized groups, or tertiles, creating low, medium, and high speaking rate subgroups. Boundaries for each of the speaking rate subgroups are shown in Table 3. It is important to note that, due to the inherent differences in the distribution of speaking rate for the different stimuli (see Tables 1 & 2 and Figures 1 & 2) the boundaries for the rate subgroups can be quite different for the various speech stimuli.

Table 3. Boundaries for the low, medium and high speaking rate groups for both paragraph-level and syllable-level stimuli.

Stimuli	*Minimum*	*Low-Medium Boundary*	*Medium-High Boundary*	*Maximum*
Rainbow	2.826	4.146	4.593	5.457
Nasal	1.794	2.671	3.026	3.817
Zoo	2.691	3.668	4.072	5.084
Sibilant	2.750	3.552	3.959	5.144
pa	0.880	2.125	3.071	4.908
ta	0.967	2.180	3.059	5.375
ka	0.991	2.136	3.096	5.557
sa	0.969	2.075	2.914	4.504
ʃa	0.960	2.121	2.904	4.278
ma	1.046	2.178	3.067	4.391
na	1.036	2.162	2.978	4.353
pi	1.048	2.117	3.202	5.270
ti	1.043	2.118	3.108	4.893
ki	1.042	2.100	3.031	4.889
si	1.015	2.071	2.930	4.750
ʃi	1.011	2.089	2.908	4.271
mi	1.064	2.201	3.212	5.198
ni	1.032	2.181	3.113	4.912

Nasalance

As described in the Methods, nasalance was adjusted using a rau transformation. For the duration of the results chapter, the term nasalance will be used to describe rau-transformed nasalance.

Table 4 shows the range of nasalance values for each stimulus. As expected, nasal stimuli at the paragraph (*Nasal Paragraph*) and syllable level (/ma, na, mi, ni/) resulted in significantly greater nasalance than the phonetically balanced stimuli (*Rainbow Passage*) and oral stimuli, at the paragraph (*Zoo Passage, Sibilant Passage*) and syllable level (/pa, ta, ka, sa, ʃa, pi, ti, ki, si, ʃi/).

Table 4. Minimum, maximum and quartiles of nasalance (rau) for paragraph and syllable-level stimuli.

Stimuli	*Minimum*	*25%*	*50%*	*75%*	*Maximum*
Rainbow	12.692	28.585	32.377	35.176	48.255
Nasal	41.634	56.985	59.507	62.995	73.145
Zoo	-3.935	2.575	6.300	11.420	32.616
Sibilant	-3.796	3.389	8.121	12.545	31.520
/pa/	-8.069	-3.546	-0.605	6.181	25.095
/ta/	-7.144	-2.036	1.848	12.272	33.334
/ka/	-6.843	-2.147	1.957	10.445	33.423
/sa/	-7.239	-2.344	2.243	13.833	28.645
/ʃa/	-7817	-3.266	1.514	13. 297	35.556
/ma/	30.531	46.381	54.162	59.810	81.343
/na/	32.554	48.156	55.705	60.680	76.699
/pi/	.975	9.722	16.359	24.431	56.454
/ti/	2.609	13.316	20.233	31.378	54.120
/ki/	2.263	14.799	21.658	31.554	54.825
/si/	1.121	12.743	19.532	28.903	54.038
/ʃi/	-6.624	10.261	18.333	27.026	56.557
/mi/	50.840	71.247	78.814	84.203	93.348
/ni/	55.5583	74.800	80.109	85.307	95.483

For both oral and nasal syllables, stimuli containing /a/ were associated with lower mean nasalance than stimuli containing /i/. Figure 3 shows this relationship for oral syllables for all speaking rate groups. Figure 4 shows this relationship for nasal syllables for all speaking rate groups.

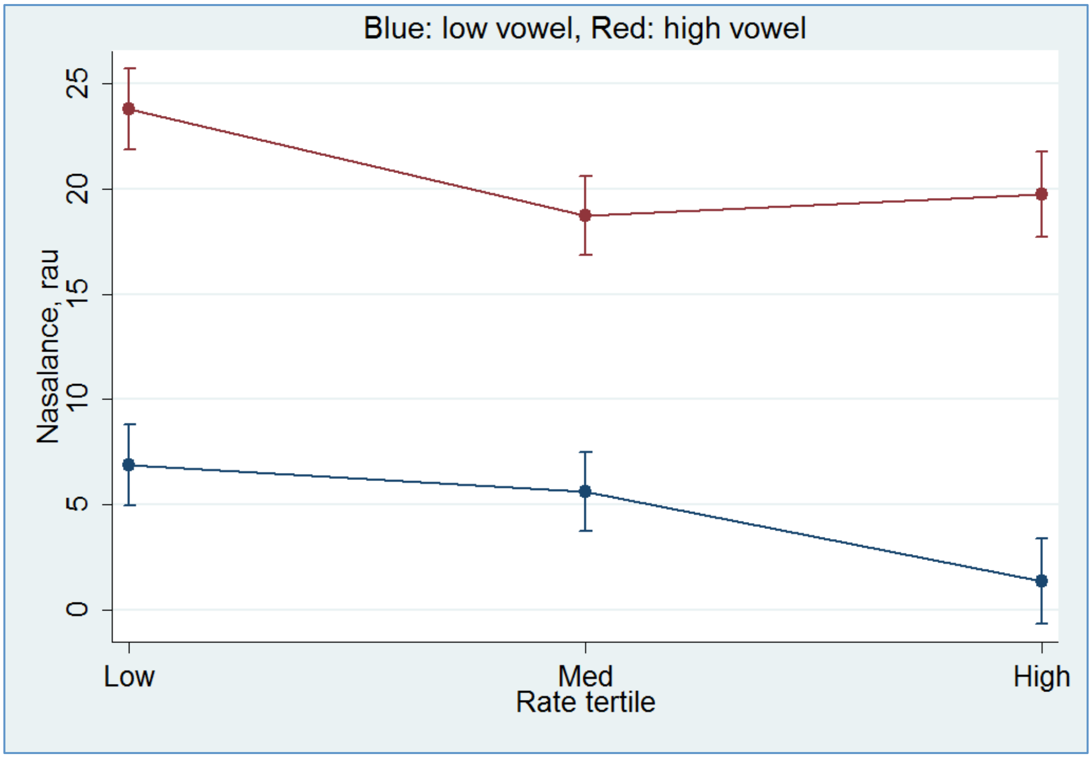

Figure 3. Mean nasalance plotted as a function of speaking rate group for the oral syllable repetition task, organized by vowel type.

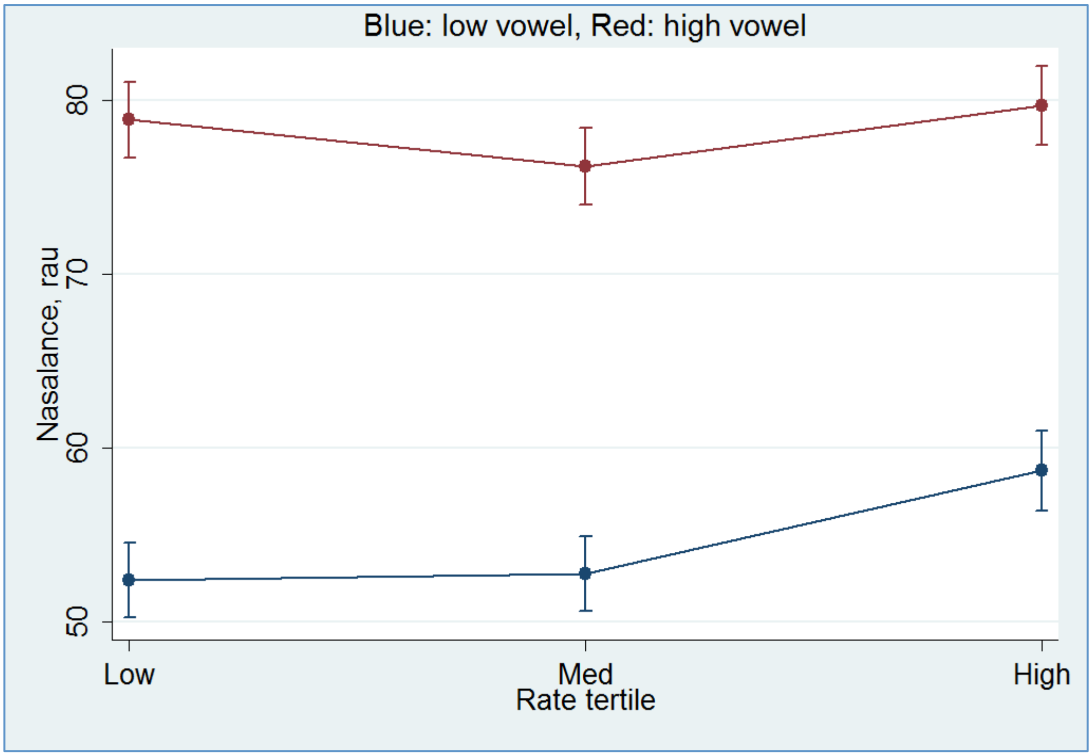

Figure 4. Mean nasalance plotted as a function of speaking rate group for the nasal syllable repetition task, organized by vowel type.

Effects of Speaking Rate on Nasalance

Multi-level regression analysis was performed to examine if nasalance systematically varied as a function of speaking rate group, while controlling for factors such as speech stimuli, gender, and repeated (correlated) observations obtained within subjects. The Wald Chi-Square statistic used to assess the overall model was significant (X^2 (49) = 30820, p<0.00005), suggesting that at least one comparison within the model was statistically significant. Appendices D and E provide detailed results of the statistical models for the paragraph and syllable level stimuli. As noted in the Methods, post-hoc comparisons of model coefficients were conducted using two criteria; one was very conservative (i.e. Bonferroni-adjusted) and one was very liberal (unadjusted *p*-values). Table 5 summarizes the post-hoc comparisons focused on the influence of speaking rate on nasalance.

Table 5. Summary of post-hoc comparisons evaluating the effects of speaking rate group on nasalance across the range of speech stimuli. Statistically significant comparisons are in boldface. Stimulus conditions sharing the same color exhibit identical patterns in the post-hoc comparisons.

Stimuli	*Comparisons using unadjusted p-values*	*Comparisons using Bonferroni adjusted p-values*
Rainbow	-	-
Nasal	-	-
Zoo	low=med **low>high** **med>high**	-
Sibilant	**low>med** **low>high** med=high	low=med **low>high** med=high
/pa/	low=med **low>high** **med>high**	low= med **low>high** med=high
/ta/	low=med **low>high** **med>high**	-
/ka/	low=med **low>high** med=high	-
/sa/	low=med **low>high** **med>high**	-
/ʃa/	low=med **low>high** **med>high**	-
/ma/	low=med **low<high** **med<high**	low=med **low<high** **med<high**
/na/	low=med **low<high** **med<high**	-
/pi/	**low>med** **low>high** med=high	low=med **low>high** med=high
/ti/	**low>med** low=high med=high	-
/ki/	**low>med** **low>high** med=high	-
/si/	**low>med** low=high med< high	-
/ʃi/	**low>med** **low>high** med=high	**low>med** low=high med=high
/mi/	**low>med** low=high med< high	-
/ni/	-	-

Paragraph Stimuli

Figure 5 plots mean nasalance for the three different rate groups across the four different reading passages. Statistical analysis revealed that for the *Rainbow Passage* and *Nasal Paragraph*, no relationship between speaking rate group and nasalance was observed. For the *Zoo Passage*, the high speaking rate group exhibited higher nasalance values than the low or medium speaking rate groups (unadjusted *p*-value). However when the Bonferroni adjustment was applied, the group differences were no longer significant. In the case of the *Sibilant Passage*, when p-values were unadjusted, the low speaking rate group was found to exhibit higher nasalance than the medium and high speaking rate groups. With the Bonferroni adjustment, the only significant comparison was the low vs. high rate group and neither the low speaking rate group nor high speaking rate group was significantly different from the medium speaking rate group.

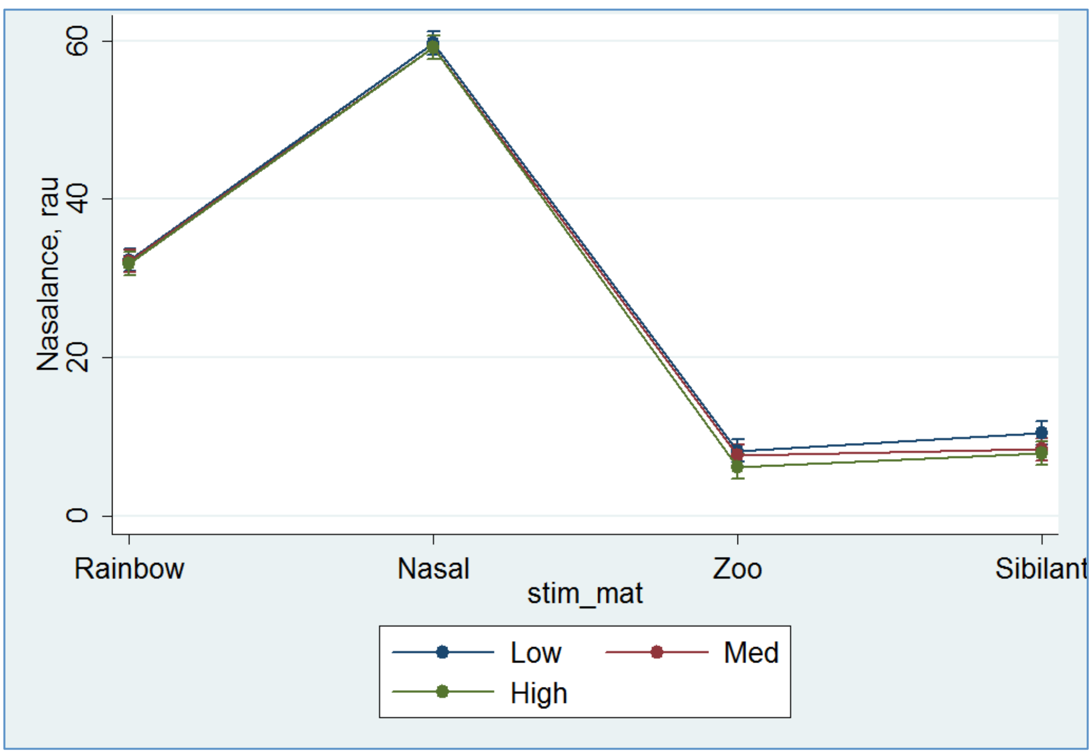

Figure 5. Mean nasalance plotted as a function of speech task for paragraph-level stimuli. Low, medium and high speaking rate groups are identified by blue, green and red symbols and lines respectively.

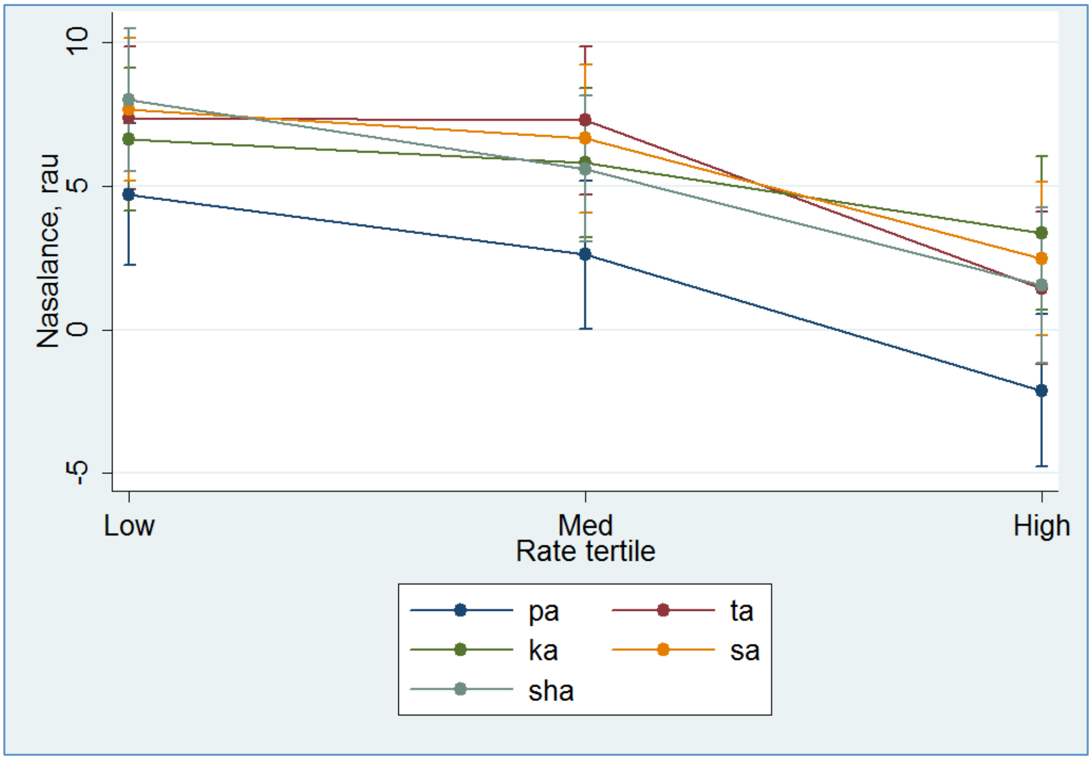

Figure 6. Mean nasalance plotted as a function of speaking rate group for oral syllable-level stimuli and the vowel /a/.

Syllable Stimuli: Oral Syllables

Table 5 as well as Figures 3 and 6 summarize the results for the oral syllable stimuli coupled with the vowel /a/. When examining all oral phonemes coupled with the vowel /a/, the low and medium speaking rate groups exhibited lower nasalance than the high speaking rate group ($p<.05$). No difference between the low and medium speaking rate groups was observed (Figure 3). For the repeated syllable /pa/, /ta/, /sa/, and /ʃa/, the high speaking rate group was associated with significantly lower nasalance than the low and the medium speaking rate groups (unadjusted *p*-values). There was no difference between the low and medium groups. When the Bonferroni adjustment was applied, no significant differences were found for the /ta/, /sa/, and /ʃa/ conditions. For the repeated syllable /ka/, the high speaking rate group was associated with significantly lower nasalance than the low group, and no differences were found between the low and medium groups or the medium and high groups (unadjusted *p*-value). When the Bonferroni adjustment was applied, the high-low comparison did not reach statistical significance. For the repeated syllable /pa/, when the Bonferroni adjustment is applied, the high speaking rate group exhibited lower nasalance than the low speaking rate group, but there is no difference between the low and medium group and the medium and high group.

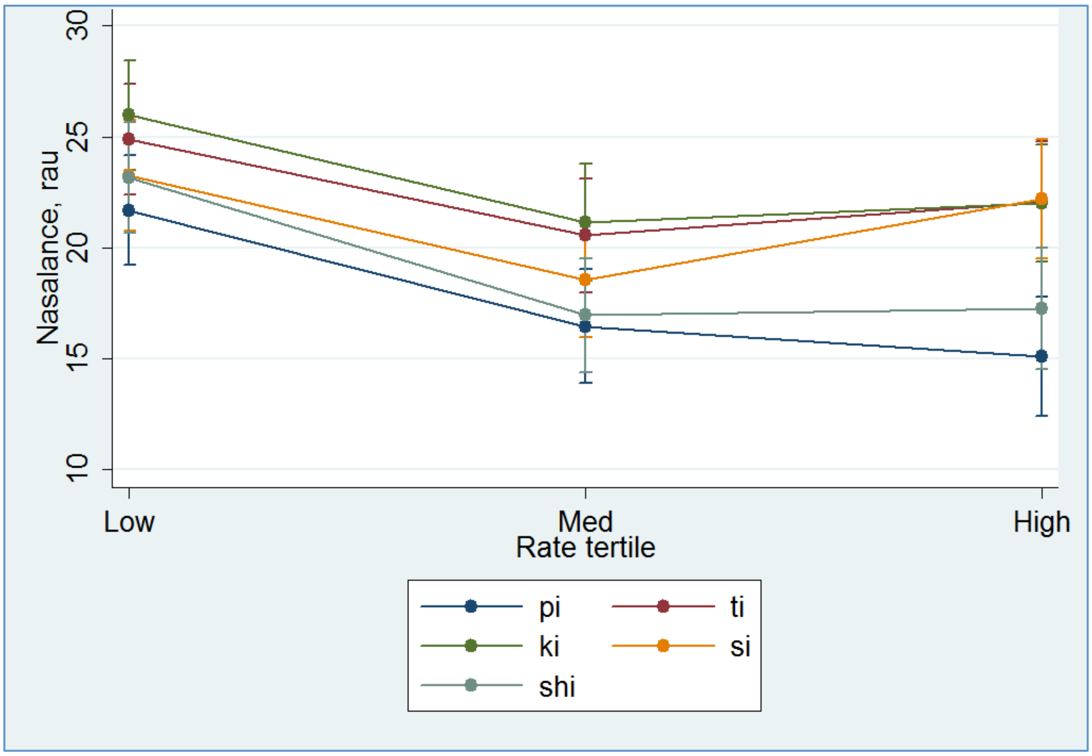

Figure 7. Mean nasalance plotted as a function of speaking rate group for oral syllable-level stimuli and the vowel /i/.

The results for the oral syllable stimuli coupled with the vowel /i/ can be found in Table 5 as well as Figures 3 and 7. When examining all oral + /i/ stimuli, the low speaking rate group was associated with higher nasalance than the medium and high speaking rate groups (p<.05). No differences were observed between the medium and high rate groups (Figure 3). For the repeated syllables /pi/, /ki/, and /ʃi/, the medium speaking rate group was associated with significantly lower nasalance than the low group and the high speaking rate group was associated with lower nasalance than the low speaking rate group (unadjusted *p*-

values). There were no differences between the high and medium groups. When the Bonferroni adjustment was applied, the difference reached significance for /pi/, such that the high speaking rate group exhibited lower nasalance than the low speaking rate group. However, there was no difference between the low and medium group and the medium and high group. For the repeated syllable /ki/, when the Bonferroni adjustment was applied, the comparisons did not reach statistical significance. For the repeated syllable/ʃi/, the medium speaking rate group exhibited lower nasalance than the low rate group when a Bonferroni adjustment was applied. There were no significant differences between the medium and the high rate groups or the high and low rate groups. For the repeated syllable /ti/, the medium speaking rate group was associated with significantly lower nasalance than the low rate group and there were no significant difference between the high and low rate groups or the high and medium rate groups (unadjusted *p*-values). When a Bonferroni adjustment was applied, none of the comparisons were significant. For the repeated syllable /si/, the medium speaking rate group was associated with significantly lower nasalance than the low and high groups and there was no significant difference between the high and low rate groups (unadjusted *p*-values). When the Bonferroni adjustment was applied, all comparisons failed to reach significance.

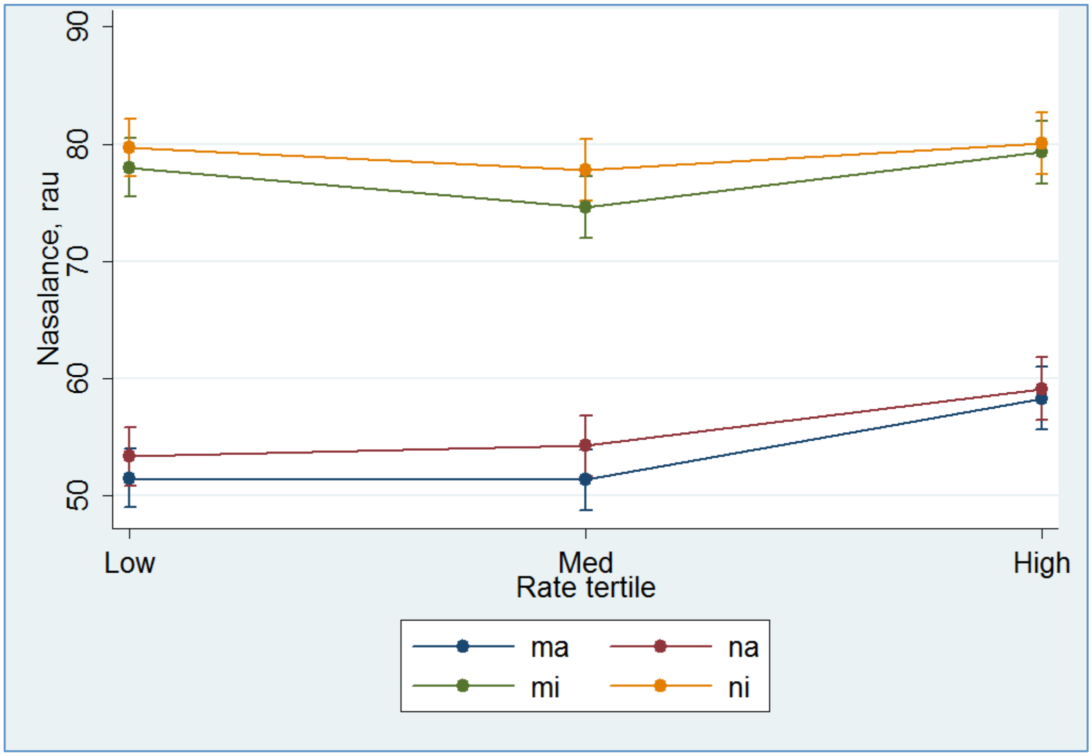

Figure 8. Mean nasalance plotted as a function of speaking rate group for nasal syllable-level stimuli.

Syllable Stimuli: Nasal Syllables

The results for the nasal syllable stimuli can be found in Table 5 as well as Figures 4 and 8. When examining nasal + /a/ stimuli, the low rate group was associated with lower nasalance values than the high rate group (p <0.05), and no differences were observed between the low and medium rate groups or the medium and high rate groups (Figure 4). When examining nasal + /i/ stimuli no significant interaction between speaking rate group and nasalance was observed (Figure 4). For the repeated syllables /ma/ and /na/, the high speaking rate group was associated with significantly higher nasalance than the low and medium rate groups while there was no difference between the low and medium rate groups (unadjusted p-values). For the syllable /na/, when the Bonferroni adjustment was applied, these comparisons failed to reach statistical significance. For the syllable /ma/, differences remained to reach significance when Bonferroni adjustment was applied. For the repeated syllable /mi/, the medium speaking rate group was associated with significantly lower nasalance than the high and low rate groups and no difference was observed between the low and high speaking rate groups (unadjusted *p*-values). When the Bonferroni adjustment was applied, none of the comparisons reached significance. For the repeated syllable /ni/, no comparisons were significant (unadjusted *p*-values).

DISCUSSION

The purpose of this study was to identify a potential relationship between variations in speaking rate and nasalance using four common paragraph length stimuli (the *Rainbow Passage*, the *Nasal Paragraph*, the *Zoo Passage*, and the *Sibilant Passage*) and the repeated syllables from the SNAP R-TEST protocol (/p, t, k, s, ʃ, m, n/ paired with the vowels /a/ and /i/) (Kummer, 2005). Results indicate that speaking rate does influence nasalance for selected paragraph and syllable-level tasks.

Influence of Speaking Rate Variation by Stimuli

Fletcher and Daly (1976) reported that the slower readings of the *Zoo Passage* were associated with higher nasalance values; however the present study found no variation in nasalance based on speaking rate for this task. Differing results could be due to different systems being used to measure nasalance; Fletcher and Daly (1976) used the TONAR II system, while the present study utilized the Nasometer II. Dissimilar populations could also contribute to the inconsistency, as pediatric and young adult populations were used in the Fletcher and Daly research (1976) and a young adult population was used in the present study.

In the current study, oral stimuli, at the paragraph (*Sibilant Passage*) and syllable level, produced at faster speaking rate is associated with lower nasalance values. This is inconsistent with the finding from Achenbaugh (2012), in which it was reported that faster productions of an oral sentence ("buy bobby a puppy") were predictive of higher nasalance values in a pediatric population. Gauster et al. (2010) also reported no statistical differences in nasalance based on speaking rate with the oral sentence ("buy bobby a puppy") when examining an adult population.   In the current study, nasal syllables, produced at faster speaking rate, are associated with higher nasalance values. This is also inconsistent with Achenbaugh's research, which found that faster productions of the sentence containing nasals were predictive of lower nasalance values. Gauster et al. reported no relationship between speaking rate and nasalance for the nasal sentence. These inconsistencies could be due to the fact that the speaking tasks are different or that the participants in these studies were intentionally altering speaking rate and the present study examined natural variation in speaking rate.

In the current study, paragraph speaking rates ranged from 1.79 to 5.46 syllables per second and syllable repetition speaking rates ranged from 0.88 to 5.56 syllables per second. Durational measures were not provided in the Gauster et al. (2010) research, but rather percentages of change between each speaking rate task. Achenbaugh (2012) reported speaking rates in means and standard deviations for the sentence tasks. The slowest mean speaking rate reported was 0.77 syllables per second and the fastest mean speaking rate reported was 7.23 syllables per second. The results of the current study are based on a narrower, natural range in speaking rate, whereas Gauster et al. and Achenbaugh elicited intentional rate modification within the speaker pool. Therefore, the differences between the current and previous studies may be due to either the method of rate modification or the different ranges of speaking rate.

Rate Manipulation Methodology

Rate variation can be achieved through several methods. Prolongation of pauses, vowels, or consonants results in a slower rate, whereas truncation of any or all will achieve a faster rate. The manner of production of plosives and affricates makes it difficult to prolong or truncate these phonemes, and therefore may be less likely to be involved in speaking rate modification.

The oral phonemes /p, t, k, s, ʃ/, produced in isolation, are associated with very low (almost zero) nasalance values (Kay-Pentax, 2013). According to the KayPentax manual

(2013), the vowels /a/ and /i/ are associated with normative values greater than the oral phonemes (/a/ mean: 6 %, SD: 3 %; /i/ mean: 19 %, SD 9 %). Therefore, when the oral phonemes are combined with /a/ or /i/ for repeated syllable tasks, the vowel identity may be principally responsible for the elevated nasalance values. Oral syllables produced at a faster rate of speech may have shorter vowel durations, and thus a lower nasalance value. Conversely, nasal phonemes /m, n/ are associated with high nasalance values (>90). When the nasal phonemes are combined with /a/ or /i/ for repeated syllable tasks, the vowel may be responsible for the decreased nasalance values. Nasal syllables produced at a faster rate of speech may have shorter vowel durations, and thus a higher nasalance value (Kay-Pentax, 2013). These explanations are currently speculative, as direct measures of vowel and consonant durations were not completed.

A slowed speaking rate can be achieved in several ways. With the nasal sentence (“mama made some lemon jam”) used in the Gauster et al. (2010) and Achenbaugh (2012), both the nasals and vowels could be extended to produce “slow” and “slowest” speech. If the speaker chose to extend the nasals and produce the vowel for a “normal” duration, then the nasalance of the slower productions would be higher than the nasalance at the “normal” rate. If the speaker chose to extend the vowels and produce the nasals for a “normal” duration, then the nasalance of the slower productions would be lower than the nasalance at the “normal” rate. The oral sentence (“buy Bobby a puppy”) used by the Gauster et al. (2010) and Achenbaugh (2012), is comprised of vowels and bilabial plosives. When producing intentionally slower versions of this sentence without pausing between words, as directed by the investigators, the vowels are the obligatory phonemes for elongation. As vowels have greater nasalance than plosives, the slower productions of the oral sentence would result in higher nasalance.

Other Findings

The role of gender on nasalance values has been examined by previous studies and the results have been equivocal (Achenbaugh, 2012; Gauster et al., 2010; Goberman et al., 2001; Seaver et al., 1991). The current result failed to reveal a gender difference.

In typical speaking populations, nasal phonemes are associated with greater nasalance than oral phonemes (Bressmann, 2004; Kay-Pentax, 2013). The current study produced equivalent findings when examining paragraphs and repeated syllables containing these phonemes. It is widely accepted that the vowel /i/ is associated with greater nasalance than the vowel /a/ (Kay-Pentax, 2013; Lewis et al., 2000). The current study produced equivalent findings when examining repeated syllables containing these vowels.

Clinical Relevance

Kummer (2008) suggested that repeated syllables be produced at a “normal” rate. This statement implicitly presumes that speaking rate may have some effect on nasalance values. However, with “normal” rate being undefined, clients and clinicians will take it upon themselves to determine “normal rate”. From the present research, it is clear that clinicians should pay attention to speaking rate when interpreting nasalance values. Syllable stimuli appear to be more sensitive to rate variations, as 13 of the 14 stimuli were affected by variation of speaking rate. The frequency of occurrence histograms for the syllable stimuli had a wider range than the paragraph stimuli, further supporting the postulation that these stimuli are more susceptible to speaking rate variation. Though nasalance values for paragraph stimuli appear to be more resistant to rate variation, some comparisons are significant or trending towards significance. These results suggest that when left to self-selection, speakers may choose from a wide range of speaking rates.

There are several potential solutions to the speaking rate predicament when measuring nasalance. One option would be to develop norms for various speaking rates. A normative data table that included ranges in syllables per second for stimuli could help the clinician compare their client to others who speak at the same rate.

Another option would be to establish a standardized instruction system. Most standardized speech-language assessments used by clinicians have a strict script for administration. It would not be difficult to include a supplementary set of audio instructions along with the Nasometer. These instructions, recorded with a standard speech rate, would provide each client with the same directions for the speech stimuli, thus eliminating the potential influence of stimulus modeling and rate of speech by the clinician. As it is the intention of the Americleft group to assemble objective outcome data from cleft palate centers across the country, a standardized instruction method could result in a more valid comparison within and across centers.

Limitations

The current study arose out of a larger research project aimed at establishing regional nasalance norms. Once a high degree of natural variation in speaking rate within and among participants was noted, a need for a study evaluating the speaking rate-nasalance relationship was identified. However, no attempt was made to collect data specifically on fast and slow speakers. Therefore, it is unclear how well this dataset represents the range of natural variation within a population.

A second limitation is that the participants in the current study may not accurately represent the clinical populations. In clinical populations with resonance and motor speech disorders, the client's articulation tends to be less stable. As a result, variations in clinical populations may be greater than variations observed in the current study. Additionally, the age range of the experimental group does not align with typical clinical populations, which often include children (i.e. cleft palate) and older adults (i.e. neurogenic speech disorders).

The measurement of syllable rate in the current study was somewhat coarse since it was found by dividing the number of syllables produced by the duration of the speech signal. A more refined measure that includes phonetic durations and pauses should be considered in future studies to better understand the speaking rate-nasalance relationship.

The current study limited the investigation to individuals with a dialect from the lower peninsula of Michigan. Findings from this study may not generalize to dialects in other regions of the United States. Byrd (1994) reported that Northern (Wisconsin) speakers have a higher articulation rate than Southern (North Carolina) speakers in reading and speaking tasks. Additionally, Byrd (1994) found that younger Northern adults spoke faster than older Northern adults, which could make the findings from the current study less significant when considering more diverse populations. Jacewicz, Fox, & Salmons (2007) examined vowel length in three English dialects in the United States: Inland North (south-central Wisconsin), Midlands (central Ohio), and South (western North Carolina). Jacewicz and colleagues (2007) reported that longer vowel durations were associated with the Southern group, and shorter vowel durations were associated with the Inland North group. With systematic differences identified between dialects pertaining to speaking rate and vowel length, it is highly likely that the current study does not address all factors relevant to dialect.

Future Research

Future studies could focus on a more refined examination of how speaking rate is manipulated (e.g. altering pauses durations vs. phoneme durations) and whether these varied rate modification approaches differentially influence nasalance. Second, since current nasometry protocols are somewhat vague with regard to instructions about speaking rate, future studies should focus on standardizing instructions. For example, an experimental study could examine if pre-recorded audio instructions stabilizes speaking rate.

Finally, the methods of the current study should be expanded to clinical populations to examine the influence of speaking rate on nasalance. As function of the velopharyngeal port vary greatly among groups with resonance disorders (nasal airway impairments, hearing impairments, motor speech disorders), analyses should be conducted for different clinical populations.

APPENDICES

APPENDIX A

HUMAN SUBJECT INSTITUTIONAL REVIEW BOARD APPROVAL LETTER

WESTERN MICHIGAN UNIVERSITY

Human Subjects Institutional Review Board

Date: September 13, 2012

To: Helen Sharp, Principal Investigator
Stephen Tasko, Co-Principal Investigator
Greg Flamme, Co-Principal Investigator
Emily Winters, Student Investigator

From: Amy Naugle, Ph.D., Chair Amy Naugle

Re: HSIRB Project Number 12-04-03

This letter will serve as confirmation that the change to your research project titled "Normative Nasalance for Adult Speakers from the Northern Mid-West Dialect Region" requested in your memo received September 12, 2012 (Add student investigator Rachel Whitney and modify consent document to reflect these changes) has been approved by the Human Subjects Institutional Review Board.

The conditions and the duration of this approval are specified in the Policies of Western Michigan University.

Please note that you may **only** conduct this research exactly in the form it was approved. You must seek specific board approval for any changes in this project. You must also seek reapproval if the project extends beyond the termination date noted below. In addition if there are any unanticipated adverse reactions or unanticipated events associated with the conduct of this research, you should immediately suspend the project and contact the Chair of the HSIRB for consultation.

The Board wishes you success in the pursuit of your research goals.

Approval Termination: April 10, 2013

Walwood Hall, Kalamazoo, MI 49008-5456
PHONE: (269) 387-8293 FAX: (269) 387-8276

APPENDIX B

HISTORY QUESTIONAIRE

NASOMETRY STUDY:
BACKGROUND INFORMATION FORM

1. **Gender:** ☐ Male ☐ Female

2. **Age:** ____________________________(in years)

3. **Do you have a history of cleft lip or palate?** ☐ Yes ☐ No

   If yes, please specify the type of cleft: ________________________________

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

   If yes, what for? ____

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

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

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

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

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

☐ White

☐ Black/African American

☐ American Indian/Alaskan Native

☐ Asian

☐ Native Hawaiian/Pacific Islander

☐ Hispanic/Latino Origin

☐ Other Race/Ethnicity

☐ Prefer not to answer

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 C

SPEECH STIMULI

Repeated Syllables of the SNAP-R Protocol:
pa, ta, ka, sa, ʃa, ma, na, pi, ti, ki, si, ʃi, mi, ni

Rainbow Passage
When the sunlight strikes raindrops in the air they act like a prism and form a rainbow. The rainbow is a division of white light into many beautiful colors. These take the shape of a long round arch with its path high above and its two ends apparently beyond the horizion. There is according to legand a boiling pot of gold at one end. When a man looks for something beyond his reach, his friends say he is looking for a pot of gold at the end of the rainbow.

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

Sibilant Paragraph
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.

Zoo Passage
Look at this book with us. It's a story about a zoo. That is where bears go. Today it's very cold out of doors but we see a cloud overhead that is a pretty white fluffy shape. We hear straw covers the floor of the 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.

APPENDIX D

MULTI-LEVEL ANALYTIC MODEL: PARAGRAPH STIMULI

Multi-level analytic model: Paragraph Stimuli

Wald chi2(49) = 30820.62
Log likelihood = -8086.5255
Prob > chi2 = 0.0000

Nasalance,rau	Coefficient	Standard Error	z	P>|z|	95% Confidence Interval
Rate					
Medium Rate	-.1553465	.6258089	-0.25	0.804	-1.381909 to 1.071216
High Rate	-.4362378	.7016211	-0.62	0.534	-1.81139 to .9389142
Stimuli					
Nasal Stim	27.39013	.5762351	47.53	0.000	26.26073 to 28.51953
Zoo Stim	-24.0504	.5679403	-42.35	0.000	-25.16354 to -22.93725
Sibilant Stim	-21.85863	.5902616	-37.03	0.000	-23.01553 to -20.70174
Rate by Stimuli					
Med Nasal	-.3808793	.8455547	-0.45	0.652	-2.038136 to 1.276378
Med Zoo	-.4856667	.830746	-0.58	0.559	-2.113899 to 1.142566
Med Sibilant	-1.882454	.8462619	-2.22	0.026	-3.541097 to -.2238111
High Nasal	-.0603689	.859911	-0.07	0.944	-1.745764 to 1.625026
High Zoo	-1.589944	.858657	-1.85	0.064	-3.272881 to.0929929
High Sibilant	-2.130691	.8652136	-2.46	0.014	-3.826479 to -.4349039
Gender					
female	1.832399	1.293755	1.42	0.157	-.7033145 to 4.368112
Tester Providing Instructions					
1	4.628315	1.962965	2.36	0.018	.7809746 to 8.475655
2	3.649341	2.318181	1.57	0.115	-.8942097 to 8.192893
3	-1.516915	4.917246	-0.31	0.758	-11.15454 to 8.12071
4	6.295261	2.176747	2.89	0.004	2.028916 to 10.56161
5	7.519963	2.293101	3.28	0.001	3.025569 to 12.01436
6	3.654981	2.492055	1.47	0.142	-1.229356 to 8.539319
7	9.742325	2.765991	3.52	0.000	4.321082 to 15.16357
_cons	26.64871	1.934915	13.77	0.000	22.85634 to 30.44107

APPENDIX E

MULTI-LEVEL ANALYTIC MODEL: SYLLABLE STIMULI

Multi-level analytic model: Syllable Stimuli

Wald chi2(49) = 30820.62
Log likelihood = -8086.5255
Prob > chi2 = 0.0000

Nasalance,rau	Coefficient	Standard Error	z	P>|z|	95% Confidence Interval
Rate					
Medium Rate	-2.096802	1.472564	-1.42	0.154	-4.982975 to .7893705
High Rate	-6.817902	1.573405	-4.33	0.000	-9.901719 to -3.734085
Stimuli					
/ta/	2.681738	1.252707	2.14	0.032	.2264784 to 5.136998
/ka/	1.929301	1.257816	1.53	0.125	-.5359737 to 4.394576
/sa/	2.96447	1.257704	2.36	0.018	.4994152 to 5.429525
/ʃa/	3.274271	1.257875	2.60	0.009	.8088809 to 5.739662
/ma/	46.76928	1.265066	36.97	0.000	44.2898 to 49.24877
/na/	48.57449	1.259576	38.56	0.000	46.10576 to 51.04321
/pi/	16.96733	1.260075	13.47	0.000	14.49763 to 19.43703
/ti/	20.19072	1.258497	16.04	0.000	17.72411 to 22.65733
/ki/	21.2656	1.254355	16.95	0.000	18.80711 to 23.72409
/si/	18.5499	1.258728	14.74	0.000	16.08284 to 21.01696
/ʃi/	18.45747	1.258646	14.66	0.000	15.99057 to 20.92437
/mi/	73.29709	1.260724	58.14	0.000	70.82611 to 75.76806
/ni/	74.98024	1.255216	59.73	0.000	72.52006 to 77.44042
Rate by Stimuli					
Med /ta/	2.016061	1.907649	1.06	0.291	-1.722862 to 5.754985
Med /ka/	1.270591	1.911967	0.66	0.506	-2.476796 to 5.017978
Med /sa/	1.080525	1.911669	0.57	0.572	-2.666278 to 4.827328
Med /ʃa/	-.2852607	1.902058	-0.15	0.881	-4.013226 to 3.442705
Med /ma/	1.916813	1.917653	1.00	0.318	-1.841719 to 5.675344
Med /na/	3.032314	1.916681	1.58	0.114	-.7243113 to 6.78894
Med /pi/	-3.123276	1.913974	-1.63	0.103	-6.874596 to .6280445
Med /ti/	-2.246936	1.90575	-1.18	0.238	-5.982138 to 1.488265
Med /ki/	-2.717274	1.932113	-1.41	0.160	-6.504145 to 1.069598
Med /si/	-2.587373	1.916398	-1.35	0.177	-6.343444 to 1.168698
Med /ʃi/	-4.106294	1.905855	-2.15	0.031	-7.841701 to -.3708874
Med /mi/	-1.311109	1.929164	-0.68	0.497	-5.092202 to 2.469984
Med /ni/	.1533734	1.933944	0.08	0.937	-3.637088 to 3.943835
High /ta/	.8905892	1.872086	0.48	0.634	-2.778633 to 4.559811
High /ka/	3.530321	1.880887	1.88	0.061	-.156149 to 7.216792
High /sa/	1.61622	1.881334	0.86	0.390	-2.071127 to 5.303568
High /ʃa/	.3653233	1.892297	0.19	0.847	-3.34351 to 4.074157
High /ma/	13.62454	1.887064	7.22	0.000	9.925966 to 17.32312
High /na/	12.606	1.887763	6.68	0.000	8.906056 to 16.30595
High /pi/	.2236051	1.889209	0.12	0.906	-3.479176 to 3.926387
High /ti/	3.994406	1.893809	2.11	0.035	.2826079 to 7.706204
High /ki/	2.859612	1.875202	1.52	0.127	-.8157167 to 6.534941
High /si/	5.756681	1.888434	3.05	0.002	2.055419 to 9.457943
High /ʃi/	.9280887	1.899652	0.49	0.625	-2.795162 to 4.651339
High /mi/	8.101385	1.885154	4.20	0.000	4.406552 to 11.79622

High /ni/	7.171754	1.875415	3.82	0.000	3.496008 to 10.8475
Gender					
female	3.738708	1.778383	2.10	0.036	.2531403 to 7.224275
Tester Providing Instructions					
1	6.747685	2.658023	2.54	0.011	1.538055 to 11.95732
2	6.268766	3.131288	2.00	0.045	.1315537 to 12.40598
3	-1.777445	6.627466	-0.27	0.789	-14.76704 to 11.21215
4	7.573022	2.933486	2.58	0.010	1.823496 to 13.32255
5	11.0579	3.222368	3.43	0.001	4.742175 to 17.37362
6	7.378601	3.356408	2.20	0.028	.8001612 to 13.95704
7	10.91265	3.722202	2.93	0.003	3.617268 to 18.20803
_cons	-3.985031	2.764649	-1.44	0.149	-9.403644 to 1.433582

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