AN ACOUSTICALLY BASED CONTRASTIVE STUDY OF L1 AND L2 NASAL CODA PRODUCTION

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The present study adopts an acoustic approach to examine Mandarin speakers' production of Mandarin and English nasal codas /n, ŋ/ in different vowel contexts. Its purposes are to explore the interrelationship between nasal codas and the preceding vowels in both L1 and L2 production and to identify and explain similarities and differences between the L1 and L2 production.

1.   Background

1.1   Motivation for the Study

According to Ladefoged and Maddieson (1999), nasals are among the most common sounds in languages around the world.   As the most common sounds, these three nasals are presumably among the easiest to produce and acquire. However, Mandarin speakers seem to have difficulty articulating English /n, ŋ/ codas.   For example, Hansen's (2001) study reveals that Mandarin speakers tend to produce English /ŋ/ as /n/ in words such as *sing* and *song*, which renders *sing/song* similar to *sin/son*.

However, the confusion between English /n, ŋ/ seems not only limited to Beijing Mandarin speakers but also common among othe Chinese speakers and even native English speakers.   For example, in Zee's (1981) perceptual study of nasal coda identification by native English speakers, /n, ŋ/ are often confused in the high vowel context.   Thus, a more satisfactory explanation is needed to account for the alternation of English /n, ŋ/ by Mandarin speakers.

1.2   Research Questions and Hypotheses

Research questions:

(1)   How do vowel context and nasal place interact respectively in L1 and L2 production?

(2)   Can systematic similarities and differences be identified between the L1 and L2 production?   If yes, what linguistic factors may come into play?

Research hypotheses:

(1)   The actual nasal place in Mandarin speakers' production of English and Mandarin velar /ŋ/ is different.

The basis for this claim is that Mandarin speakers should be able to distinguish the two nasal codas /n/ and /ŋ/ in their Mandarin production, but that their ability to produce the two codas distinctively in Mandarin does not carry over to their English production.

(2)   English post-vocalic nasal production by Mandarin speakers is related to supra-segmental factors.

The basis for this claim is that if nasal codas /n/ and /ŋ/ by themselves are among the easiest segments to produce, then Mandarin speakers' ability to produce the two codas distinctively in English may be instead hampered by high-level constraints (such as syllabic and prosodic constraints in L1 or L2).

1.3   The Acoustic Properties of Vowels and Nasals

Vowels are traditionally described in terms of height, backness, and roundness. Syrdal and Gopal's (1986) perceptual study of American vowels and Sussman's (1990) study of the front/back vowel distinction respectively use F1-F0 (the difference between the first vowel formant and the fundamental frequencies) and F3-F2 (the difference between the third and second vowel formant frequencies) to correlate vowel height and backness because vowels can be more clearly separated by these two acoustic parameters.   Generally, the higher a vowel, the lower the F1-F0; the further back a vowel, the greater the F3-F2.

As for nasal place correlates, Kurowski and Blumstein (1987) found that there is less change in energy in the region of Bark 5-7 (395-770Hz) relative to that of Bark 11-14 (1265-2310Hz) for /n/ than for /m/. Since the Bark 5-7 and Bark 11-14 regions respectively encompass the first nasal zeros of /m, n/, the energy reduction difference in the two nasals, /m, n/ is largely due to the first nasal zero influence. Inferred from Kurowski and Blumstein's (1987) findings, this study assumes a larger energy reduction for /n/ than for /ŋ/ in the low-mid frequency (<3000Hz) region due to the higher first nasal zero value for /ŋ/ (> 3000Hz) than for /n/ (<3000Hz). In other words, the first nasal zero should be absent for /ŋ/ but present for /n/ in the low-mid frequency region, so there should be less energy reduction in this region for /ŋ/ than for /n/.

As for the nasal formant difference in nasal place, because the first, second, and third nasal formants (N1, N2, & N3) of all nasals have a similar frequency level respectively at 250Hz, 2500Hz, and 3250Hz (Ladefoged, 2001), they are generally not good nasal place cues. Nonetheless, they will still be measured here just in case they do show significance in detecting nasal place.

1.4   Vowel-nasal Coarticulation

Previous physiological studies seem to agree that "there is strong interaction between oral and nasal sounds" (Chafcouloff & Marchal, 1999, p. 70). For example, Chen's (2000) acoustic study of Mandarin VN production finds that when followed by /ŋ/, the three vowels /i, a, ə/ tend to move backward. Note that Chen's (2000) finding reflects the same backness constraint that Mandarin rimes agree in backness (Lin, 2007).

Nasalization is also found to have an impact on vowel duration depending on vowel context. For example, Clumeck (1976) found that low vowels have both a longer vowel duration and a longer duration of vowel nasalization than high vowels. Also, the duration of vowel nasalization is relatively long in American English and Brazilian Portuguese but short in Hindi, French, Swedish long vowels, and Amoy Chinese.

In fact, Manuel (1999) claimed that languages differing in their coarticulation patterns may be associated with their individual prosody patterns. For example, in a syllable-timed language such as Mandarin Chinese, each

syllable tends to have the same length (i.e., the syllable duration is relatively fixed), whereas in a stress-timed language such as English, syllable duration varies with syllable length.   Also, White and Mattys explicitly stated that speech rhythm implies "some form of top-down control of speech segment duration to regularise the language- specific rhythmic intervals" (2007, p.19).   If rhythm indeed has a top-down influence on nasal production, then VN production in different languages should have a different coarticulation pattern and segmental duration.

As for the relationship between the place of articulation and duration, Recasens' (1983) study of Catalan VN# found that m is 78ms long (the preceding vowel is 75ms long), but n is only 62 ms long (the preceding vowel is 87ms long). Chen (1972) also claimed that Mandarin /ŋ/ is two times longer than /n/. However, Chen (1972) did not provide acoustic evidence to support his claim.

Because open (low) vowels are longer than close (high) vowels, and /ŋ/ is longer than /n/, V_{open}ŋ (an open vowel followed by ŋ) and V_{close}n (a close vowel followed by n) may respectively have the longest and shortest duration among the four types of VN rimes, V_{open}ŋ, V_{open}n, V_{close}ŋ, and V_{close}n.

2.   Experiment

2.1   Participants and Speech Materials

Twenty Mandarin Chinese speakers (10 females and 10 males) participated in this study.   The participants were mostly international students from the University of Victoriain.   Eleven of them had received 10 years' formal English education before they came to Victoria.   Their background infomation was elicited through a questionnaire, and their speech data were collected through word-list reading.

Table 2-1 provides 4 English and 4 Mandarin test words used in the word-listing reading task.   All the words have the VN type of rime, forming a 4-way contrast in vowel context (open vs. close) and nasal place (alveolar vs. velar).

Table 2-1 Four English and four Mandarin CVN words

vowel context	English[1]		Mandarin[2]	
	/n/	/ŋ/	/n/	/ŋ/
close	*sin* (/sɪn/)	*sing* (/sɪŋ/)	*xìn* (/ɕin/)	*xìng* (/ɕiŋ/)
open	*son* (/sʌn/)	*song* (/sɔŋ/)	*sàn* (/san/)	*sàng* (/saŋ/)

[1] The English transcription is based on O'Grady & Archibald (2000).

[2] The Mandarin transcription is based on Lin (2001).

Note that all the Mandarin test words bear the falling Mandarin fourth tone to simulate the natural falling pitch of the English test words, though the pitch fall is much more gradual in English than in the Mandarin fourth tone.

2.2   Data Collection Procedure

Participants were instructed to perform the on-screen reading of the test words presented randomly in a PowerPoint Window. Each test word successively appeared 4 times (hence 4 tokens for each word) in a slide, with a 2-second interval following each appearance of a word. A total of 88 tokens (22x4) were collected for each participant.

The recording was carried out in a sound-attenuated room in the phonetics laboratory of the University of Victoria. The recording workstation was a Windows XP PC, and the recording software was Audacity 1.2.4. The sampling frequency was 44100Hz. Speech data were acoustically analyzed using Praat 4.4.22.

2.3   Data Analysis

The following acoustic parameters of vowels and nasals were measured by using Praat scripts and used to correlate with (⇔) a segmental feature of vowels or nasals:

(1)   F1-F0_fh & _sh (the difference between the mean F1 and F0 over the first and second half of the vowel duration) ⇔ Vowel height: If F1-F0_fh >

_sh, then the vowel height decreases over the duration.

(2)   F3-F2_fh & _sh (the difference between the mean F3 and F2 over the first and second half of the vowel duration) ⇔ Vowel backness: If F3-F2_fh < _sh, then the vowel backness increases over the duration.

(3)   N_D% (the percentage of the nasal murmur duration over the total vowel and nasal duration; i.e., N_D/D, D = V_D + N_D)⇔ The degree of vowel-nasal coupling: The greater the N_D %, the less the vowel and the nasal overlap in time and the less the degree of vowel-nasal coupling.

(4)   N1/N2/N3 and ΔdB ⇔ nasal place: the greater the N1/N2 (N3 does not seem to be a useful predictor of nasal place), and the smaller the ΔdB, the more backed the nasal place.

2.4   Statistical Analyses

Two t-tests were carried out to compare respectively between mean F1-F0_fh and _sh and between mean F3-F2_fh and _sh for each test word across tokens and speakers.   The statistical results were used to predict the significance of nasal coda influence on the preceding vowel.   Also, six ANOVA tests each were carried out to compare respectively among mean N_D%s, mean Ds, mean N1s, mean N2s, mean N3s, and mean ΔdBs for the 8 test words across tokens and speakers.   The statistical results were used to indicate whether or not a word is significantly different from the remaining words in terms of N_D%, D, N1/N2/N3, and ΔdB.   All the statistical results from these ANOVA tests were used to infer the nasal place difference among test words.

3.   Results

3.1   Vowel Measurements

Figure 3-1 and 3-2 respectively illustrate vowel height/backness changes over the duration for the 4 English words, *sin/sing/son/song*, and the 4 Mandarin

words, *xìn/xìng/sàn/sàng*.   The start point of each arrowed line represents mean F3-F2 (the x-axis) and mean F1-F0 (the y-axis) over the first half of the vowel duration, and the end point (where the arrow head is) represents mean F3-F2 and mean F1-F0 over the second half of the duration.

*Figure 3-1   Mean F3-F2 and mean F1-F0 over the first and second half of vowel duration for **sin/sing/xìn/xìng** (Unit: Hz)*
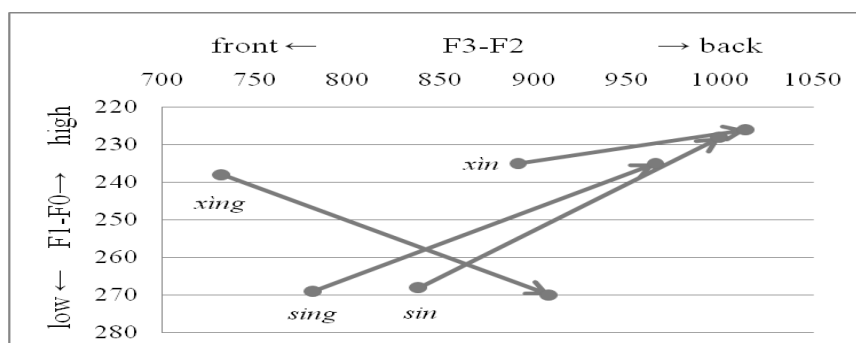

Figure 3-1 shows that only for *xìng,* the vowel movement over the duration is towards low back rather than high back.   A 2-tailed paired samples t-test revealed that the difference between mean F3-F2_fh and _sh is significant for *xìng* at the 5% level: t_{19} = -2.461, *p* = .024, which shows that there is a significant change in vowel backness for *xìng* over the duration.

*Figure 3-2 Mean F3-F2 and mean F1-F0 over the first and second half of vowel duration for **son/song/sàn/sàng** (unit: Hz)*
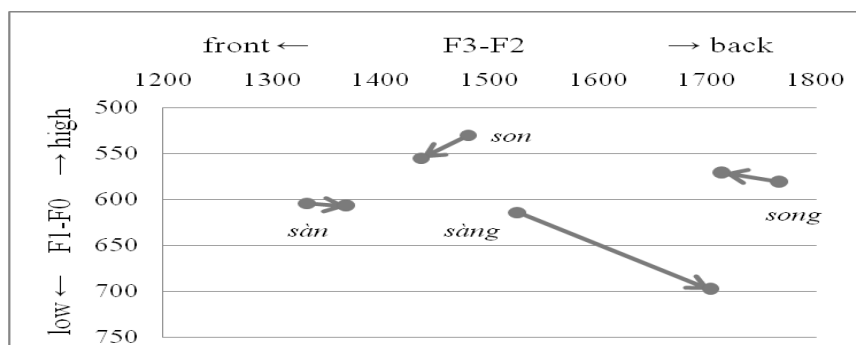
Figure 3-2 shows that there are greater vowel height/backness changes over the duration for *sàng* than for the rest of the words. A 2-tailed paired samples t-test revealed that the difference between mean F1-F0_fh and _sh is significant for *sàng* at the 5% level: t_{19} = -2.370, p = .029, which shows that there is a significant change in vowel height for *sàng* over the duration.

Figure 3-1 and 3-2 together show that Mandarin velar /ŋ/ can be distinguished from alveolar /n/ in terms of its significant influence on the preceding vowel. In contrast, English /ŋ/ produced by the Mandarin speakers does not have a significant influence on the preceding vowel.

3.2   Durational measurements

Figure 3-3 illustrates mean V_D (vowel duration), mean N_D (nasal murmur duration), and mean D (the total vowel and nasal duration) for each of the 8 words across tokens and speakers. The x-axis represents the duration in second (s) and each bar along the y-axis represent each of the 8 words.

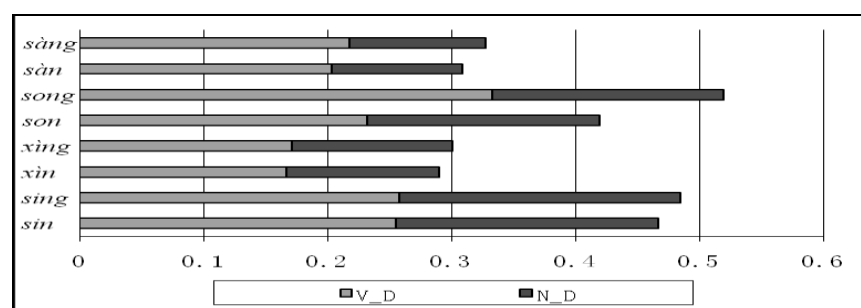*Figure 3-3 Mean V_D, N_D, and D for **sin/sing/xìn/xìng/ son/song/sàn/sàng***

Figure 3-3 shows that the 4 Mandarin words, *xìn/xìng/sàn/sàng* (their average D = 0.31s), are shorter than the 4 English words, *sin/sing/son/song,* (their average D = 0.47s), which is expected because the 4th tone (hence the associated word) is the shortest among all 4 Mandarin tones when produced in isolation (Ho, 1976). Notice that all the 4 Mandarin words have a similar D around 0.3s, despite their difference in vowel context and/or nasal place. As mentioned in Section 1.4, Mandarin is a syllable-timed language, so the duration of the 4 Mandarin words

(i.e., 4 syllables) is expected to be relatively equal. Although the 4 English words are all monosyllabic, their D is varied depending on the vowel context; specifically, *sin/sing* have similar duration but *son*/*song* respectively have the shortest and the longest duration among the 4 English words.

A repeated measures one-way ANOVA test revealed that there is a significant difference among mean Ds for the 8 words, $F_{7, 133} = 25.786$, $p < .001$, and this is a medium effect size (partial eta-squared = .576). Specifically, D for *xìn/xìng/sàn/sàng* is significantly smaller than for *sin/sing/son/song* at the 5% level: $p < .001$. Also, D for *son* is significantly smaller than *song* at the 5% level: $p = .014$. Note that the difference in D between *son* and *song* mainly results from the difference in V_D; that is, V_D for *son* is much smaller than in *song*, suggesting that the vowel /ʌ/ in *son* is higher and thus shorter than the vowel /ɔ/ in *song*.

Figure 3-4 illustrates mean N_D% (the percentage of the nasal murmur duration over the total vowel and nasal murmur duration) for each of the 8 words across tokens and speakers. The x-axis represents N_D/D in percentage (%), and each bar along the y-axis represents each of the 8 words.

Figure 3-4 Mean N_D% for **sin/sing/xìn/xìng/son/song/sàn/sàng**

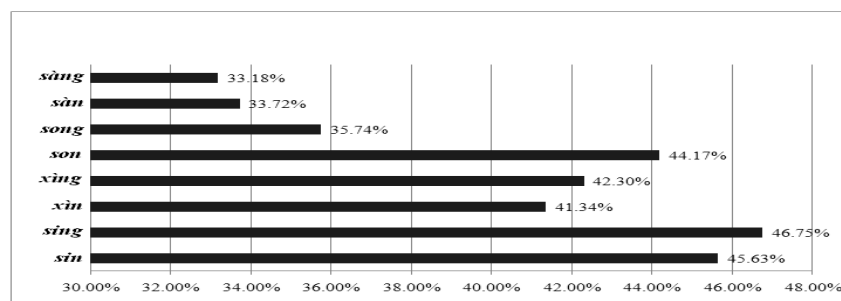Figure 3-4 shows that mean N_D% is smaller (<40%) in *song*/*sàn/sàng* than in *sin/sing/xìn/xìng*/*son* (>40%), suggesting that vowels in *song*/*sàn/sàng* are lower and thus have a higher degree of nasalization than in *sin/sing/xìn/xìng*/*son*. As mentioned in Section 1.4, the degree of vowel nasalization correlates inversely with nasal murmur duration; that is, the longer the nasal murmur duration (hence the larger N_D%), the lower the degree of vowel nasalization since there is less

overlap between the vowel and the nasal. Note that the vowel /ʌ/ in *son* is identified as being similar to high vowels in *sin/sing/xìn/xìng* rather than low vowels in *song*/*sàn/sàng* in terms of its large N_D% (44.17%). Recall in Figure 3-2, /ʌ/ in *son* is higher than in *song*/*sàn/sàng*, similar to a high-mid vowel, so it is not surprising that N_D% in *son* is comparable to that in *sin/sing/xìn/xìng* (all > 40%).

A repeated measures one-way ANOVA test revealed that there is a significant difference among mean N_D%s for the 8 words, $F_{7,\ 133} = 6.244$, $p = .022$, though this is a relatively small effect size (partial eta-squared = .247). Specifically, N_D% for *son* is significantly larger than for *song/sàn/sàng* at the 5% level: $p = .033, .001, .001$, respectively, which confirms that the vowel /ʌ/ in *son* can be considered as a high-mid rather than the presumed low-mid vowel.

Figure 3-3 and 3-4 together show that English /n, ŋ/ produced by the Mandarin speakers can be distinctively distinguished by the difference in N_D% and D in the open (low) vowel context, but this is not the case in the Mandarin /n, ŋ/ production.

3.3   Nasal Measurements

Figure 3-5 illustrates mean N1/N2/N3 for each of the 8 words across tokens and speakers. Each dot along the x-axis successively represents each of the 8 words, and the y-axis represents the formant frequency value in Hz.

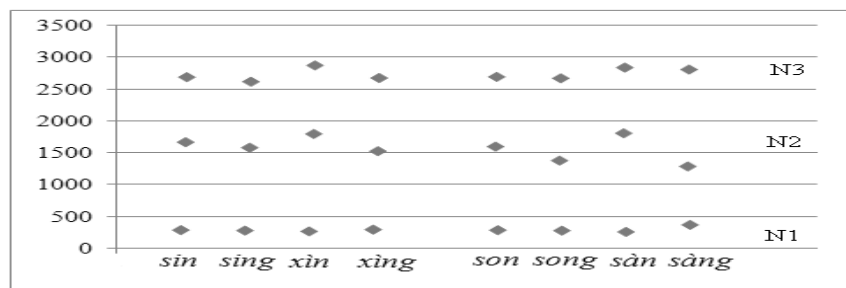*Figure 3-5 Mean N1/N2/N3 for **sin/sing/xìn/xìng/son/song/sàn/sàng***

Figure 3-5 shows that mean N2/N3 for *sing/song* and *xìng/sàng* is respectively lower than for *sin/son* and *xìn/sàn*.   A repeated measures one-way ANOVA test

revealed that there is a significant difference among mean N2s for the 8 words, $F_{7, 133} = 6.139$, $p = .023$, though this is a relatively small effect size (partial eta-squared = .244).   Specifically, N2 for *xìng/sàng* is significantly lower than for *xìn/sàn* at the 5% level: $p = .034$ between *xìng* and *xìn*, and $p < .001$ between *sang* and *sàn*.   Thus, the nasal place is distinctively different in the L1 production of Mandarin *xìn/sàn* and *xìng/sang* but not in the L2 production of English *sin/son* and *sing/song*.

Figure 3-6 illustrates mean ΔdB for each of the 8 words across tokens and speakers.   The y-axis represents the band energy difference in Decibels (dB), and each pair of bars represents each pair of words that contrast in nasal place.

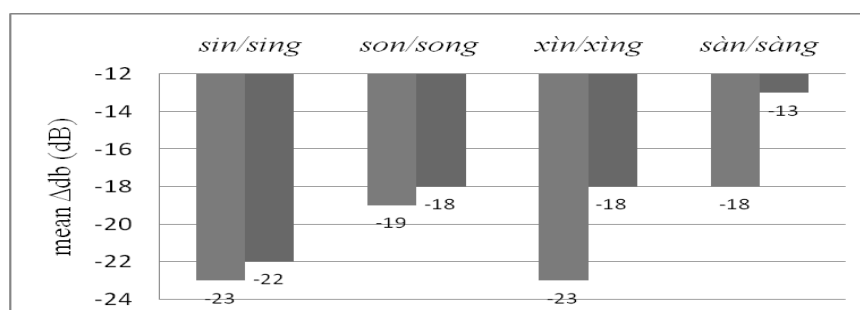*Figure 3-6 Mean ΔdB for **sin/sing/xìn/xìng/son/song/sàn/sàng***

Figure 3-6 shows that mean ΔdB in *sàng* is the smallest (the closer to zero the negative number, the smaller the ΔdB) among the 8 words.   A repeated measures one-way ANOVA test revealed that there is a significant difference among mean ΔdBs for the 8 words, $F_{7, 133} = 9.189$, $p = .007$, though this is a relatively small effect size (partial eta-squared = .326).   Specifically, mean ΔdB for *xìng/sàng* is significantly smaller than for *xìn/sàn* at the 5% level: $p = .009$ between *xìng* and *xìn*, and $p < .001$ between *sang* and *sàn*, confirming that *xìn/sàn* are significantly contrasted with *xìng/sàng* by nasal place.

Figure 3-5 and 3-6 together show that Mandarin /n/ is distinctively different from /ŋ/ in terms of both N2 and ΔdB.

4.   **Discussion**

The acoustic results suggest that Mandarin speakers rely on different acoustic cues to distinguish nasal place in their L1 and L2 production. Table 4-1 summarizes the significant cues used to differentiate English *sin/sing* and *son/song* and Mandarin *xìn/xìng* and *sàn/sàng*.

*Table 4-1 Significant acoustic cues used to differentiate English **sin/sing** and **son/song** and Mandarin **xìn/xìng** and **sàn/sàng***

cues	*sin vs. sing*	*xìn vs. xìng*	*son vs. song*	*sàn vs. sàng*
F3-F2/ F1-F0	n.s.*	front vs. central	high- vs. low-mid central vs. back	low-mid vs. low
N2	n.s.	large vs. small	n.s.	large vs. small
ΔdB	n.s.	large vs. small	n.s.	large vs. small
D	n.s.	n.s.	small vs. large	n.s.
N_D%	n.s.	n.s.	large vs. small	n.s.

*not significant.

Table 4-1 shows that English nasal place is distinguished mainly by durational measurements, D and N_D% (*sin/sing* are not distinctively produced in terms of any acoustic parameters), rather than nasal place measurements, N2 and ΔdB. Specifically, D for *son* is significantly smaller than for *song,* and N_D% for *son* is significantly larger than for *song*.

The durational difference between English /n/ and /ŋ/ produced by the Mandarin participants provides an explanation for why Mandarin speakers are often heard to confuse them. Since the durational difference in the nasal place, intrinsic or extrinsic, are easily lost in casual settings, without additional cues such as vowel quality change over the duration to enhance the nasal place perception, /n, ŋ/ produced by Mandarin speakers can sound very similar, especially in the high (close) vowel context (e.g., *sin/sing*) where the vowel-nasal coupling effect is inherently weak.

It is not surprising that duration is not a good cue for distinguishing Mandarin nasal place, given that Mandarin is a syllable-timed tone language. As a syllable-timed language, to stabilize syllable length and duration is crucial to

maintain the rhythmic regularity of the language. Also as a tone language, vowel quantity (duration) is closely linked to the tonal difference as well as segmental difference (Lin & Wang, 2008). For example, the short duration of Mandarin VN rimes may be determined by the inherent short 4th tone based on Lin's (2002) tone dominance theory. Therefore, the durational contrast is very likely reserved for rhythmic/tonal purposes in Mandarin. However, the Mandarin participants relied on durational cues in their English nasal place distinction. Why did they not rely on the same cues used in their L1 production to produce L2 nasals? The reason may be attributed to the Mandarin participants' awareness of the rhythmic difference between Mandarin and English.

As shown in the acoustic results, the Mandarin VN rimes tend to have a high degree of vowel-nasal coarticulation and relatively fixed and short duration. Given that English is a stress-timed language and its syllable duration is flexible depending on the stress number/location, it is plausible that the vowel-nasal coarticulation effect in English is not as strong as in Mandarin. If Mandarin speakers are aware, for example, that English does not encourage a strong vowel-nasal coarticulation due to flexible syllable duration/length, they will not be likely to use the vowel quality change to cue nasal place in English.

5. Conclusion

Answers to the two research questions and evaluations for the two hypotheses are as follows:

(1) How do vowel context and nasal place interact respectively in L1 and L2 production?

In the L1 VN production, the nasal place tends to co-vary with the backness of the preceding vowel, whereas in the L2 production, the nasal place tends to covary with the syllable duration. Consequently, Mandarin /n, ŋ/ are more distinctively differentitated than English /n, ŋ/, which supports the first hypothesis that the actual nasal place in Mandarin speakers' production of English and Mandarin velar /ŋ/ is different.

(2) Can systematic similarities and differences be identified in the L1 and L2 production? If yes, what linguistic factors may come into play?

Yes. Mandarin VN production is different from English VN production in both vowel quality change over the duration and nasal place.

The difference between the L1 and L2 VN production can be attributed to the different degrees of the vowel-nasal coarticulation effect. The strong effect in the L1 VN production and the weak effect in the L2 VN production are respectively related to the syllable-timed nature of Mandarin and the stress-timed nature of English. The difference found in the L1 and L2 nasal coda production also supports the second hypothesis that English nasal coda production by Mandarin speakers is related to supra-segmental factors, or specifically, rhythmic factors.

To sum up, this study provides an acoustic account of how nasal codas, /n, ŋ/, are differentiated both in L1 and L2 production and in different vowel contexts. By appealing to prosody, it provides a relatively satisfactory explanation to account for the difference between the L1 and L2 production; that is, L2 nasal coda production is ultimately shaped by L2 speakers' interpretaion of the rhythmic difference between L1 and L2.

References

Chafcouloff, Michael, and Alain Marchal. 1999. Velopharyngeal coarticulation. In *Coarticulation: Theory, data and techniques*, eds. William J. Hardcastle and Nigel Hewlett, 69-79. Cambridge: Cambridge University Press.

Chen, Marilyn Y. 2000. Acoustic analysis of simple vowels preceding a nasal in standard Chinese. *Journal of Phonetics* 28:43-67.

Clumeck, Harold. 1976. Patterns of soft palate movements in six languages. *Journals of Phonetics* 4 (4):337-351.

Fox, Anthony. 2000. *Prosodic features and prosodic structure: The phonology of suprasegmentals*. New York: Oxford University Press.

Hansen, Jette. G. 2001. Linguistic constraints on the acquisition of English syllable codas by native speakers of Mandarin Chinese. *Applied Linguistics* 22 (3):338-365.

Ho, Aichen T. 1976. The acoustic variation of Mandarin tones. *Phonetica* 33:353-367.

Kurowski, Kathleen, and Sheila E. Blumstein. 1987. Acoustic properties for place of articulation in nasal consonants. *Journal of the Acoustic Society of America* 81(6):1917-1927.

Ladefoged, Peter, and Ian Maddieson. 1996. *The sounds of the world's languages*. Cambridge: Blackwell.

Ladefoged, Peter. 2001. *Vowels and consonants: An introduction to the sounds of languages*. Malden, MA: Blackwell.

Lin, Hua. 2001. *A grammar of Mandarin Chinese*. Muenchen: Lincom Europa.

Lin, Hua. 2002. Tone dominance in MandarinChinese. Paper presented at the Conference in Celebration of the 50-Year Anniversary of the Journal of Chinese Linguistics. Nanchang, China, June 27-July 1, 2002.

Lin, Hua, and Qian Wang. 2008. Mandarin rhythm: An acoustic study. *Journal of Chinese Linguistics and Computing* 17(3):127-140.

Lin, Yin-Wei. 2007. *The sounds of Chinese*. New York: Cambridge University Press.

Manuel, Shannon. 1999. Cross-language studies: Relating language-particular coarticulation patterns to other language-particular facts. In *Coarticulation: Theory, data and techniques*, eds. William J. Hardcastle and Nigel Hewlett, 179-198. Cambridge: Cambridge University Press.

O'Grady, William, and John Archibald. eds. 2000. *Contemporary linguistic analysis: An introduction.* Toronto: Pearson Education Canada.

Recasens, Daniel. 1983. Place cues for nasal consonants with special reference to Catalan. *Journal of the Acoustic Society of America* 73 (4):1346-1353.

Sussman, Harvey M. 1990. Acoustic correlates of the front/back vowel distinction: A comparison of transition onset versus steady state. *Journal of the Acoustic Society of America* 88 (1):87-96.

White, Laurence, and Sven L. Mattys. 2007. Calibrating rhythm: First language and second language studies. *Journal of Phonetics* 35 (4):501-522.

Zee, Eric. 1981. Effect of vowel quality on perception of post-vocalic nasal consonants in noise. *Journal of Phonetics* 9 (1):35-48.