## 1. Introduction

Syllable-final nasals are cross-linguistically susceptible to change (Chen 1991b; Hajek 1997; Li 1999). How to define the changing nature in nasal endings has been widely documented. The relative importance of murmurs and transitions as nasal place cues has been assessed in previous acoustic reports of English nasals. Certain issues still remain. Some studies have indicated that nasal place of articulation was cued primarily by transitions (Malécot 1956; Recasen 1983). Others (Kurowski & Blumstein 1984; Repp 1986) showed that murmur made significant contribution to place of articulation. Kurowski and Blumstein (1984), for example, pinpointed that nasal murmur was as effective as transitions in cueing place of articulation. This leads to a current perspective on acoustic correlates to nasal consonants; nasal place of articulation is determined by both murmur and transitions together (Harrington 1994; Mou 2006; Ohde 1994). It has been recently reported that variable formant transitions, when combined with murmurs, have been claimed most optimal for the different places of articulation in English nasals.

In Mandarin, codas only allow nasals [n] and [ŋ]. Universal instability of nasal codas has also been found in Mandarin Chinese spoken in Taiwan. Speakers of Mandarin in Taiwan are specified with an accent of Taiwan Mandarin[1], as opposed to the Standard Mandarin, spoken in Beijing in Mandarin China[2] (Lin & Yan, 1991; Mou, 2006). In Taiwan, the syllable-final distinction is frequently dropped, particularly by the younger generation (Hsu & Tse 2007; Tse 1992; Yueh 1992). Bifurcated conclusions, however, have been reached in terms of merging directions. Some researchers (Kubler 1985; Tse 1992) argued that alveolarization was the predominant trend of syllable-final nasal merger in [i] and [ə]. Others (Chen 1991a; Hsu & Tse 2007; Ing 1985) claimed that the syllable-final

1 Taiwan Mandarin, as Hsu & Tse (2007: 2) define, refers to the "Mandarin natively spoken by people in Taiwan, particularly young people." With the constant contact with local languages, Taiwan Mandarin develops its own linguistic system and becomes distinct from the Standard Mandarin, which is mainly modeled after Beijing Mandarin.

2 The term "Standard Mandarin" was equivalent to "Standard Chinese," adopted in Lin & Yan (1991) and Mou (2006). It referred to the accent of Mandarin spoken in Beijing in Mandarin China.

nasal following [i] was more likely to be velarized. These previous reports were somewhat limited, lacking detailed discussion on acoustic information in the vowel and murmur regions.

Recently, the Chinese language has attracted extensive interests from students who want to speak the language and from linguists who want to study the language. An increasing number of learners came to Taiwan to learn Mandarin Chinese. So far, few detailed acoustic reports on these learners' Mandarin nasal production have been made. Whether they could distinguish Mandarin syllable-final nasals or they suffered from nasal mergers, as the young generation in Taiwan did, await further investigation.

Inspired by previous literature, the researcher aims to address to what extent murmur and vowel contribute to the place of articulation distinction in Mandarin Chinese nasal codas. Ten young native speakers of Mandarin in Taiwan and ten native speakers of Burmese who learned Chinese as a second language (CSL) participated in the present research. To what extent and in which acoustic dimensions L1 and L2 speakers of Mandarin differed significantly in Mandarin syllable-final nasal production would be elaborated. Additionally, the current acoustic results would be compared and discussed with those articulated by speakers of Standard Mandarin (Lin & Yan 1991; Mou 2006) to examine the possible driving force of nasal merger in the younger generation in Taiwan.

Discussions in this study are conducted in the following sections. The second section reviews literature on acoustic correlates to nasal place of articulation and on nasal mergers in Taiwan Mandarin. Description of subjects, stimulus materials, and data analysis is presented in the third section. The fourth section reports major findings in acoustic measurements and offers a general discussion on the statistical results. The last section summarizes the main findings and highlights some possible implications as well as recommendations for future research.

## 2. Literature Review

The present research intends to examine the acoustic cues in Mandarin syllable-final nasal contrasts. Previous studies concerning acoustic correlates to place of nasal articulation are reviewed in this section.

## 2.1 Acoustic Correlates to the Place of Nasal Articulation Distinction

Several acoustic properties provide information for different places of nasal articulation. One is the formant transition which signals the tongue movement from the target vowel to an adjacent nasal. Formant transitions in the vowel-nasal boundary reflect prominent coarticulated properties (Lin & Yan 1991; Lin 2002; Mou 2006; Ohde 1994), shown in the changing vocal tract shape under the influence of both the target vowel and the following nasal. It is generally assumed that the tongue body becomes more fronted when a vowel precedes an alveolar nasal, and more backed when the vowel takes precedence over a velar nasal (Figure 1). The change in vowel acoustics can be quantitatively tracked by the second formant frequency, F2, which is roughly equivalent to the tongue advancement (Ladefoged 1993, 2001a 2001b; Pickett 1999). The higher F2 is, the more advanced the vowel is. Hence, a fronted vowel has higher F2, and a backed vowel possesses lower F2.

Another property which may enhance the perception of nasal place is nasal murmur which shows resonance characteristics of nasal consonants. A number of researchers (cf. Cheng 1972; Chung 1990; Zhang 1996) have argued for the anticipatory effect, under which nasalization in the velar [ŋ] context is greater than that in the alveolar [n] context. As shown in Figure 2, the extent of nasalization can be measured in terms of A1-P0 (the difference in amplitudes of the first formant frequency and the first nasal pole) for the low vowel or A1-P1 (the difference in amplitudes of the first formant frequency and the second nasal pole) for the high vowel, as Chen (1995, 1997, 2000) suggested. The smaller the measurements of A1-P0 or A1-P1, the more nasalized the vowel becomes.

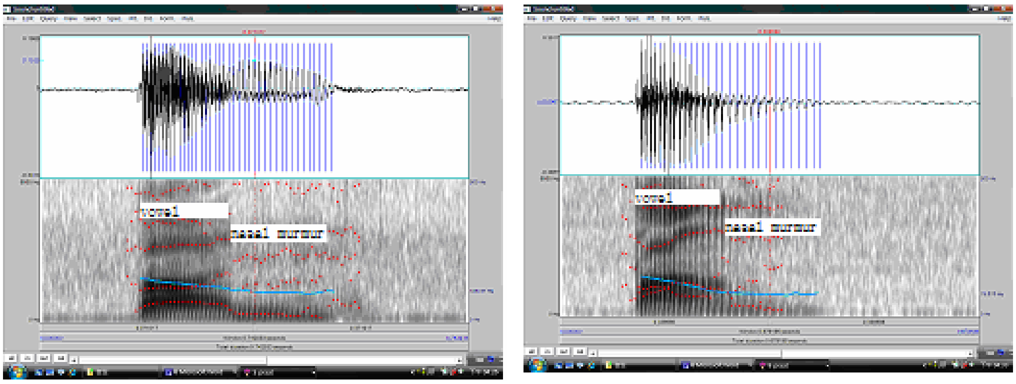


Figure 1. Spectrograms of [an] (the right panel) and [aŋ] (the left panel)

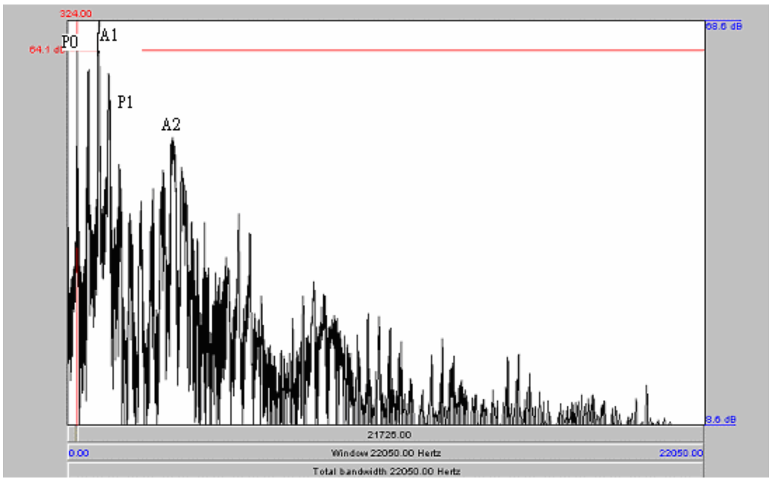


Figure 2. P0, P1, A1 and A2 in spectrogram of [an]

Relative importance of murmurs and transitions as nasal place cues have been assessed in previous acoustic reports and certain controversy has remained. Some studies on natural and synthetic speech have indicated that murmur offered predominant information about manner of articulation and that nasal place of articulation was cued primarily by transitions (Malécot 1956; Recasen 1983). Though transitions were more important than murmurs, Recasens (1983) showed that murmurs contributed significantly to the [ŋ]-[n] distinction. The contribution to place of articulation made by murmur was also reported in other studies (Kurowski & Blumstein 1984; Repp 1986). Kurowski and Blumstein (1984), for example, pinpointed that the nasal murmur was as effective as transitions in cueing place of articulation. This leads to a current perspective on the acoustic cues to nasal consonants; the nasal place of articulation is determined by both the murmur and transitions together (Harrington 1994; Mou 2006; Ohde 1994). It has been widely documented (Kurowski & Blumstein 1984; Ohde & Haley 1992; Ohde & Ochs 1992; Ohde & Perry 1994; Repp 1986) that in the high vowel [i] both murmur and transition cues are required to have accurate identification of place of articulation.

In sum, variable formant transitions, F2 in particular, when combined with murmurs, have been claimed most optimal for different places of articulation.

A third possible acoustic correlate is temporal cues in the vowel region and in the murmur region. So far, few studies examine the contribution of temporal cues in syllable-final nasal distinction. As Lin (2002) suggests, acoustic differences in dimensions of vowel duration and nasal duration are worthy of investigation.

### 2.2 Syllable-final Nasal Mergers in Taiwan Mandarin

Nasal endings in Mandarin Chinese are historically reported being susceptible to change and to undergo merging from Old Chinese, Middle Chinese, to Modern Chinese (Chen 1991b; Li 1999). Instability of nasal codas has also been recently found in Mandarin spoken in Taiwan.

Previous research on syllable-final nasal mergers in Taiwan Mandarin, however, has been bifurcated regarding the merging directions. Some researchers (Kubler 1985; Tse 1992; Yueh 1992) argued that alveolarization was the predominant trend of syllable-final nasal merger in [i] and [ə]. Tse (1992), for instance, examined production and perception of Mandarin syllable-final [n] and [ŋ] by young speakers of Mandarin in Taiwan. In production, factors of vowel types and nasal types were significant. The accuracy hierarchy of production was [aN] > [iN] > [əN][3] for three vowel types and [alveolar nasal] > [velar nasal] for two nasal types. The finding that final [n] was more accurately produced than final [ŋ]

[3] In Tse (1992), the capital N was used as a cover term for nasals, including both the alveolar nasal and the velar nasal.

was in agreement with Yueh's sociolinguistic (1992) observation of on-going merger of [-ŋ] > [-n] in Mandarin spoken in Taiwan.

Others (Chen 1991a, 1991b; Hsu & Tse 2007; Ing 1985; Lin 2002) claimed that the syllable-final nasal, when following [i], was more likely to be velarized. Both Chen (1991b) and Hsu & Tse (2007) collected data from speakers of different age groups in Taipei, the major city in northern Taiwan. Tendencies for *–in* to merge into *–ing* and for *–eng* to merge into *–en* were revealed in their findings. Discrepancies about the leading merger have remained. Chen (1991a) indicated that [in] to [iŋ] was in the leading position, while Hsu & Tse (2007) suggested that [əŋ] to [ən] has been lost its distinction for decades.

Previous reports, however, are limited in a certain way. Chen (1991b), for example, merely investigated nasal endings in two vowel contexts (i.e. [i] and [ə]). Tse (1992), though involving three target vowels (i.e. [i], [ə] and [a]), judged whether a syllable ended in [n] or [ŋ] on the sole basis of the experimenter's ears. In a most recent study, Hsu & Tse (2007) referred to spectrograms in their analysis, but the realization of the syllable-final nasals was determined mainly by the velar pinch, an acoustic cue for the velar nasal [ŋ] with the coming together of falling F3 and rising F2. But, one may question whether the perceptual judgment or the velar pinch truly revealed the nasal performance of Mandarin speakers in Taiwan[4]?

As reviewed in the preceding section, there are several acoustic correlates that may contribute to the distinction in nasal place of articulation, such as formant transitions in vowel-nasal boundary, the extent of nasalization, or temporal cues. Lin & Yan (1991) examined Standard Mandarin spoken in Beijing, and significant differences between F2 were observed at the end-point for non-high vowels to distinguish the alveolar-velar nasal codas. Mou (2006) recruited speakers of Standard Mandarin and compared their nasal production in English

[4] In the current investigation, several subjects' productions of the velar nasal were perfectly rated as [ŋ] by the rater, but no velar pinch was shown in their spectrograms. The spectrogram of [aŋ] with a falling F2 at the vowel-nasal boundary in Figure 1 (the right panel) was an example that somewhat contradicted to the criteria adopted in Hsu & Tse (2007). Hence, velar pinch might not be a reliable criterion in the analysis of Mandarin alveolar-velar distinction in nasal codas.

and in Standard Mandarin. Standard Mandarin low and mid vowels (i.e. [a], [ə]) shifted in F2, while the high vowel [i] did not. These studies, however, excluded the other acoustic correlates, such as nasalization, vowel duration and nasal duration. How young L1 speakers and CSL learners in Taiwan adopted these acoustic cues have remained unknown. Whether Mandarin Chinese nasal codas (i.e. [n] and [ŋ]) articulated in Taiwan Mandarin correspond to those in Standard Mandarin (Lin & Yan 1991; Mou 2006) and which acoustic cue is the determining factor for CSL learners' foreign accent are worthy of investigation.

## 3. Method

An acoustic experiment on Mandarin nasal codas is carried out. Description of subjects, stimulus materials, and data analysis is presented in this section.

### 3.1 Subjects and Stimulus Materials

Twenty subjects without any reported speech or hearing defects participated in the production experiment. Among the twenty subjects, ten were L1 speakers of Mandarin in Taiwan (the TW group) and ten were CSL learners from Burma (the CSL group). Both the L1 and L2 speakers of Mandarin were currently college students in southern Taiwan and their ages ranged from twenty to twenty-three years old. These L2 speakers of Mandarin learned Chinese for one to two years and their Chinese proficiency was at the low-intermediate level. They were chosen because their native language – Burmese – enjoys a more marked nasal system (i.e. [m], [n], [ɲ] and [ŋ]). It would be interesting to examine whether L2 learners, endowed with a more marked L1 system, would have no difficulty producing less marked L2 segments.

Speakers in the TW group were young bilinguals with Mandarin and Taiwan Min as their mother tongues. The major rationale for choosing these speakers was that this age group in Taiwan has been observed to confuse final [n] and [ŋ] in their Mandarin production (Hsu & Tse 2007; Tse 1992; Yueh 1992). It was expected that youngsters of this age would have alveolar-velar mergers to some degree.

These participants were invited to articulate the alveolar-velar nasal pairs ([-n] vs. [-ŋ]) in three vowel contexts ([i], [ə], [a]) with the rising tone (i.e. ying /iŋ/

"camp", yin /in/ "silver", chen /tʂʰən/ "Chen" (family name), cheng /tʂʰəŋ/ "Cheng" (family name), pan /pʰan/ "dish", pang /pʰaŋ/ "side". These target words were embedded in a paragraph (Appendix A). Nasal production of each subject was recorded individually in a quiet room free from ambient noise. The researcher monitored the recording session. These subjects were invited to read aloud the given wordlists in the most spontaneous way. During the process of recording, the researcher did not give them any hint or correction if they made any pronunciation error in the hope that subjects would articulate the segments in the most natural way.

## 3.2 Data Analysis

The tape-recorded readings were later transformed into the wave files in Praat (Boersma & Weenink 1999-2000). Several acoustic correlates in the vowel region (i.e. F2 value at the vowel-nasal boundary, duration of target vowel) and in the nasal murmur region (i.e. extent of nasalization and duration of nasal murmur) were analyzed. The temporal cues are easily calculated in the spectrograms by defining the vowel region and the nasal murmur, as specified in Figure 1. The vowel region is usually characterized by visible periodic waves and vertical pulses in spectrograms (Fry 2001; Ladefoged 1993, 2001a, 2001b). Murmur with lower or weaker formants is symbolic of the nasal region, which starts with some abrupt changes in the waveform from the nucleus vowel. Additionally, the audible differences in Praat screens can offer an explicit way to distinguish the vowel region from the nasal region. The degree of nasalization in nasal murmur was then measured in terms of A1-P0 (the difference in amplitudes of the first formant frequency and the first nasal pole) for the low vowel or A1-P1 (the difference in amplitudes of the first formant frequency and the second nasal pole) for the high vowel (Chen 1995, 1997, 2000). The smaller the measurements of A1-P0 or A1-P1, the more nasalized the vowel became.

Four major acoustic cues of nasals were investigated in the data analysis, including the formant transitions at the vowel-nasal boundary (in Hz), degrees of nasalization (in dB), vowel duration (in msec) and nasal duration (in msec). According to the coarticulated properties, it was expected that vowels became more fronted next to [n], and more backed next to [ŋ], as manifested in F2 in the vowel region. If speakers could refer to this acoustic cue provided by the transition of the second formant frequency, they might have less difficulty in distinguishing the places of nasal articulation. As for nasalization, greater anticipatory effect was expected in the vowel preceding [ŋ] (Cheng 1972; Chung 1990; Zhang 1996). Greater extent of nasalization was anticipated in the [-ŋ] context than in the [-n] context. Finally, the role of temporal cues in distinguishing the alveolar-velar nasal pairs, though being neglected in the preceding research reports, was addressed in the current study. It was assumed that both L1 and L2 speakers might resort to vowel duration or nasal duration when articulating the alveolar-velar nasal pairs.

An Independent t-test was performed to examine possible significant differences in the collected acoustic data. To what extent the speakers distinguished alveolar-velar nasal pairs and to what extent murmur and vowel contributed to the distinction were further discussed.

## 4. Results and Discussion

Several acoustic factors in the vowel region and in the murmur region are compared to demonstrate the way how the L1 and L2 speakers of Mandarin Chinese in Taiwan differentiate the syllable-final nasal contrast. Statistical results are presented in terms of formant transitions in vowels, extent of nasalization, and temporal cues.

### 4.1 Formant Transitions in Vowels

The mean values of F2 at the vowel-nasal boundary, produced by L1 and L2 speakers of Mandarin Chinese are respectively displayed in Table 1. Comparisons between the alveolar-velar nasal pairs in three vowel contexts were done with statistical t-tests. An asterisk “*” ($*p < .05$) in tables indicates a significant difference between the alveolar-velar nasal pairs.

Table 1

*Means, SD, Minimum and Maximum in F2 (in Hz) at the vowel-nasal boundary*

| Group | Sound | N | Mean | SD | Max | Min | t-value |
|---|---|---|---|---|---|---|---|
| TW | [in] | 10 | 1895 | 279 | 1354 | 2339 | -1.77 |
| | [iŋ] | 10 | 2136 | 239 | 1812 | 2534 | |
| | [ən] | 10 | 1590 | 136 | 1434 | 1923 | 0.77 |
| | [əŋ] | 10 | 1532 | 231 | 1139 | 1985 | |
| | [an] | 10 | 1569 | 168 | 1373 | 1946 | 1.98* |
| | [aŋ] | 10 | 1244 | 256 | 1022 | 1910 | |
| CSL | [in] | 10 | 1813 | 508 | 1227 | 2822 | -2.77 |
| | [iŋ] | 10 | 2367 | 503 | 1543 | 3167 | |
| | [ən] | 10 | 1672 | 236 | 1404 | 2133 | 0.67 |
| | [əŋ] | 10 | 1630 | 322 | 1084 | 2230 | |
| | [an] | 10 | 1645 | 156 | 1227 | 2822 | 3.64* |
| | [aŋ] | 10 | 1426 | 291 | 1063 | 1918 | |

Note: N=number; SD= standard deviations; Max= maximum; Min= minimum; $^{**}p < .01$; $^{*}p < .05$

Several major observations can be made from Table 1. For L1 speakers of Mandarin in Taiwan, coarticulated properties in formant transitions (Lin & Yan 1991; Lin, 2002; Mou 2006; Ohde 1994) were shown in the vowel-nasal boundary in non-high vowels (i.e. [ə] and [a]), both of which were underspecified [back] (Chung 1990). The average F2 in alveolar nasal [n] was higher than that in the velar nasal [ŋ]. The vowels uttered by these L1 speakers were more fronted next to [-n], as manifested in higher F2 in [ən] or [an], but become more backed before [-ŋ] with lower F2 in [əŋ] or [aŋ]. In other words, the speakers were able to articulate the [ə] and [a] by fronting or backing the tongue body, depending on the following nasal coda. Fronting or backing of the tongue body as an enhancing gesture for contrasting alveolar-velar nasal pairs, nonetheless, did not shown in the high vowel [i], which was specified [-back]. In the [i] context, higher mean formant values were found preceding the velar nasal [ŋ] than preceding the alveolar [n]. This finding echoes Chung's (1990) assumption that the high vowel is specified for the feature [-back] and that the speakers cannot change the position of the tongue body to accommodate the place of articulation of the following nasal. It can be argued that these speakers were most confused in the [in]-[iŋ] pair among the three vowel contexts.

Additionally, L1 speakers of Mandarin Chinese Taiwan produced the alveolar-velar nasal pairs in the low vowel [a] with significant differences in formant transitions. As for the [in]-[iŋ] and [ən]-[əŋ] pairs, no significant distinction was found in the mean values of F2 at the vowel-nasal boundary. This finding was in agreement with that in Lin & Yan (1991) and Mou (2006), where the end-points of F2 in the low vowel pair (i.e. [an]-[aŋ]) showed significant differences and the end-points of F2 in the high vowel (i.e. [in]-[iŋ]) did not show much significant deviance. But, different from Lin & Yan (1991) and Mou (2006), the current investigation indicated the speakers of Taiwan Mandarin did not pronounce the [ən]-[əŋ] pair with significantly different formant transitions. It can be argued that such a discrepancy was not only suggestive of productive confusion in the alveolar-velar nasal distinction for speakers of Mandarin in Taiwan, but representative of the accented speech, specified as Taiwan Mandarin.

Similar accented patterns in Mandarin nasal production were also observed in the CSL learners in Taiwan. They could significantly differentiate the Mandarin [an]-[aŋ], but not [in]-[iŋ] and [ən]-[əŋ]. Most confusion was found in the [in]-[iŋ] pair due to the lack of coarticulated properties in formant transitions. The hierarchy of production in the current investigation was [aN] > [əN] > [iN] from the perspective of formant transitions. Since Burmese enjoys a more marked nasal system (i.e. [m], [n], [ɲ] and [ŋ]) than Mandarin, it is expected the native speakers of Burmese should not have difficulty distinguishing a less marked Mandarin nasal codas. Therefore, it can be argued that this confusion doesn’t result from the phonological system of their own native language (i.e. Burmese), but from the merging nasals of the target language.

### 4.2 Extent of Nasalization

Mean values of A1-P0 or A1-P1, abbreviated as AP, at the nasal murmur region produced by L1 and L2 speakers of Mandarin in Taiwan are summarized in Table 2 and plotted in Figure 3 (the TW group) and Figure 4 (the CSL group).

Statistical t-tests were performed to make comparisons between the alveolar nasal and the velar nasal in three vowel contexts.

Table 2

*Means, SD, Minimum and Maximum in AP (in dB)*

| Group | Sound | N | Mean | SD | Max | Min | t-value |
|---|---|---|---|---|---|---|---|
| TW | [in] | 10 | 5.55 | 3.14 | 1.10 | 10.70 | 2.13 |
| | [iŋ] | 10 | 3.93 | 3.76 | 0.60 | 12.90 | |
| | [ən] | 10 | 6.23 | 3.01 | 0.80 | 11.00 | 1.60 |
| | [əŋ] | 10 | 4.49 | 3.06 | 0.80 | 10.30 | |
| | [an] | 10 | 4.95 | 1.73 | 2.50 | 7.90 | 2.85* |
| | [aŋ] | 10 | 2.79 | 1.37 | 0.80 | 5.60 | |
| CSL | [in] | 10 | 8.12 | 4.02 | 3.00 | 14.60 | -0.01 |
| | [iŋ] | 10 | 8.13 | 3.33 | 4.00 | 15.90 | |
| | [ən] | 10 | 6.54 | 3.49 | 1.60 | 12.60 | 1.27 |
| | [əŋ] | 10 | 5.27 | 2.78 | 1.90 | 11.30 | |
| | [an] | 10 | 6.77 | 2.73 | 2.30 | 11.20 | 0.84 |
| | [aŋ] | 10 | 5.46 | 3.68 | 0.60 | 13.00 | |

Note: N=number; SD= standard deviations; Max= maximum; Min= minimum; ***p*< .01; **p*< .05

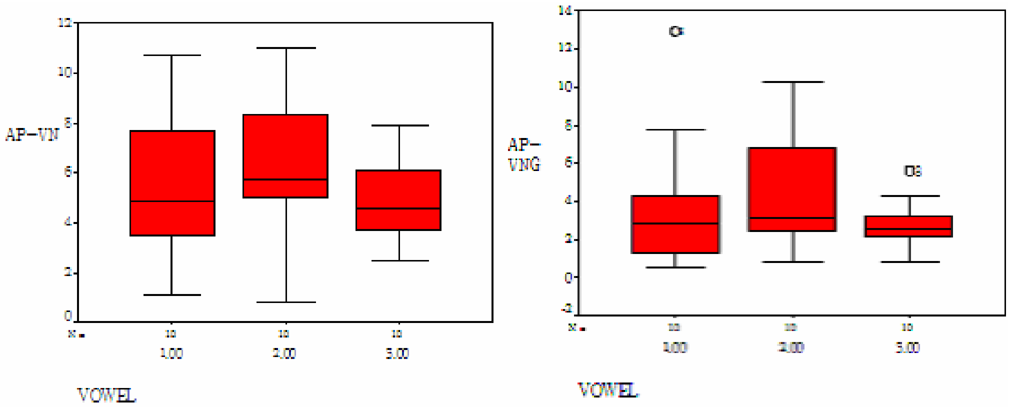


Figure 3. Box-plots for the AP in VN context (the left panel) and in VNG context (the right panel) for the TW group. AP (dB) stands for A1-P0 or A1-P1.Vowels [i], [ə] and [a] are respectively specified as 1, 2, and 3.

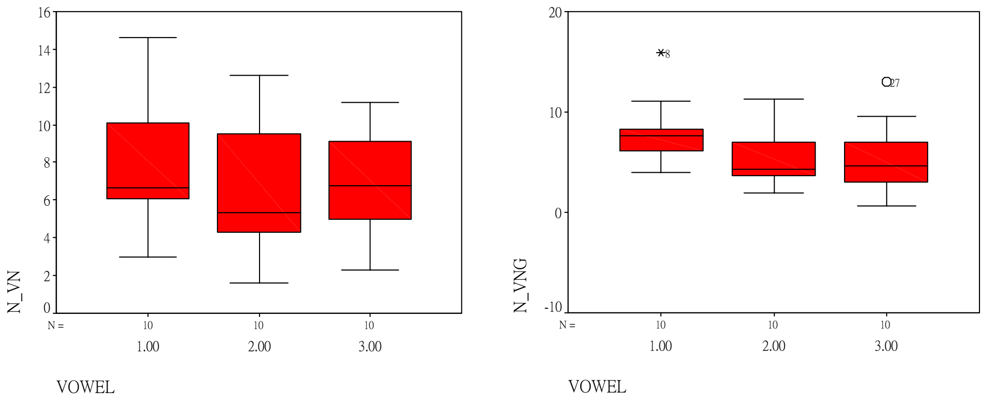


Figure 4. Box-plots for the AP in VN context (the left panel) and in VNG context (the right panel) for the CSL group. AP (dB) stands for A1-P0 or A1-P1.Vowels [i], [ə] and [a] are respectively specified as 1, 2, and 3.

Figure 3 (the TW group) and Figure 4 (the CSL group) demonstrate the extent of nasalization for three vowels in two nasal types. For the VN context, all the data fell within the inner fences, indicating there were no outliers. In the VNG context, two subjects in each group were respectively located beyond the inner fences (circle sign) for the [i] vowel and the [a] vowel. For the outliers, a follow-up check was conducted to examine if these extreme values were a result of some coding errors or of their speaking characteristics. Since no coding errors were found in the current investigation, these data were a reflection of personal acoustic properties, indicating some confusion between the alveolar-velar nasal pairs.

Major acoustic patterns in nasalization can be revealed in Table 2. To start with, the anticipatory effect, postulated in Cheng (1972), Chung (1990) and Zhang (1996), was further substantiated in the TW group. As shown in the above figures, mean values and ranges of A1-P1 or A1-P0 in alveolar nasal [n] were generally larger than those in the velar nasal [ŋ] in all three vowel types. As measurements of A1-P0 or A1-P1 were inversely correlated with the extent of nasalization, it can be inferred that the one preceding [ŋ] was more nasalized than the vowel preceding [n]. For all three vowels, L1 speakers of Mandarin nasalized to a lesser extent in VN context than in VNG context.

In terms of vowel types, the greatest degree of nasalization was found in the low vowel [a], followed by the high vowel [i], for native speakers of Mandarin. In the mid vowel [ə], L1 speakers of Mandarin in Taiwan nasalized to the least extent. This finding echoed Cohn (1994) and Chen (2000), who compared vowels followed by different nasal codas. It was found that anticipation of nasals was weakest in the case of [ə], and strongest in [a]. This reflected a less open velo-pharyngeal port, which neither dampened the first formant amplitude (A1), nor generated a prominent nasal pole with amplitude (P0) (Hyman 1972). In sum, to be perceived as nasals, less nasalization in the mid vowel [ə] than in [i] and [a] was required in Taiwan Mandarin.

The alveolar-velar distinction, however, was not overall significant from the perspective of nasalization. As indicated in the *p* value, L1 speakers of Mandarin in Taiwan uttered the alveolar-velar nasal pairs in the low vowel [a] with significant differences in nasalization. No significant deviance was observed in the high vowel [i] and the mid vowel [ə]. It can be inferred that L1 speakers of Mandarin made more use of nasalization as an enhancing gesture to distinguish nasal codas following the low vowel [a]. But, in the high and mid vowels (i.e. [i], [ə]), differences in nasalization were not significantly enough to make alveolar-velar contrasts. This finding was consistent with findings of formant transitions at the vowel-nasal boundary (Table 1). It can be argued that insignificant nasal distinction in [i] and [ə] might imply that these speakers were confused about the alveolar-velar nasal codas to some extent, resulting in the unique acoustic patterns of the linguistic variants in Taiwan Mandarin.

The CSL group, by contrast, reflected different nasalized patterns from the TW group. Except for the [an]-[aŋ] pair, the remaining two pairs (i.e. [in]-[iŋ] and [ən]-[əŋ]) were in disagreement with the anticipatory effect of nasalization (Cheng 1972; Chung 1990; Zhang 1996). The vowels [i] and [ə] preceding [ŋ] was less nasalized than those preceding [n]. Unlike the L1 pattern, these L2 speakers of Mandarin nasalized to a greater extent in the VN context than in the VNG context. Considering the different vowel types, the L2 speakers of Mandarin were most nasalized in the mid vowel [ə] (AP=5.27 for [əŋ]; 6.54 for [ən]) and least nasalized in the high vowel [i] (AP=8.13 for [əŋ]; 8.12 for [ən]). The hierarchy of nasalization in the CSL group (i.e. [əN] > [aN] > [iN]) was obviously different from that in the TW group and in the previous reports (cf. Chen 2000; Cohn 1994) (i.e. [aN] > [iN] > [əN]). Additionally, none of the alveolar-velar pairs were significantly different in terms of nasalization (Table 2). Compared to the L1 speakers, these L2 speakers produced the Mandarin nasal pairs with less significant distinction, violating the acoustic assumptions of nasalization.

### 4.3 Temporal Cues

Besides spectral properties, temporal properties might contribute to the syllable-final nasal distinction. Mean durations in the vowel region and in the nasal murmur region were calculated. Results of t-tests conducted between the alveolar-velar nasal pairs are indicated in Table 3 (for vowel duration) and Table 4 (for nasal duration). Alveolar-to-velar ratios in duration for nasal pairs are further summarized in Table 5.

Table 3

*Means, SD, Minimum and Maximum in vowel duration (in msec)*

| Group | Sound | N | Mean | SD | Max | Min | t-value |
|---|---|---|---|---|---|---|---|
| TW | [in] | 10 | 153.10 | 36.82 | 101 | 214 | -0.70 |
| | [iŋ] | 10 | 157.80 | 38.18 | 88 | 220 | |
| | [ən] | 10 | 149.50 | 31.09 | 100 | 202 | 1.40 |
| | [əŋ] | 10 | 138.80 | 26.18 | 97 | 185 | |
| | [an] | 10 | 150.00 | 37.59 | 89 | 227 | 1.93 |
| | [aŋ] | 10 | 132.80 | 20.72 | 107 | 161 | |
| CSL | [in] | 10 | 157.70 | 36.62 | 113 | 220 | 1.17 |
| | [iŋ] | 10 | 143.70 | 45.74 | 98 | 247 | |
| | [ən] | 10 | 150.00 | 46.55 | 120 | 279 | -0.55 |
| | [əŋ] | 10 | 155.00 | 41.62 | 103 | 241 | |
| | [an] | 10 | 125.90 | 30.37 | 91 | 180 | 1.32 |
| | [aŋ] | 10 | 117.00 | 20.41 | 88 | 162 | |

Note: N=number; SD= standard deviations; Max= maximum; Min= minimum; $^{**}p< .01$; $^{*}p< .05$

Table 4

*Means, SD, Minimum and Maximum in nasal duration (in msec)*

| Group | Sound | N | Mean | SD | Max | Min | t-value |
|---|---|---|---|---|---|---|---|
| TW | [in] | 10 | 167.00 | 28.88 | 127 | 218 | 1.61 |
| | [iŋ] | 10 | 145.80 | 42.04 | 80 | 202 | |
| | [ən] | 10 | 166.00 | 73.78 | 48 | 289 | 1.60 |
| | [əŋ] | 10 | 150.90 | 56.62 | 52 | 211 | |
| | [an] | 10 | 120.40 | 47.87 | 44 | 196 | 1.36 |
| | [aŋ] | 10 | 112.10 | 39.45 | 44 | 166 | |
| CSL | [in] | 10 | 167.70 | 41.39 | 115 | 242 | 0.75 |
| | [iŋ] | 10 | 159.00 | 22.24 | 126 | 207 | |
| | [ən] | 10 | 154.70 | 57.40 | 56 | 222 | 0.28 |
| | [əŋ] | 10 | 150.60 | 39.89 | 88 | 204 | |
| | [an] | 10 | 098.50 | 38.00 | 55 | 177 | 0.19 |
| | [aŋ] | 10 | 097.10 | 41.65 | 51 | 190 | |

Note: N=number; SD= standard deviations; Max= maximum; Min= minimum; ** $p < .01$; * $p < .05$

Table 5

*Alveolar-to-velar ratios in duration for nasal pairs*

| TW | [in]-[iŋ] | [ən]-[əŋ] | [an]-[aŋ] |
|---|---|---|---|
| Vowel duration | 0.97 | 1.08 | 1.13 |
| Murmur duration | 1.15 | 1.10 | 1.07 |
| CSL | [in]-[iŋ] | [ən]-[əŋ] | [an]-[aŋ] |
| Vowel duration | 1.10 | 0.97 | 1.08 |
| Murmur duration | 1.05 | 1.03 | 1.07 |

Across all three vowel types, no significant difference for the alveolar-velar pair was found in vowel duration (Table 3) and in nasal duration (Table 4) for L1 and L2 speakers of Mandarin. The alveolar-to-velar ratios, however, seemed to tell a different story, as indicated in Table 5. Compared with unity (i.e. 1.00), the ratios in murmur duration were obviously larger in all three pairs for both groups ([in]-[iŋ]: 1.15 for TW & 1.05 for CSL, [ən]-[əŋ]: 1.10 for TW & 1.03 for CSL,

[an]-[aŋ]: 1.07 for TW & 1.07 for CSL). The vowel length was obviously longer in [ən]-[əŋ], [an]-[aŋ] pairs for the TW group, and in [in]-[iŋ], [an]-[aŋ] pairs for the CSL group. Smaller ratio than unity was found in [in]-[iŋ] for the TW group (0.97) and in [ən]-[əŋ] for the CSL group (0.97). Such a discrepancy might imply that these speakers used the temporal cues to differentiate the alveolar nasal from the velar nasal. Take the [in]-[iŋ] pair in the TW group for example. In pronouncing [in], these speakers tended to sacrifice the vowel length by prolonging nasal murmur. The [iŋ] token, however, displayed an opposite acoustic pattern, in which vowel duration was lengthened and nasal murmur was shortened. In a similar vein, the CSL group produced [ən] with shorter vowel duration and longer murmur duration. Opposite temporal pattern was identified in the articulation of [əŋ]. It can be argued that the vowel length and the murmur length were recognized as acoustic cues of importance for these speakers in distinguishing the syllable-final nasal codas.

### 4.4 General Discussion

The current study addresses to what extent murmur and vowel contribute to the place of articulation distinction in Mandarin Chinese nasal codas. It was found that L1 speakers of Mandarin in Taiwan differentiated the [an]-[aŋ] pair significantly in terms of the second formant frequencies (Table 1) and nasalization (Table 2). Despite no significant contrasts, [in]-[iŋ] and [ən]-[əŋ] pairs followed the anticipatory effect of nasalization (Cheng 1972; Chung 1990; Zhang 1996). These two pairs, however, were produced with different patterns of formant transitions. It was the [ən]-[əŋ] pair, not the [in]-[iŋ] pair, that agreed with the coarticulated properties (Lin 2002; Lin & Yan 1991; Mou 2006; Ohde 1994). It can be argued that the hierarchy of production was [aN] > [əN] > [iN] for the L1 speakers in the current investigation.

Like L1 speakers, L2 speakers followed the same hierarchy of production, especially in formant transitions. Different from the L1 speakers, these L2 speakers were less sensitive to the Mandarin syllable-final nasal contrast. They produced the alveolar-velar nasal pairs with insignificant differences and were extremely confused about Mandarin syllable-final nasal contrasts from the perspective of nasalization. As a compensational strategy, the temporal cues were used by speakers to make the alveolar-velar distinction, especially in the case of the [in]-[iŋ] pair (the TW group) and of the [ən]-[əŋ] pair (the CSL group).

The hierarchy of production in the current investigation (i.e. [aN] > [əN] > [iN]), though being different from that in Tse (1992) (i.e. [aN] > [iN] > [əN]), was supported in other empirical findings. This hierarchy of nasal coda production was in accord with the developmental stage of syllable-final nasals in the first language acquisition. As Hsu (2003) observed twenty children who learned Mandarin as their first language, the [an]-[aŋ] pair was acquired earliest at around the age of 1;4, followed by the [ən]-[əŋ] contrast at the approximate age of 1;10. The [in]-[iŋ] distinction was not made until children were two and half years old. This explains why the [an]-[aŋ] distinction was produced with the most salient difference, followed by the [ən]-[əŋ] pair. The contrast between [in] and [iŋ], however, was last acquired, thus being articulated with the least distinction.

There are two additional reasons why L1 speakers of Mandarin Chinese in Taiwan were more confused with [in]-[iŋ] and [ən]-[əŋ] pairs. To start with, greater difficulty in the [in]-[iŋ] distinction might be a result of the fact that both murmur and transition in the high vowel [i] were required to have accurate identification of nasal place, as reported in Kutowski & Blumstein (1994) and Repp (1986). Inappropriate use of acoustic cues offers another explanation. Failure in making appropriate reference to the acoustic correlates in both the vowel region and the nasal region might eventually lead to these speakers' greatest confusion with [in]-[iŋ] contrast. Instead of referring to vowel transition or nasalization, speakers of Mandarin in Taiwan made more use of temporal cues in the high vowel [i] to distinguish the alveolar-velar nasal pairs (Table 5).

The current investigation shed new light on two academic fields, including Sociophonetics and Interlanguage Phonetics. Sociophonetics, highlighted by Thomas (2000) and Clopper & Pisoni (2004), was elaborated in the context of Mandarin syllable-final nasals. These acoustic patterns in Mandarin nasals produced by speakers in Taiwan were extremely different from those in Standard Mandarin, as reported in Lin & Yan (1991) and Mou (2006). In Standard Mandarin, significant differences in F2 at the end-point for the non-high vowels (i.e. [ə] and [a]) helped distinguish the alveolar-velar nasal codas. In Taiwan, Mandarin speakers produced the [an]-[aŋ] pair with prominent differences in the late position of F2. Confusion in the [ən]-[əŋ] pairs with insignificant vowel formant transitions was thus representative of the modified nasals in Taiwan Mandarin. It can be argued that speakers of Mandarin in Taiwan produced these nasals in a more relaxed manner with less fronting or backing of the tongue body than those of Standard Mandarin.

As for CSL learners, they were less sensitive to Mandarin nasal contrasts, demonstrating an interlanguage pattern in acoustic phonetics. For example, the anticipatory effect in Mandarin nasals (Cheng 1972; Chung 1990; Zhang 1996) was empirically substantiated in the TW group, but not in the CSL group. Except for the [an]-[aŋ] pair, the CSL learners articulated [in]-[iŋ] and [ən]-[əŋ] with greater nasalization in the VN context than in the VNG context. This specific acoustic pattern explicitly indicated these CSL learners' own version of Mandarin nasal production, distinctive from the native targets, pronounced by L1 speakers of Mandarin in Taiwan. This interlanguage pattern indexes the knowledge that language learners have obtained concerning the target sound system (Tsukada, 2006). It might further help the language teachers improve the way in which CSL learners produce the language and train learners towards the native-like targets.

## 5. Conclusion

The current study addressed to what extent vowel and nasal murmur contribute to the place of articulation distinction in Mandarin Chinese nasal codas. Acoustic analysis identified phonetic features adopted by L1 and L2 speakers of Mandarin Chinese to distinguish the [n]-[ŋ] pair. Results revealed that both formant transition and nasalization count if the speakers want to significantly distinguish Mandarin nasal codas. L1 speakers performed excellently in Mandarin [an]-[aŋ] contrast, but failed to some extent in the other pairs (i.e. [in]-[iŋ], [ən]-[əŋ]). It can be argued that the spectral difference, found in Standard Mandarin, was not significant in Taiwan Mandarin, which displayed nasal mergers to some extent. Compared with L1 speakers, L2 learners were more confused about Mandarin syllable-final nasals, especially in degrees of nasalization. This is a major result from the merging nasals of the target language, not from the phonological system of their own native language (i.e. Burmese).

The present investigation makes prominent contributions to two academic fields, that is, Sociophonetics and Interlanguage Phonetics. Social studies on language changes in Mandarin have focused less on intensive instrumental analyses in acoustics and might sometimes erroneously or subjectively describe the linguistic variants. The current acoustic discussion specified to what extent and in what way Standard Mandarin differs from Taiwan Mandarin in the syllable-final nasals. By examining the phonetic behavior of subjects of regional or social variations, more scientific support in acoustic measurements can be offered to account for the accented or dialectal speech in socio-linguistic variants. The gap between experimental phonetics and sociolinguistics can also be bridged. Additionally, the current study shed light on Interlanguage Phonetics on Mandarin nasals. The acoustic structures could adequately exemplify how far away the CSL learners deviated from the native targets, produced by L1 speakers. It can further offer pedagogical implications for both language learners and language instructors in regards to what extent and in which acoustic dimensions more phonetic modifications are essential to acquire the native-like outputs. The ideas of coarticulated properties in formant transitions and anticipatory effect in nasalization might be helpful in future clinical treatment.

In the current pure acoustic analysis, the issue about the contribution of acoustic correlates to perceptual saliency is not addressed. In the future study, perceptual judgment or perceptual rating can be included to examine the possible merger direction for L1 and L2 speakers of Mandarin and the relations between acoustic cues and perceptual saliency for the alveolar-velar nasal distinction. How native speakers of Mandarin with the alveolar-velar contrast categorized talkers with possible nasal mergers can be determined. The possible interaction and the predictive power of acoustic measurements can thus be elaborated.

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## Appendix A

Please read the following paragraph in Chinese.

| |
|---|
| 又到了年度軍營中，軍官們盤點軍銀的時間。只見姓程的軍官端進一盤又一盤的銀兩，但是，姓陳的軍官卻只站在一旁，袖手旁觀。 |

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# 華語母語者與華語爲第二語言學習者之華語鼻音結尾發音之研究

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## 摘要

本研究探討母音共陣峰與鼻音鼻化對華語鼻音結尾之區辨程度。十位台籍華語母語人士與十位緬甸籍以華語爲第二語言學習者參與本聲學研究。發音語料爲三母音語境中（[i], [ə], [a]）之舌根鼻音與舌尖鼻音（[-n] vs. [-ŋ]）；聲學分析重點含：母音共陣峰走勢、鼻音鼻化程度、母音時長、與鼻音時長。主要結果指出：母音共陣峰與鼻音鼻化對華語鼻音結尾之區辨扮演重要角色；台籍華語母語人士之母音共陣峰及鼻化程度僅於[an]-[aŋ]達顯著差異，但於其他兩組（[in]-[iŋ], [ən]-[əŋ]）未達顯著差異，反應出台籍華語鼻音結尾發音合流趨勢。此外，緬甸籍以華語爲第二語言學習者，未因其母語具較複雜鼻音結構而享優勢，亦呈現類似華語鼻音結尾發音合流現象，其混淆程度更劇。

**關鍵詞**：聲學語音學，華語鼻音結尾，華語爲第二語言

（歡迎影印轉知華語文學者、專家）

# 第九屆世界華語文教學研討會

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