Assessing the Nasalance of Native Mandarin Speakers in Mandarin and English

by

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The purpose of the study is to determine whether native Mandarin speakers show a difference in nasalance measurement in their native language compared to English and analyze the effect of predictors on nasalance scores. The participants included 45 native Mandarin-speakers (20 males, 25 females) from mainland China between 20 and 54 years of age. All participants were tested in the speech laboratory of East Carolina University. Participants completed a questionnaire about cultural and linguistic background. All participants recorded three Mandarin sentences and vowels, and three English sentences and vowels, designed to phonetically match Mandarin speech stimuli. Nasalance measurements were taken from the Nasometer II 6450. Participants were randomly selected to repeat recordings for test-retest reliability. A paired samples t-test revealed a significant difference between mean nasalance scores of English and Mandarin sentences ($p < 0.008$). Scores for English and Mandarin vowels did not yield significant results. A multiple linear regression model revealed significant gender-based differences ($p < 0.05$). Age, English language exposure, mean English language preference and dialect did not yield significant results. It was concluded that Native Mandarin speakers yield different nasalance scores in their native language compared to English. This confirms that separate nasalance score norms are needed for the Mandarin language. Gender-based differences should be considered in the collection and analysis of nasalance scores. Reported Nasometer scores can be used for preliminary normative data.

ASSESSING THE NASALANCE OF NATIVE MANDARIN SPEAKERS IN MANDARIN AND ENGLISH

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CHAPTER 1: INTRODUCTION

Velopharyngeal Function and Cleft Lip and Palate Management

The velopharyngeal mechanism is the primary mechanism affected in children born with cleft lip and palate. The mechanism is responsible for opening and closing the velopharyngeal port which connects the nasal and oral cavity. Complete velopharyngeal closure requires normal anatomy and physiology of the hard palate, soft palate, posterior pharyngeal wall and lateral pharyngeal walls (Perry, 2011). Proper seal and coordination of velopharyngeal closure is needed for speech production. Contraction of velopharyngeal muscles is required for the opening of the port for nasal sounds and closure to achieve oral sounds. These muscles, particularly the levator veli palatini and musculus uvulae, are impaired in children born with cleft lip and palate. Even after palatoplasty to repair the cleft and restore the function of velopharyngeal muscles, 15-45% of children still require speech or further surgical intervention (Bicknell, McFadden, & Curran, 2002). Speech evaluation is important to determine the appropriate next steps. Henningsson et al. (2008) describes the five universal speech parameters that should be evaluated for individuals with cleft palate: hypernasality, hyponasality, audible nasal air emission, articulation errors and voice disorder.

The Nasometer and Cleft Lip and/or Palate Speech Assessment

The Nasometer (Kay Elemetrics, Lincoln Park, NJ) is a device that can be used to provide objective measurements for velopharyngeal function. It is a noninvasive method for assessing nasal resonance that is used clinically and in research (Dalston, Warren, & Dalston, 1991b). The Nasometer contains two microphones separated by a plate that rests on the upper lip. It calculates the ratio of nasal to nasal-plus-oral acoustic energy during speech which is multiplied by 100 to yield a percentage nasalance score. The nasalance score can be used in the diagnosis of resonance problems associated with velopharyngeal insufficiency and nasal obstruction, providing visual feedback to the patient, or used to measure pre- and post-treatment effectiveness (Dalston, Warren, & Dalston, 1991a; Kummer, 2008).

Complete velopharyngeal closure is indicated by low nasalance scores during a speech sequence with no nasal consonants (Dalston et al., 1991b). Incomplete velopharyngeal closure would result in elevated nasalance scores during a non-nasal speech sample, also known as hypernasality. Excessive velopharyngeal closure or obstruction in the velopharyngeal port would result in lowered nasalance scores during nasal-loaded speech samples, also known as hyponasality.

The Nasometer was first introduced in 1970 by Fletcher as The Oral Nasal Ratiometer (TONAR). Since then, studies have confirmed strong correlations between perceptual ratings and nasalance scores, presenting the Nasometer as a reliable alternative to quantifying speech resonance (Brunnegard, Lohmander, & Van Doorn, 2012; Dalston et al., 1991b; Dalston, Neiman, & Gonzalez-Landa, 1993; Hardin, Demark, Morris, & Payne, 1992). In 2003, the Nasometer 6200 was upgraded to the Nasometer II 6400, changing the level of the nasal and oral microphone signals at a rate of 120 Hz at 8 bits of resolution to 11025 Hz at 16 bits of resolution. Awan and Virani (2013) noted significantly different mean nasalance scores between the two models for the Zoo Passage and Rainbow Passage. However, Watterson, Lewis, & Brancamp (2005) observed no significant differences between nasalance scores obtained with the two models.

Similar devices utilized for measuring nasalance include the NasalView (Tiger Electronics Inc., Seattle, WA) and the OroNasal system (Glottal Enterprises Inc., Syracuse, NY).

Awan (1997) compared measurements obtained by NasalView and the Nasometer, reporting nasalance scores with the NasalView were higher for oral stimuli and lower for nasal stimuli. The difference is attributed to the lack of bandpass filtering in the NasalView. Bressmann (2005) compared nasalance scores obtained by the three instruments, concluding that the nasalance scores are not interchangeable and should not be compared directly. The Nasometer remains the gold standard for quantifying nasality, supported by extensive literature across different languages and disorders. There is an increasing use of the Nasometer internationally and across languages (Krakow & Huffman, 1993; C. Mayo & R. Mayo, 2011).

Standardized speech stimuli have been established for the Nasometer, establishing cut-off scores for different passages. The most commonly used passages are the Zoo passage, Rainbow Passage and Nasal Sentences passage, which are included in the manufacturer's manual (Kay Elemetrics, 2010). The Zoo Passage contains all oral consonants, the Rainbow Passage contains a mixture of oral and nasal consonants, and the Nasal Sentences passage is loaded with nasal consonants. These normative data were established based on studies of children and adults with varying regional dialects and speech characteristics.

Another example of standardized speech stimuli includes the MacKay-Kummer SNAP Test-R, which is a clinical assessment widely used to evaluate the nasalance of children with resonance disorders (Kummer, 2005). This protocol contains three subtests: Syllable Repetition/Prolonged Sounds, Picture-Cued, and Reading Passages subtest. Normative data were reported for children aged 3 to 9 years old residing in the Midwest region of the United States to provide threshold values useful for clinical interpretation of nasalance values.

While perceptual assessments are considered the gold standard for evaluating resonance, intra- and inter-judge variability presents as a challenge for qualitative assessments, particularly when the listener is a non-native language speaker. It is important that perceptual assessments are supplemented with objective instrumental assessments to provide quantitative measures.

Cleft Lip and Palate Incidence and Management in Native Mandarin Speakers

Studies show that those of Asian descent have the largest occurrence of cleft lip and/or palate with an incidence report of 1 in 500 (Kling, Taub, Ye, & Jabs, 2014). Because of this higher incidence, Mandarin, for which most speakers are of Asian descent, are important in the study of nasalance. Mandarin, also known as Putonghua, is the most commonly spoken dialect of Chinese and has the largest population of native speakers in the world (889 million speakers), with approximately 1.3 billion speakers (Lewis, Simons, & Fennig, 2016). Speakers reside in all parts of the world but predominantly in mainland China. In China alone, there are more than 40,000 new cases of cleft lip and/or palate each year; however, there are currently no clinical protocols comparable to those in English established for assessing nasality in native speakers of Mandarin (Kling et al., 2014).

Past Studies about Nasalance of Mandarin Speakers

There are four studies that discuss nasalance scores for native Mandarin speakers, two reported mean nasalance values of children while the other two reported on adults (Kim, Yu, Cao, Liu & Huang, 2016; Lim, 2011; Luo, 1992; Tsai, Wang, & Lee, 2012). Luo (1992) utilized Nasometer 6200 (Kay Elemetrics, Lincoln Park, NJ) to collect nasalance values using one oral sentence and one nasal sentence among 120 children between 6;6 and 7;6 years old (75 male, 45 female) living in China. Luo concluded that nasalance scores for normal head and neck anatomy yields a score less than 50% for the oral sentence and less than 70% for the nasal sentence, with no significant difference between genders. Luo (1992) reported mean nasalance scores by syllables, with stimuli of 10 syllables. Lim's (2011) unpublished study in Malaysia reported normative scores for 50 children 6;0 to 7;11 years old (24 male, 26 female) using an oral passage, oral-nasal passage, and a nasal passage. The outcomes of Lim's study provided a mean nasalance score of 16.08% for the oral passage, 55.44% for the nasal passage, and 25.20% for the oral-nasal passage, revealing a statistically significant difference of 1.6% between genders.

Tsai et al. (2012) reported nasalance scores using the Nasometer II 6400 (KayPENTAX, Lincoln Park, NJ) from ten native Mandarin speakers in Taiwan, 22 to 24 years old (6 male, 4 female) using English and Mandarin speech materials. The English speech stimuli included the first six sentences of the Zoo Passage (oral), the first two sentences of the Rainbow Passage (oro-nasal), and English Nasal Sentences (Fletcher, 1978; KayPENTAX, 2007). The Mandarin speech stimuli included a non-nasal and nasal (36.2% nasal phonemes) passage designed by the author. Tsai et al. did not report the influence of gender on nasalance scores. The mean nasalance scores were 6.7% for the Zoo Passage, 24.9% for the Rainbow Passage, and 48.1% for the English Nasal Sentences. For the Mandarin speech materials, mean nasalance scores were 11.8% for the non-nasal sentence, and 53.8% for the nasal sentence. Tsai et al. (2012) noted that native speakers of Mandarin yielded lower nasalance scores for English Zoo passage, Rainbow Passage, and English Nasal Sentences compared to English normative data.

The most recent study by Kim et al. (2016) utilized NasalView (Tiger Electronics Inc., Seattle, WA) to compare dialectal and gender differences in mean nasalance scores of 400 healthy, Chinese adults ages 18 to 23 living in China. The speech stimuli included a Mandarin oral sentence (100% high-pressure consonants), Mandarin oro-nasal sentence (50% oral and 50% nasal consonants), Mandarin nasal sentence (100% nasal consonants), and sustained vowels /a/,

/i/ and /u/. Sentences were 16 syllables in length and mean nasalance scores were as follows: 27.84% (oral), 45.72% (oro-nasal), 54.10% (nasal). The sustained vowels yielded mean nasalance scores of 31.45% for /a/, 37.21% for /i/, and 26.24% for /u/. Kim et al. also reported significant differences in nasalance due to regional dialects and gender.

Overall, the results from Tsai et al. (2012) suggest that there is a difference in nasalance scores of native speakers of Mandarin compared to normative data of speakers of English. Additionally, the mean nasalance scores of sustained vowels /a/ and /i/, 31.45% and 26.24%, reported by Kim et al. (2016) differ significantly when compared to the norm values, 6% and 19% respectively, from the MacKay-Kummer SNAP-R Test (Kummer, 2005). In the compilation of normative nasalance values across languages by C. Mayo and R. Mayo (2011), the authors suggested that further research is needed to compare nasalance values in the speakers' primary versus secondary language.

Influence of Race, Age, Gender, Dialect, and Language on Nasalance Scores

Numerous studies have examined the effects of speaker characteristics on nasality. These characteristics include race, age, gender, dialect, and native language. Corey, Gungor, Liu, Nelson, and Fredberg (1998) utilized a two-microphone acoustic rhinometer to compare nasal cross-sectional area between healthy adults of White, Black, Hispanic, and Asian racial or ethnic groups. The study concluded that race is one of the most important factors affecting nasal geometry. Therefore, normal values for nasal volumes or cross sectional areas should be calculated according to race. Xue, Hao, and Mayo (2005) confirmed that vocal tract dimensions differ between healthy White American, African American, and Chinese adult male speakers, resulting in formant frequency differences for vowel sounds. Similarly, Y. Liu, Lowe, Zeng, Fu, and Fleetham (2000) investigated cephalometric radiographs of Chinese and Caucasian individuals, noting that Chinese individuals had smaller maxilla and mandibles, steeper and shorter anterior cranial base, larger nasopharynx and oropharynx cross-sectional area, and smaller tongue height. A study by R. Mayo, Floyd, Warren, Dalston, and C. Mayo (1996) observed higher nasalance scores in white American adults than African American adults in reading of the Nasal Sentences. A review of past literature confirms that race should be considered in the comparison of nasalance scores due to morphological differences leading to acoustic differences.

There are conflicting results on the influence of age on nasalance scores; however, most studies noted a difference in nasalance scores across age, though not always clinically significant. Some studies indicated that children yield higher nasalance scores than adults (Park et al., 2014; Prathanee, Thanaviratananich, Pongjunyakul, & Rengpatanakij, 2003) while others report that adults yield increased nasalance scores compared to children (Ha & Cho, 2015; Hirschberg et al., 2006; Hutchinson, Robinson, & Nerbonne, 1978, Seaver, Dalston, Leeper, & Adams, 1991). Children between ages 4-6 showed no significant difference in nasalance score (Ha & Cho, 2015). These changes can be attributed to orofacial structural changes in the cross-sectional area of the nasal cavity that occurs with growth. As the vocal tract lengthens from childhood to adulthood, the facial height, depth, and width may change (Warren, 1979). There may also be physiological changes with age, as adults can have better neuromuscular control of the velopharyngeal port.

Multiple studies have reported higher nasalance scores in women compared to men (Park et al., 2014; Seaver et al., 1991). However, these differences are not clinically significant. Zajac, Lutz, and Mayo (1996) attribute the differences between males and females to sensitivity variations in frequency response of Nasometer microphones, which interact differently with female vocal tract. Another reason for the differences could be that females require more time to achieve velopharyngeal closure (Zajac & Mayo, 1996).

As for the effect of dialect, Awan et al. (2015) examined the nasalance scores of speakers residing in six North American dialectal regions. Awan et al. concluded that dialect accounted for a 7-9% variation in nasalance scores. This confirms the findings of Seaver et al. (1991) that the Mid-Atlantic dialect yields higher nasalance scores than Southern or Mid-Western dialect. Kummer (2008) attributes these differences to tongue position during vowel production. Dialectal regions are distinguished by vowel production, leading to the conclusion that higher tongue position relates to higher nasalance scores. There is also a difference between varieties of English such as American, Canadian, Irish, and Australian. Lee and Browne (2013) observed lower nasalance values for adult speakers from Southern Ireland than English speakers from North America. Tsai et al. (2012) showed that Native Mandarin speakers from Taiwan had lower nasalance scores of English passages compared to native English speakers, which may be attributed to foreign accent or differences in articulation.

The use of the Nasometer internationally across English and non-English-speaking countries have led to studies reporting normative data for different languages. Studies have compared nasalance scores between Canadian English and Canadian French, and Castilian Spanish and American English (Leeper, Rochet, & MacKay, 1992; Roche, P., 1998; Santos-Terron, Gonzalez-Landa, & Sanchez-Ruiz, 1991). These studies concluded that nasalance values can vary with language. C. Mayo and R. Mayo (2011) compiled the published nasalance norms for Canadian French, Spanish, European, and Asian languages. However, there are many languages still in need of normative nasalance data, including Mandarin Chinese.

In summary, past literature has demonstrated that race and native language yield significantly different nasalance scores while gender, regional dialect, and age show a difference in nasalance scores but do not require separate norms. In conclusion of the literature review comparing the nasalance scores of different languages, C. Mayo and R. Mayo (2011) assert that every language requires normative nasalance data with culturally and linguistically relevant speech stimuli. Research is also needed for comparison of nasalance scores in primary and secondary language.

Mandarin and English Language Effects on Nasalance

Mandarin is the most-spoken dialect of Chinese consisting of 22 consonants, nine simple vowels, and four tones (Hua & Dodd, 2000). There are four possible syllable structures: V, CV, VC, and CVC. Twenty-one of the 22 consonants can occur in syllable-initial position while only two occur in the syllable-final position, both of which are nasal /n, ŋ/. There are six pairs of aspirated and unaspirated consonants, all of which are voiceless. Aspiration serves as a distinctive feature of Mandarin consonants. Eight of the 22 consonants are produced in the retroflex or alveolo-palatal placement. There are no consonant clusters in Mandarin. The vowels can be classified into nine simple vowels, nine diphthongs, and four triphthongs. The vowel system is distinguished by three height levels (Catford et al., 1974). There are no lax vowels in Mandarin because all are produced with stress. There are four tones in Mandarin which provide phonemic information and are characterized by voice pitch, length, and intensity (Hua & Dodd, 2000).

Standard American English contains 14 vowels and 24 consonants. Voicing serves as a distinctive feature of English consonants, with eight pairs of voice and voiceless consonants (Catford et al., 1974). There are six plosives, nine fricatives, two affricates, three nasal consonants and four approximants. There are no consonants produced in the alveolo-palatal placement and only one /r/ that is occasionally produced with retroflex placement. There are up to three-consonant clusters for prevocalic position and up to four-consonant cluster for post-vocalic positions (Hua & Dodd, 2000). The vowels can be classified into 11 simple vowels and three diphthongs. Vowels are distinguished by tongue position (low, mid, high), rounding (rounded or unrounded) and stress (lax, neutral, tense). There are many differences between Mandarin and Standard American English phonology, some of which may influence nasalance scores and some which may not. Regardless, it is important to note the differences which include voicing, aspiration, stress patterns, tone, and consonant frequency of occurrence.

In Mandarin, there are no voiced stops, affricates or fricatives (Hua & Dodd, 2000). The voiced consonants are the nasals /m, n, ŋ/, and the approximants /ɹ, l/. The difference in the acoustic aspects of consonant voicing between Mandarin and English can lead to differences in voice onset time. Voice onset time is described as the interval between the release of oral occlusion and onset of vocal fold vibration during consonant production (Jiang, McPherson, & Ng, 2016). Zlatin (1974) showed that voiceless stops have longer voice onset time compared to voiced stops. Longer voice onset time requires increased time for pressure to increase and greater oral pressure measurements (Lisker & Abramson, 1964).

Aspiration is a supplemental feature of English related to the location of the consonant in the syllable. Voiceless consonants are only strongly aspirated in word-initial position. In Mandarin, aspiration is a distinctive feature of the language. Aspirated consonants are typically strongly aspirated (Catford et al., 1974). S. Liu (1996) established that aspirated stops have longer voice onset time than the unaspirated counterpart. In English, consonants in initial position tend to receive more stress than those in medial or final position in syllables, which results in unreleased final consonants (Catford et al., 1974). In Mandarin Chinese, final consonants are often produced distinctly and fully. Lisker and Abramson (1967) explored eleven languages and noted that stressed voiceless stops have longer voice onset time than their unstressed counterparts. These articulatory features observed across languages can lead to acoustic differences when calculating nasalance scores.

A major difference between English and Chinese vowel production is the use of tones in Mandarin Chinese to distinguish vowel identity. The four tones in Mandarin include the high level, high rising, falling-rising, and high falling. These tones provide phonemic information to distinguish word meaning and are characterized by voice pitch, length, and intensity (Hua & Dodd, 2000). A study of tongue and jaw movement during production of the tones found that there is a retraction of tongue and jaw together with the lowering of the tongue for the falling-rising tone (Hoole & Hu, 2004). Rochet and Fei (1992) showed that tongue position acts as an acoustic impedance for the oral and nasal cavities. High vowel /i/ and /u/ yielded longer duration of nasalance and higher nasalance scores. There is a difference between the size of vowel space for Mandarin. While English vowels include four corners of the oral cavity forming a quadrilateral space (high-front, high-back, low-front, low-back), Mandarin vowels occupy only a triangular space (high-front, high-back, low-central). Increased proportion of high vowels can lead to increased nasality due to acoustic impedance for oral cavity.

An analysis of the frequency of occurrence of Mandarin consonants and vowels can provide valuable information concerning the expected nasalance of typical Mandarin-speaking adults. The China National Acoustic Standard Association (1995) established that the most frequently occurring consonants in syllable-initial position include /ʂ, tʂ, tɕ, t/. It was also reported that affricates are most frequently occurring (26%) followed by plosives (24%), fricatives (21%), nasals (7%), and approximants (7%). Approximately 15% of syllables contain no initial consonant. The frequency in which the nasal consonants occur in final position is 33%, with /n/ occurring at 17.2% of the time, and /ŋ/ at 15.8%. The falling tone (39.3%) and rising tone (22%) have the highest occurrence rate, followed by the falling-rising (19.6%) and high level (19.1%) tone.

For English, Mines, Hanson, and Shoup (1978) observed that almost two-thirds of consonants are voiced (64.73%) in conversational speech. Plosives were found to be the most frequently occurring (29.21%) followed by sonorants (19.42%) and nasals (18.46%). Majority of the vowels are articulated near the front of the mouth, front, and central vowels, accounting for approximately 72% of the vowels. These significant differences between SAE and Mandarin need to be considered when constructing the speech stimuli and reporting nasalance scores.

Purpose and Hypothesis

The purpose of this study is to determine whether native Mandarin speakers show a difference in nasalance in their native language compared to English. Additionally, secondary analysis will examine the effect of age, gender, dialect, English language preference, and mean English language exposure on nasalance scores. It is hypothesized that nasalance scores will differ based on acoustic and phonological differences such as voicing, aspiration, and consonant position within syllables. It is likely that gender will influence nasalance scores due to differences in vocal tract and fundamental frequency. Because little variation is expected in vocal tract dimensions within the age range of the participants, age is not hypothesized to influence nasalance scores. Dialect, English language preference, and mean English language exposure may influence scores because previous studies have published that regional and foreign accent alter nasalance scores (Tsai et al., 2012).

CHAPTER 2: METHODS

Participants

The methodology of this study was reviewed and approved by the Institutional Review Board at East Carolina University. The participants included 45 native Mandarin-speakers of (20 male and 25 female) between 20 and 54 years of age (Mean = 34.93, SD = 8.70 years). Litzaw and Dalston (1992) showed that nasalance scores and cross-sectional areas between genders for adults over the age of 18 did not differ. Other studies established that gender differences are small but persist due to differences between the female and male vocal tract (Zajac et al., 1996). To account for gender differences in this study, nasalance scores were reported from a balanced number of male and female participants. All participants were of Asian descent to control for anatomical variation affecting resonance, such as cephalometric dimensions and nasal cross-sectional area, attributed to racial differences (Xue, Hao, & Mayo, 2005).

A screening questionnaire was used to ensure that participants met the inclusion criteria (Appendix A). Participants who reported a cold or nasal blockage on the day of data collection were excluded to remove the effect of nasal congestion on resonance (Watterson, Lewis, J. Ludlow, & P. Ludlow, 2006). Participants with a history of speech disorder, craniofacial anomalies, musculoskeletal disorders, neurological disorders, swallowing disorders or hearing impairments were excluded. A brief oral mechanism examination was administered on all participants to confirm structurally and functionally normal anatomy for speech production.

Past studies have shown that dialectical differences have a significant impact on nasalance scores (Awan et al., 2015; Kim et al., 2016). Therefore, participants who were not from mainland China were excluded. The mean length of time the participants have spent in the United States was 91 months, with two months as the shortest and 294 months as the longest.

The Language Experience and Proficiency Questionnaire (LEAP-Q) was used to obtain self-reported information about participant's age, gender, dialect, current exposure to English, and English language preference (Marian, Blumenfeld, & Kaushanskaya, 2007). The information collected from the LEAP-Q will be used to determine the effect of predictors on nasalance score (Appendix B).

Nasometer Data Collection

The Nasometer II (model 6450, KayPENTAX, Lincoln Park, NJ) was used to audio-record and analyze the oral and nasal acoustic energy of participants' speech. Before data collection, the Nasometer was calibrated and the headgear was adjusted and placed according to manufacturer's instructions. The participants were asked to practice speaking with the device in place to ensure unobstructed speech production prior to data collection. The stimulus sets were presented in randomized order to control for fatigue or adjustment due to instrumentation. Mean nasalance values were obtained for each stimulus set only when the sounds, sentences, and passages were uttered without unusual hesitations, abnormal delays, revisions, and/or production errors.

Speech Stimuli

All participants were asked to perform three Mandarin sentences, three Mandarin vowels, three English sentences, and three English vowels while using the Nasometer (Appendix C). The Mandarin speech materials in the study included the oral, oro-nasal, nasal sentence, and three Mandarin vowels /a/, /i/ and /u/ from Kim et al. (2016). The English speech materials were designed to phonetically match the Mandarin speech stimuli. The most frequently occurring consonants in English /n, t, s, d, k, m, z, b, p/ were used to form the English stimuli (Mines, Hanson, & Shoup, 1978). Both the Mandarin and English oral sentence contain 16 non-nasal syllables with 100% high-pressure consonants. The English and Mandarin oro-nasal sentences contain 16 syllables, 50% oral and 50% nasal consonants with 50% high pressure consonants and 50% low pressure consonants. The Mandarin and English sentences contain 16 nasal syllables with 0% high pressure consonants. The Mandarin vowels were elicited following the three Mandarin sentences and the English vowels were elicited following the three English sentences. To investigate test-retest reliability of instrumentation and variation between individuals, 12 subjects were randomly selected to repeat recordings. The headset was not removed between recordings for all materials.

Data Analysis

The mean nasalance values were measured using the Nasometer II software. The overall mean and standard deviation were generated via statistical software (SPSS version 24.0). The mean nasalance scores for the English and Mandarin stimuli were compared using a paired samples t-test, defining a p-value < 0.008 after the Bonferroni correction due to six comparisons performed on the data set. The six comparisons are as follows: English oral sentence and Mandarin oral sentence, English oro-nasal sentence and Mandarin oro-nasal sentence, English nasal sentence and Mandarin nasal sentence, English /a/ vowel and Mandarin /a/ vowel, English /i/ vowel and Mandarin /i/ vowel, English /u/ vowel and Mandarin /u/ vowel. The significance of predictors (age, gender, dialect, current exposure to English, and English language preference) on nasalance scores were analyzed using the multiple linear regression model because there are more than two factors.

CHAPTER 3: RESULTS

Mandarin and English Language Effects on Nasalance

The English and Mandarin sentence mean nasalance score comparisons yielded significant results (Table 1). The mean nasalance score of the English oral sentence (M = 20.02, SD = 7.83) was significantly greater than score of the Mandarin oral sentence (M = 17.64, SD = 7.33), t(44) = 3.71, *p* = 0.001. The mean nasalance score of the English oro-nasal sentences (M = 58.71, SD = 7.59) was significantly greater than score of the Mandarin oro-nasal sentence (M = 54.62, SD = 7.81), t(44) = 5.98, *p* = 0.000. The mean nasalance score of the English nasal sentence (M = 65.27, SD = 7.45) was significantly less than score of the Mandarin nasal sentence (M = 68.73, SD = 8.09), t(44) = -5.65, *p* = 0.000.

Table 1. Mean Nasalance Scores of English and Mandarin Stimuli (N = 45)

Language and Speech Stimuli	**English Mean (Standard Deviation)**	**Mandarin Mean (Standard Deviation)**	***p-value***
Oral Passage	20.02 (7.83)	17.64 (7.33)	0.001*
Oro-nasal Passage	58.71 (7.59)	54.62 (7.81)	0.000*
Nasal Passage	65.27 (7.45)	68.73 (8.09)	0.000*
/a/ vowel	32.22 (14.84)	33.98 (15.57)	0.254
/i/ vowel	47.07 (18.08)	47.18 (19.18)	0.946
/u/ vowel	15.62 (10.40)	15.51 (12.66)	0.931

*$p < 0.008$

The English and Mandarin vowel comparisons did not yield significant results. The mean nasalance score of the English vowel /a/ (M = 32.22, SD = 14.84) was less than the score of Mandarin /a/ vowel (M = 33.98, SD = 15.57) but was not statistically significant, t(44) = 1.16, *p* = 0.25. The mean nasalance score of the English /i/ vowel (M = 47.07, SD = 18.08) was less than the score of Mandarin /i/ vowel (M = 47.18, SD = 19.18) but yielded no significant difference, t(44) = 0.07, *p* = 0.95. The mean nasalance score of the English /u/ vowel (M = 15.62, SD =

10.40) was slightly greater than the score of the Mandarin /u/ vowel (M = 15.51, SD = 12.66) but yielded no significant difference, $t(44) = 0.09$, $p = 0.93$.

Influence of Gender, Dialect, Age, and English Language on Nasalance Scores

The relationships between the mean nasalance scores for the oral, oro-nasal, and nasal sentences were examined using a multiple linear regression model. The regression coefficient and *p*-values are reported in Table 2.

Participants included 20 males and 25 females. There were significant gender-based differences in nasalance scores for the English and Mandarin oro-nasal and nasal passages. Men scored lower than women for the English oro-nasal sentences ($\beta = -5.42$, $p = 0.02$), Mandarin oro-nasal sentences ($\beta = -6.51$, $p = 0.01$), English nasal sentences ($\beta = -7.15$, $p = 0.00$) and Mandarin nasal sentences ($\beta = -7.32$, $p = 0.00$). However, there were no gender-based differences in nasalance scores for the English and Mandarin oral sentences.

There was no significant correlation between dialect and mean nasalance score on any of the speech materials. The dialects were separated into three categories: south (n = 19), east (n = 13) and other (n = 13). The dialects from the south included Yue (n = 1), Hunan (n = 3), Minnan (n = 2), Chaoshan (n = 1), Henan (n = 3) and Hubei dialects (n = 9). The dialects from the east included Shanghainese (n = 3), Anhui (n = 2), Jiangsu (n = 7) and Zhejiang dialects (n = 1). The other dialects included Tianjin (n = 1), Hebei (n = 2) and no reported dialect (n = 13).

Participants ranged from 20 to 54 years old with mean age of 34.93 (SD = 8.70). Age was analyzed as a continuous covariate in the multiple regression model. The correlation coefficient and *p*-value for all speech stimuli are summarized in Table 2. There were no significant age-based differences in nasalance scores for all English and Mandarin speech stimuli.

The English language exposure and mean English language preference were measured by self-reported percentage points, with 0% representing no exposure and no preference. Participants reported the percentage in response to the question, "What percentage of the time are you currently and on average exposed to English?" on the LEAP-Q. The English language exposure was 44.53% (SD = 24.41) with a range from 2-85%. The mean English language preference was the average of two percentages reported on the LEAP-Q: (1) When reading, what percentage would you choose to read in English? (2) When speaking, what percentage would you choose to read in English? The mean English language preference of all participants was 33.81% (SD = 20.41) with a range from 0-85%. There was no significant correlation between English language exposure and mean English language preference with nasalance scores for all speech stimuli.

Table 2. Multiple Regression for Variables Predicting Nasalance Scores (N = 45)

	English Oro-Nasal		**Mandarin Oro-Nasal**		**English Oral**		**Mandarin Oral**		**English Nasal**		**Mandarin Nasal**	
	β	***p***	**β**	***p***	**β**	***p***	**β**	***p***	**β**	***p***	**β**	***P***
Male	-5.42	0.02*	-6.51	0.01*	-1.21	0.62	-0.10	0.97	-7.15	0.00*	-7.32	0.00*
Female**	0.00		0.00		0.00		0.00		0.00		0.00	
Southern Dialect	-0.66	0.81	0.32	0.91	2.85	0.34	2.09	0.46	-0.21	0.94	-2.42	0.39
Eastern Dialect	1.30	0.67	1.64	0.59	2.36	0.47	-0.22	0.94	0.04	0.99	0.84	0.78
Other**	0.00		0.00		0.00		0.00		0.00			
Age	0.18	0.20	0.13	0.33	0.20	0.16	0.20	0.16	0.10	0.45	0.05	0.71
English Exposure	-0.03	0.58	-0.02	0.69	0.03	0.60	0.00	0.96	0.01	0.92	0.02	0.80
English Preference	0.05	0.47	0.07	0.36	-0.06	0.46	-0.02	0.80	0.01	0.85	0.00	0.99
R^2	0.18		0.20		0.12		0.09		0.24		0.25	

*$p < 0.05$
**reference group

Test-Retest Reliability

The test-retest comparison of nasalance scores for 12 randomly selected subjects indicates a correlation coefficient between the first and second recordings of 0.96. The Pearson correlation for all sentences and vowels indicates a strong relationship ($p < 0.05$), confirming reliability of instrumentation and variation between individuals. The results of a paired samples t-test show that there is no significant difference between the first and second recordings confirming test-retest reliability, $t(77) = 1.47$, $p = 0.147$.

CHAPTER 3: DISCUSSION

Mandarin and English Language Effects on Nasalance

Past studies have concluded that nasalance values can vary with native language (C. Mayo & R. Mayo, 2011). There are many languages still in need of normative nasalance data with culturally and linguistically relevant speech stimuli, one of which is Mandarin Chinese. Research is also needed for comparison of nasalance scores in primary and secondary language.

The primary aim of this study was to determine whether native Mandarin speakers show a difference in nasalance in their native language compared to their achieved nasalance scores in English. Evaluation of the nasalance scores by language revealed a statistically significant difference between nasalance scores of English and Mandarin sentences. The difference in nasalance scores between English and Mandarin vowel productions was not statistically significant. Although there are differences between the quadrilateral and triangular vowel space in English and Mandarin respectively, the three vowels compared have the same tongue position in both languages (Catford et al., 1974). The three vowels /a, i, u/ are produced with a low-central, high-front, and high-back tongue position for English and Mandarin.

However, variation in articulatory features of consonants and phonotactic rules between English and Mandarin are more evident in sentence samples. Specifically, increased aspiration and decreased voicing in the consonants of Mandarin can be the result of decreased nasalance scores for oral and oro-nasal sentences (Catford et al., 1974). The presence of nasal consonants in the syllable-initial and syllable-final position of Mandarin language may contribute to higher nasalance scores of the Mandarin nasal sentence.

The Mandarin and English oral sentences each contain 16 oral syllables with frequently occurring high-pressure consonants while the oro-nasal sentences contain 8 oral syllables and 8 nasal syllables. The Mandarin oral sentences contain seven aspirated consonants and the oro-nasal sentence three aspirated consonants. Because aspiration serves as a distinctive feature in Mandarin, aspirated sounds are almost always strongly aspirated (Catford et al., 1974). In English, however, aspiration is a supplemental feature and consonants are only strongly aspirated in word-initial position. Aspirated stops have longer voice onset times than unaspirated stops, leading to greater release of oral pressure (Liu, 1996). There are no voiced stops, affricates or fricatives in Mandarin (Hua & Dodd, 2000). Zlatin (1974) showed that voiceless sounds have longer voice onset times compared to voiced sounds. The Mandarin oral sentences contain all voiceless consonants while the English oral sentences contain nine voiced consonants. Therefore, the presence of voiceless stops in Mandarin with longer voice onset times may lead to the decreased nasalance scores observed. This difference in aspiration and voicing can explain the decreased nasalance scores in Mandarin sentences. The increase in oral energy released decreases the overall nasal to nasal-plus-oral ratio.

The nasalance scores of the English nasal sentence were lower than that of the Mandarin nasal sentence. The Mandarin and English passages both contain 16 nasal syllables with 0% high pressure consonants. The higher nasalance score in Mandarin may be attributable to the presence of nasal consonants in the syllable-initial and syllable-final position of Mandarin language (Hua & Dodd, 2000). The frequency of occurrence of nasal consonants in final position is 33%, with /n/ occurring at 17.2% of the time and /ŋ/ at 15.8% (China National Acoustic Standard Association, 1995). This frequency is reflected in the Mandarin nasal stimuli, with five syllables with nasal consonants in the initial and final position. While the English nasal stimuli also contains 16 nasal syllables, it only contains three syllables with nasal consonants in the initial and final position. More nasal consonants per syllable could attribute to increased nasalance scores for the Mandarin stimuli.

Published Studies about Nasalance of Mandarin Speakers

There are a limited number of studies that have reported nasalance scores of native Mandarin speakers. Dialectal, age, and instrumentation differences should be considered when comparing nasalance scores between these studies (Table 3). The Mandarin stimuli were used to collect nasalance scores for native Mandarin speakers from China in this study. Tsai et al. (2012) reported lower nasalance scores for the oral passage collected from native Mandarin adult speakers from Taiwan. Kim et al. (2016) utilized the NasalView and found higher scores for the oral passage and lower scores for the oro-nasal and nasal passages. The 4-6% variation between the Nasometer and NasalView should be considered when comparing scores. The study among children by Luo (1992) and Lim (2011) reported oral scores consistent with this study. The 7.15% difference between the Nasometer II 6400 used in this study and the Nasometer 6200 in Luo's study should be considered (Awan & Virani, 2013), although Watterson, Lewis, & Brancamp (2005) observed no significant difference between Nasometer models.

Table 3. Comparison of Mandarin Chinese Nasalance Scores

Study	Instrument	Oral	Oro-nasal	Nasal
Pua et al.	Nasometer II 6450	17.64 (SD=7.33)	54.62 (SD=7.81)	68.73 (SD=7.45)
Tsai et al. (2012)	Nasometer II 6400	11.80 (SD=4.1)		53.80 (SD=7.4)
Kim et al. (2016)	NasalView	27.84 (SD=6.31)	45.72 (SD=6.21)	54.10 (SD=6.02)
Luo (1992)	Nasometer 6200	<50%		<70
Lim (2011)	Nasometer (unspecified)	16.08 (SD=2.57)	25.20 (SD=3.63)	55.44 (SD=4.17)

Influence of Gender, Dialect, Age, and English Language on Nasalance Scores

This study controlled for anatomical differences in race by recruiting participants of Asian descent. No significant age-based differences were noted in nasalance scores for all speech stimuli, resulting in several implications. First, this could be an indication that anatomical changes in the cross-sectional area of the nasal cavity that occurs with growth is stabilized within the age range of the participants in this study. Second, this may indicate little change in neuromuscular control of the velopharyngeal port within this age range.

The results of the study confirmed past studies showing that females have higher nasalance scores than males (Kim et al., 2016; Park et al., 2014; Seaver et al., 1991). These differences could be attributed to the sensitivity of the Nasometer microphones to variation in male and female frequencies (Zajac et al., 1996). Differences could also be reflecting a physiological difference between genders because males generate higher levels of peak intraoral air pressure than females, leading to decreased nasalance score (Zajac & Mayo, 1996).

Previous studies have indicated significant variation in nasalance between differing dialects (Awan et al., 2015; Kim et al., 2016). Kim et al. (2016) reported significantly different means for four cities in China—Beijing, Chongqing, Guangzhou and Shanghai. The dialect background in this study was grouped by larger geographical regions rather than cities. Therefore, greater variation is expected within each of the three dialect groups. More participants are needed from each geographic region to better represent the effect of dialect on nasalance scores.

It was expected that English language exposure and mean English language preference would influence English nasalance scores; however, no significant correlation was found. One factor could be the variation of self-reported percentage points. It is difficult to control for intersubject reliability in the ratings of English language exposure and preference. This suggests that other methods may be needed to better represent the effect of foreign accent.

Clinical Implications

The study indicated a significant difference between nasalance scores of native Mandarin speakers in their primary and secondary language. The mean nasalance scores in this study can be used as a reference for normative nasalance scores of native Mandarin-speaking adults, as scores for the Nasometer II has not previously been reported. However, creation of a normative database would require a significant increase in sample size with consideration to regional dialect differences. This study also demonstrated that translation of speech stimuli used to collect nasalance scores yields different results. Even when the speech sample was carefully constructed to be phonetically matched, differences such as frequency of occurrence, pressure consonants, and language phonology present difficulties. Therefore, culturally and linguistically appropriate speech stimuli should be used with normative data reported for each specific population. The results of the second aim show that gender differences should be accounted for when reporting nasalance scores. Future research is necessary to determine if these gender differences are evident in the child population.

Study Limitations

This study was conducted in eastern North Carolina. Therefore, the number of participants was limited by the population of native Mandarin speakers from mainland China currently residing in North Carolina. A larger sample size is needed to establish normative data. The effect of dialects on nasalance scores was limited because participants immigrated from many different parts of China. Data collected from participants with a larger sample from each dialectal background would provide data more indicative of dialectal influence on nasalance scores. The study reported nasalance scores from adults (ages 20-54), consequently, the nasalance scores may not be clinically relevant for children due to age differences. Further studies should aim to report nasalance scores for native Mandarin-speaking children with the same speech stimuli.

CHAPTER 4: CONCLUSION

This study determined that native Mandarin speakers yield different nasalance scores in their native language compared to English. The results yielded statistically different results in when comparing the English and Mandarin oral, oro-nasal and nasal sentences. Results from this study show that separate nasalance score norms and protocols are needed for the Mandarin language. Because nasality is best evaluated in connected speech, the results of the sentences should be considered for clinical evaluation of native Mandarin-speakers. Additionally, gender differences in nasalance scores should be considered when collecting normative data.

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APPENDIX A: SCREENING QUESTIONNAIRE

Name: ____

Age: _______ Date of Birth: ___________________ Gender: ____ Male ____ Female

Place of Birth (Please write in Chinese and English):

____

Hometown (Please write in Chinese and English):

____

Job/Occupation: ____

If student, Name of School:____

If employed, Place of Employment: ___________________________________

Date of Arrival in the United States: ____

Returns to home country since initial arrival to the United States: ________________________

____

Any history of…

Health problems?	No	If yes, ___________________________
Speech problems?	No	If yes, ___________________________
Craniofacial anomalies?	No	If yes, ___________________________
Musculoskeletal disorders?	No	If yes, ___________________________
Neurological disorders?	No	If yes, ___________________________
Swallowing problems?	No	If yes, ___________________________
Hearing impairments?	No	If yes, ___________________________
Adenoids removed?	No	If yes, ___________________________
Tonsils removed?	No	If yes, ___________________________

APPENDIX B: LANGUAGE EXPERIENCE AND PROFICIENCY QUESTIONNAIRE
(Marian et al., 2007)

Locations lived since birth:

	Location (city/town, province, country)	Length of time (month/years)
1		
2		
3		
4		

Please list all the languages you know in <u>order of dominance</u>:

Language A: ____
Language B: ____
Language C: ____

Please list all the languages you know in <u>order of acquisition</u>:

Language A: ____ (native language)
Language B: ____
Language C: ____

Dialects or languages spoken (Please write in Chinese and English):

____

What percentage of the time are you currently and on average <u>exposed</u> to each language?

Language A: _______%
Language B: _______%
Language C: _______%

When <u>reading</u>, what percentage would you choose to read it in each of your languages?

Language A: _______%
Language B: _______%
Language C: _______%

When speaking, what percentage would you choose to speak in each of your languages (to someone fluent in all your languages)?

Language A: _______%
Language B: _______%
Language C: _______%

On a scale from 0 to 10, please rate the extent to which you identify with each culture.

	Do not identify									Identify strongly
US-American	0	1	2	3	4	5	6	7	8	9	10
Chinese	0	1	2	3	4	5	6	7	8	9	10
___________	0	1	2	3	4	5	6	7	8	9	10

How many years of formal education do you have? _______ years

Please check your highest education level:

___ Less than high school
___ High School
___ Professional Training
___ Some College
___ College
___ Some Graduate
___ Masters
___ PhD/MD/JD
___ Other:

<u>CHINESE LANGUAGE</u> **This is my**: 1st 2nd 3rd Language

Age when you:

started learning	became fluent	began reading	became fluent reading

Please list the number of years and months you spent in:

Environment	**Years**	**Months**
Chinese-speaking country		
Chinese-speaking family		
Chinese-speaking school and/or working environment		

Please rate your level of proficiency in speaking, understanding and reading Chinese.

Low Level High Level

0 1 2 3 4 5 6 7 8 9 10

Please rate how much the following factors contributed to you learning Chinese:

	None										Big
Interacting with friends	0	1	2	3	4	5	6	7	8	9	10
Interacting with family	0	1	2	3	4	5	6	7	8	9	10
Reading	0	1	2	3	4	5	6	7	8	9	10
Language tapes/self-teach	0	1	2	3	4	5	6	7	8	9	10
Watching TV	0	1	2	3	4	5	6	7	8	9	10
Listening to the radio	0	1	2	3	4	5	6	7	8	9	10

Please rate how much you are exposed to Chinese now:

	None										Always
Interacting with friends	0	1	2	3	4	5	6	7	8	9	10
Interacting with family	0	1	2	3	4	5	6	7	8	9	10
Watching TV	0	1	2	3	4	5	6	7	8	9	10
Listening to the radio	0	1	2	3	4	5	6	7	8	9	10
Language-lab/self-teach	0	1	2	3	4	5	6	7	8	9	10
Reading	0	1	2	3	4	5	6	7	8	9	10

How much of a foreign accent do you have in Chinese?

None Big

0 1 2 3 4 5 6 7 8 9 10

How frequently do others identify you as a non-native Chinese speaker?

Never Always

0 1 2 3 4 5 6 7 8 9 10

ENGLISH LANGUAGE **This is my**: 1st 2nd 3rd Language

Age when you:

started learning	became fluent	began reading	became fluent reading

Please list the number of years and months you spent in:

Environment	**Years**	**Months**
English-speaking country		
English-speaking family		
English-speaking school and/or working environment		

Please rate your level of proficiency in speaking, understanding and reading English.

Low Level High Level

0 1 2 3 4 5 6 7 8 9 10

Please rate how much the following factors contributed to you learning English:

	None										Big
Interacting with friends	0	1	2	3	4	5	6	7	8	9	10
Interacting with family	0	1	2	3	4	5	6	7	8	9	10
Reading	0	1	2	3	4	5	6	7	8	9	10
Language tapes/self-teach	0	1	2	3	4	5	6	7	8	9	10
Watching TV	0	1	2	3	4	5	6	7	8	9	10
Listening to the radio	0	1	2	3	4	5	6	7	8	9	10

Please rate how much you are exposed to English now:

	None										Always
Interacting with friends	0	1	2	3	4	5	6	7	8	9	10
Interacting with family	0	1	2	3	4	5	6	7	8	9	10
Watching TV	0	1	2	3	4	5	6	7	8	9	10
Listening to the radio	0	1	2	3	4	5	6	7	8	9	10
Language-lab/self-teach	0	1	2	3	4	5	6	7	8	9	10
Reading	0	1	2	3	4	5	6	7	8	9	10

How much of a foreign accent do you have in English?

None Heavy

0 1 2 3 4 5 6 7 8 9 10

How frequently do others identify you as a non-native English speaker?

Never Always

0 1 2 3 4 5 6 7 8 9 10

APPENDIX C: SPEECH STIMULI

Mandarin Sentences (pinyin and tones)

Oral Sentence

哥哥陪**爸爸**去摘**他爱**吃的苦瓜和土豆。

(ge1gepei2ba4baqu4zhai1ta1ai4chi1deku3gua1he2tu3dou4)

Oro-nasal Sentence

奶奶梦到梅梅**买**的**鸽**子在吃地面的米。

(nai3naimeng4dao4mei2mei2mai3dege1zizai4chi1de4mian4demi3)

Nasal Sentence

内蒙**妈妈**娜娜每年**买牛奶柠**檬蜜面膜。

(nei4meng3ma1ma1na4na4mei3nian2mai3niu2nai3ning2meng2mi4mian4mo2)

English Sentences

Oral Sentence

Papa bought Katie cookies. Katie gave Papa two big kisses.

Oro-nasal Sentence

Hello, nice to meet you. My name is Bonnie. Is your name Minnie?

Nasal Sentence

My nanny Anna knew no one. My mom may know nanny Anna.

APPENDIX D: INSTITUTIONAL REVIEW BOARD APPROVAL

EAST CAROLINA UNIVERSITY
University & Medical Center Institutional Review Board Office
4N-70 Brody Medical Sciences Building· Mail Stop 682
600 Moye Boulevard · Greenville, NC 27834
Office **252-744-2914** · Fax **252-744-2284** · www.ecu.edu/irb

Notification of Amendment Approval

From: Biomedical IRB
To: Jamie Perry
CC:
Jamie Perry
Date: 9/23/2016
Re: Ame8_UMCIRB 13-001413
UMCIRB 13-001413
Aerodynamic Speech Characteristics in Upright versus Supine Positions

Your Amendment has been reviewed and approved using expedited review for the period of 9/22/2016 to 9/25/2016 . It was the determination of the UMCIRB Chairperson (or designee) that this revision does not impact the overall risk/benefit ratio of the study and is appropriate for the population and procedures proposed.

Please note that any further changes to this approved research may not be initiated without UMCIRB review except when necessary to eliminate an apparent immediate hazard to the participant. All unanticipated problems involving risks to participants and others must be promptly reported to the UMCIRB. A continuing or final review must be submitted to the UMCIRB prior to the date of study expiration.The investigator must adhere to all reporting requirements for this study.

Approved consent documents with the IRB approval date stamped on the document should be used to consent participants (consent documents with the IRB approval date stamp are found under the Documents tab in the study workspace).

The approval includes the following items:

Description
Changes to Study Team/Personnel

The Chairperson (or designee) does not have a potential for conflict of interest on this study.

IRB00000705 East Carolina U IRB #1 (Biomedical) IORG0000418
IRB00003781 East Carolina U IRB #2 (Behavioral/SS) IORG0000418