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Nasal endings of Taiwan Mandarin: Production, perception, and linguistic change

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1. Introduction

Nasal endings are cross-linguistically among the most susceptible to change. Hajek (1997) discusses the universal patterns of nasalization in various Italian languages in relation to vowel height and vowel quality. Chinese nasal endings have also undergone merging and splitting from Old Chinese to Middle Chinese, and from Middle Chinese to Modern Chinese (Li, 1999). Historical linguists of Chinese have had everlasting interest in the reconstruction of Chinese nasal endings. Hypotheses about nasalization were made (e.g. Chen, 1979); various researchers followed up examining these hypotheses by studying nasal endings in different Chinese dialects (Zee, 1985; Hess, 1990). Some researchers also looked into nasal endings in dictionaries of Old and Middle Chinese compiled in ancient China, and showed the early traces of instability (Chen, 1991).

The nasal endings in Standard Mandarin currently spoken in Taiwan are not exempt from this instability. Previous research by Chen (1991) collected data from Mandarin speakers of different age groups in Taipei, and showed a tendency for *–in* to merge into *–ing*, and for *–eng* to merge into *–en*. However, Chen (1991) only looked at nasal endings following two vowels /i/ and /ə/, and the judgments of whether a syllable ended in *–n* or *–ng* were made solely depending on the experimenters' ears.

The goal of this paper is to investigate the phonetic variation of Chinese nasal endings by studying both speakers' production and perception. I expand the scope of study by looking at nasal consonants /n/ and /ŋ/ following four different vowels [a], [ə], [ɔ], and [i]. Acoustic analyses were done comparing the first (F1), second (F2), and third (F3) formants of the vowels preceding the nasals. Reading tasks at natural speed and careful speed were also compared. Perception tasks were administered to examine the consistency between production and perception. Through this study, I wish to answer the following questions:

- Are prescribed nasal endings /-n/ and /-ŋ/ distinguished in Standard Mandarin spoken in Taiwan? If yes, how are they distinguished acoustically? If not, when (following which vowels) is the distinction lost? What do they become?
- Do natural speech and careful speech show the same patterns?
- Do listeners distinguish between /-n/ and /-ŋ/ in perception tasks? When are they and when are they not distinguished?
- Do the acoustic cues found in production help listeners distinguish /-n/ from /-ŋ/? Are listeners able to distinguish /-n/ and /-ŋ/ when the acoustic analyses of production show no significant distinction? That is, are there other cues not captured in this research that facilitate the distinction in perception?
- What does listeners' perception tell us about the direction of phonetic change?

2. Nasal endings in Mandarin and trends of phonetic change

Standard Mandarin has two nasal endings: /n/ and /ŋ/. These two nasals combine with vowels to make different rimes in Chinese. Standard Chinese has five vowel phonemes (Duanmu, 2000)[1]. Table I lists these five vowels and the diphthongs in Chinese.

TABLE I. Vowel phonemes and diphthongs of standard Chinese.

Standard Chinese vowel phonemes	
high	/i ü u/
mid	/ə/
low	/a/
diphthongs	/ia/ /ua/ /üa/

The combination of vowel and nasal endings in Mandarin undergo assimilation in some of the phonetic realizations. Table II shows the phonetic realization of different underlying combinations between vowels and nasal endings.

TABLE II. Phonetic realization of vowel-nasal combinations in Standard Mandarin.

	i	**ü**	**u**	**ə**	**a**	**ia**	**ua**	**üa**
n	[in]	[ün]	[uən]	[ən]	[æn]	[jæn]	[wæn]	[üɛn]
ŋ	[iŋ]	[jɔŋ]	[wɔŋ]	[əŋ]/[ɔŋ]	[aŋ]	[jaŋ]	[waŋ]	*

As could be seen in Table II, assimilation is very common among the VN combinations. The three VN combinations that are of interest to the current research are made of the vowels /i/, /ə/, and /a/ and the nasals /n/ and /ŋ/. These three vowels are chosen as the focus of research because they are among the most basic vowels, and because the vowel qualities in the pairs of /Vn/ and /Vŋ/ are phonetically more similar and thus more difficult to distinguish.[2]

[1] The retroflex vowel /ər/ is not included because it appears as an independent syllable only in a limited number of lexical items, e.g. /ər2/ 'son', /ər3/ 'ear', /ər4/ 'two'. In Taiwan Mandarin, these retroflexed vowels are frequently reduced to /ə/ only.

[2] The vowels in other VN combinations are more distinct because of assimilation. Recall that the goal of this paper is to study the loss of distinction between /n/ and /ŋ/ endings. Vowel qualities that make the

Previous research showed that the distinction between /n/ and /ŋ/ in [-in]/[-iŋ] and [-ən]/[-əŋ] are the most unstable among the VN combinations in the Mandarin spoken in Taiwan and Singapore (Chen, 1991). The distinction between different nasal endings according to the places of articulation is taught in school, noted in dictionaries, and useful when looking up words in dictionaries or typing Chinese characters in a word processor. In daily natural speech, however, Taiwanese people in general no longer clearly distinguish between these two nasal endings. The distinction is better kept when the nasals follow certain vowels (e.g. /a/, /u/) than others (e.g. /i/, /ə/). Chen (1991) suggests a predominant trend of [in] merging into [iŋ], and [əŋ] merging into [ən]. This paper re-examines these claims, and looks at the acoustic distinction among [an]/[aŋ], [ən]/[əŋ], [in]/[iŋ] pairs. The acoustic distinction will further be compared with the results of perception.

3. Method

There are two experiments conducted in this research. Experiment I is a reading task, in which subjects were asked to read sentences at normal and careful speeds. Experiment II is a perception task. Subjects were asked to identify the sounds they had heard in -n/-ŋ minimal pairs.

3.1. *Experiment I: Reading tasks*

This experiment intends to investigate if syllables of /n/ and /ŋ/ endings are acoustically distinguishable by studying the spectrogram of people's actual pronunciation. There are three independent variables in this experiment, which include: (1) vowels {/a/ vs. /i/ vs.

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distinction between /Vn/ and /Vŋ/ obvious and easy are not included within current scope of investigation. Diphthongs that are made of more basic vowels are also excluded.

/ə/}, (2) nasal endings of the syllables {/n/ vs. /ŋ/}, and (3) reading styles {normal vs. slow}. The dependent variables are the formant frequencies of F1, F2, and F3, in both early and late positions. The early position is defined as the point at one-fourth of vowel duration after the onset of the vowel. The late position is defined as the endpoint of the vowel right preceding the nasals. Figure 1 illustrates where the early and late positions of measurements are. It is hypothesized that if the nasal endings are different, then for the same vowel, the late formants should show transitions into different endings.

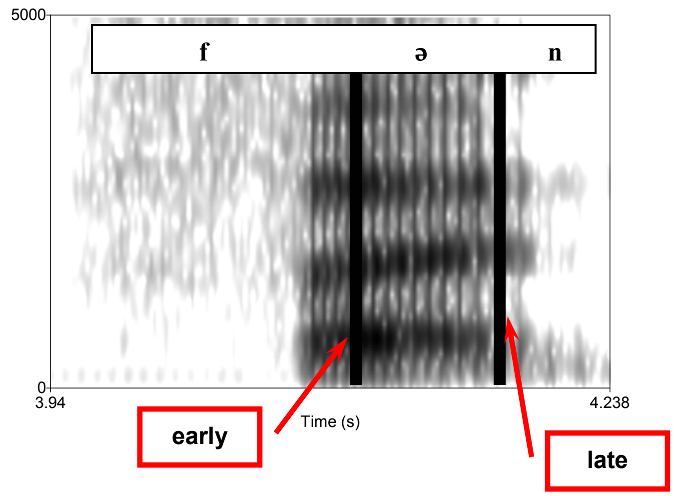


Figure 1. Measurement points of early and late formant positions.

3.1.1 *Subjects*

Two male speakers of Taiwan Mandarin at the age of 18 and 20 participated in the reading tasks. Both speakers were exposed to Taiwan Mandarin in Taipei since birth. They speak no other dialects of Chinese. English was learned as a second language after age 7 for both subjects.

3.1.2 *Material*

Fifty-six Chinese sentences and phrases were constructed with the target items placed at the last syllable of each sentence (for better measurement of the syllables without influence from following syllables). The test items were composed of 56 syllables (each corresponding to a Chinese character) distributed in six experimental groups. The composition of items in the experimental groups is shown in Table III. The target items were all of falling tone (the fourth tone in Mandarin), as the falling tone is generally lower in pitch, making the formants in the spectrogram clearer for measurement. These target items were minimal pairs that differed only in the nasal endings according to their prescribed underlying representation. The materials were randomized into seven lists of eight sentences. The sentences used in this experiment are provided in the appendix.

TABLE III. Target items used in the reading tasks.

Type	Items (Pinyin)	Type	Items (Pinyin)
/an/	fan ban huan zhan shan kan san pan lan dan (**N=10**)	**/aŋ/**	fang bang huang zhang shang kang sang pang lang dang (**N=10**)
/ən/	fen fen zhen chen shen zhen shen nen (**N=8**)	**/əŋ/**	feng feng zheng cheng sheng zheng sheng nong (**N=8**)
/in/	bin xin jin yin yin jin jin jin jin lin (**N=10**)	**/iŋ/**	bing xing jing ying ying jing jing jing jing ling (**N=10**)

3.1.3 *Procedure*

The subjects were recorded in a sound-proof booth. They were instructed to read each sentence twice, to first read the sentence at normal speed, then to read slowly character by character. They were told that the whole experiment consisted of 56 sentences, with 8 sentences in each list. The lists were separated by short pauses between them.

The data were recorded and analyzed using *Praat (Version 4.0.5)*. The early and late points in the vowels were measured for values of F1, F2, and F3. It is hypothesized that if the -n/-ŋ distinction exists, the later points of vowel formants will show significant differences in the transition into the nasals of different places of articulation.

3.1.4 *Results and discussion*

The underlying forms /an/ and /aŋ/ are phonetically realized as [æn] and [aŋ] respectively. They turned out not to be minimal pairs because the vowels are distinct from each other.

This is supported by the statistical analyses. Paired-samples *t*-tests showed that the values of F2 in both early points (natural speech: $p < .01$, $t = 5.934$, $df = 19$; careful speech: $p < .01$, $t = 5.774$, $df = 19$) and late points (natural speech: $p < .01$, $t = 12.106$, $df = 19$; careful speech: $p < .01$, $t = 14.925$, $df = 19$) are distinct for syllables ending in [æn] and [aŋ]. Formant frequencies in F1 and F3 do not show significant difference. The average values of F1, F2, and F3 for [æn] and [aŋ] (when carefully read out) are plotted in Figure 2. Spectrograms for [bæn] and [baŋ] are given in Figure 3 as an illustration.

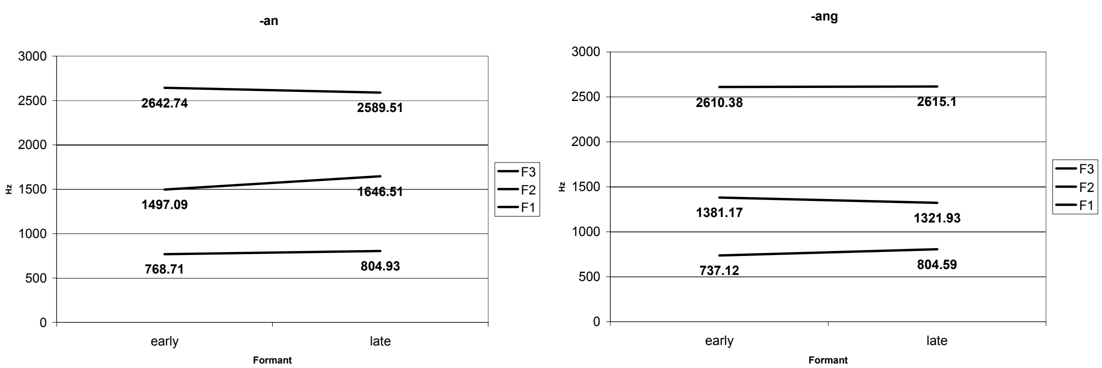


Figure 2. Average F1, F2, and F3 of syllables ending in [æn] and [aŋ].

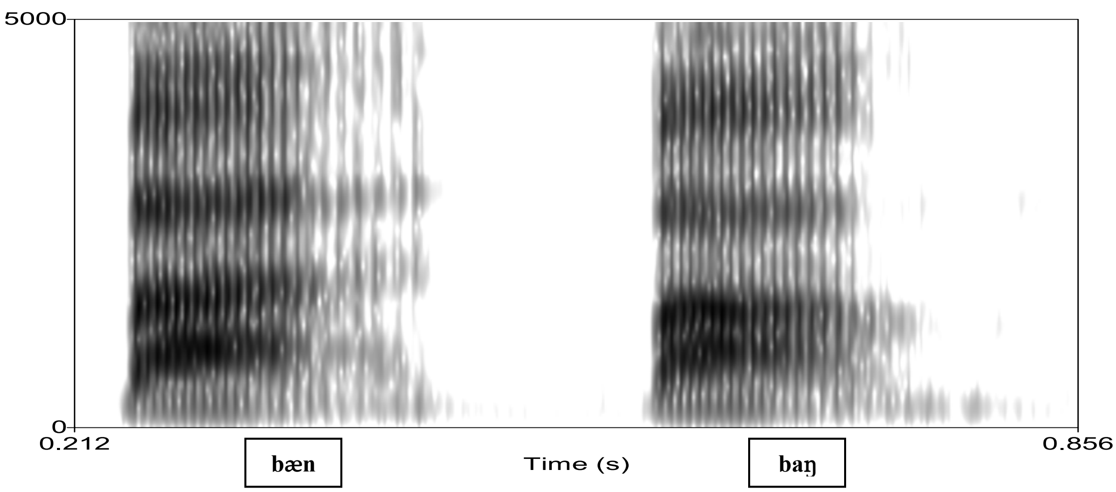


Figure 3. Spectrograms for [bæn] and [baŋ].

The results suggest that Chinese /an/ is assimilated as [æn], the difference between the vowels [æ] in [æn] and [a] in [aŋ] lying primarily in F2. The F2 for [æn] is lower than that for [aŋ]. The F2 for [æn] rises towards the nasal coda, while that for [aŋ] descends towards the nasal. These differences make /an/ and /aŋ/ acoustically distinct.

As for /ən/ and /əŋ/, there is a split in phonetic realization for /əŋ/. In certain environments, /əŋ/ is predominantly pronounced as [ɔŋ]; in others, it is realized as [əŋ]. Therefore, we treat the two phonetic realizations differently in the statistical analysis. First of all, [ən] and [ɔŋ] are significantly different in F2, a finding that is similar to what we found between [æn] and [aŋ]. Paired-samples *t*-tests show that the values of F2 in both early points (natural speech: $t = 10.690$; careful speech: $t = 9.305$) and late points (natural speech: $t = 22.508$; careful speech: $t = 20.541$) are significantly different ($p < .01$, $df = 5$) for syllables ending in [ən] and [ɔŋ]. Formant frequencies in F1 and F3 do not show significant difference, even though the average values of F1 are pretty different. The average values of F1, F2, and F3 for [ən] and [ɔŋ] (read in careful style) are plotted in Figure 4.

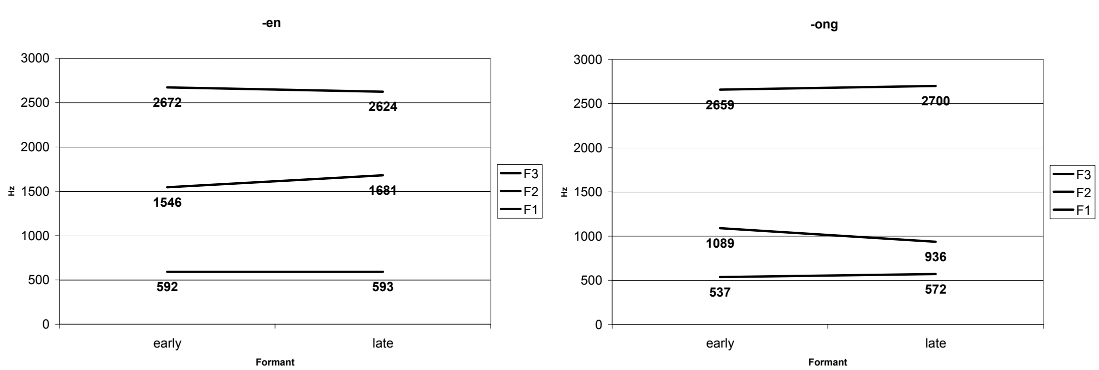


Figure 4. Average F1, F2, and F3 of syllables ending in [ən] and [ɔŋ].

The main difference between [ən] and [ɔŋ] is that the F2 for [ɔŋ] is lower and shows a descending pattern over time, while that for [ən] is higher and shows an ascending pattern. This difference, however, results from differences in vowel qualities rather than differences in the nasal endings. The spectrograms for [fən] and [fɔŋ] are given in Figure 5.

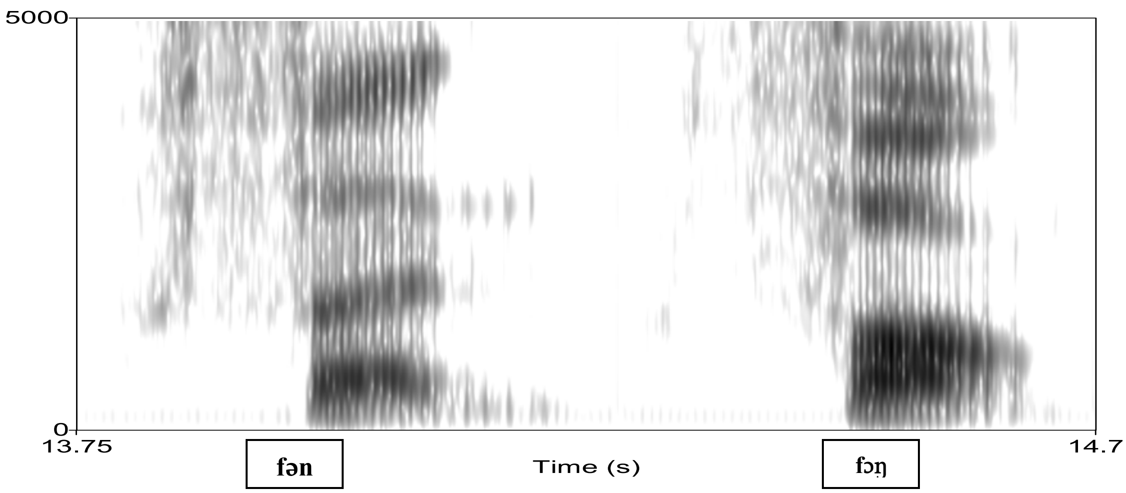


Figure 5. Spectrograms for [fən] and [fɔŋ].

Let us now turn to real minimal pairs between /n/ and /ŋ/. The first pair to consider is [ən] and [əŋ]. Paired-samples *t*-tests show no significant differences between [ən] and [əŋ]. The examination of F1, F2, and F3 among syllables that are supposed to show distinctions between [ən] and [əŋ] in prescribed grammar does not show acoustic differences in real speech. The average values of F1, F2, and F3 for [ən] and [əŋ] (read in careful style) are plotted in Figure 6. The spectrograms for [tʂən] and [tʂəŋ] are given in Figure 7. The results suggest that by looking at the vowel formants in [ən] and [əŋ], we find no acoustic differences in F1, F2, and F3. The two rimes [ən] and [əŋ] are either not distinguished in production, or distinguished in the nasal endings while not affecting preceding vowels. The latter account does not seem possible, since nasal endings of different places of articulation should affect vowel transitions at least at the later point of the formants. From our data, it is reasonable to conclude that speakers no longer distinguish between [ən] and [əŋ] in production.

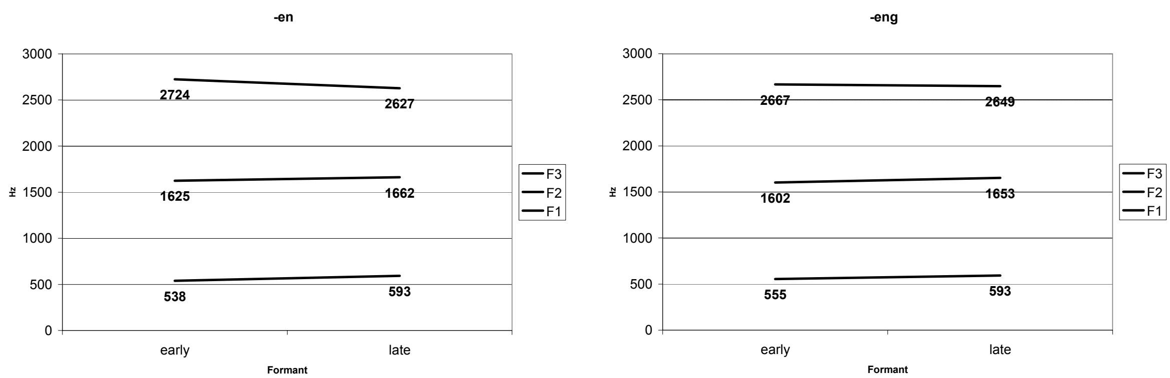


Figure 6. Average F1, F2, and F3 of syllables ending in [ən] and [əŋ].

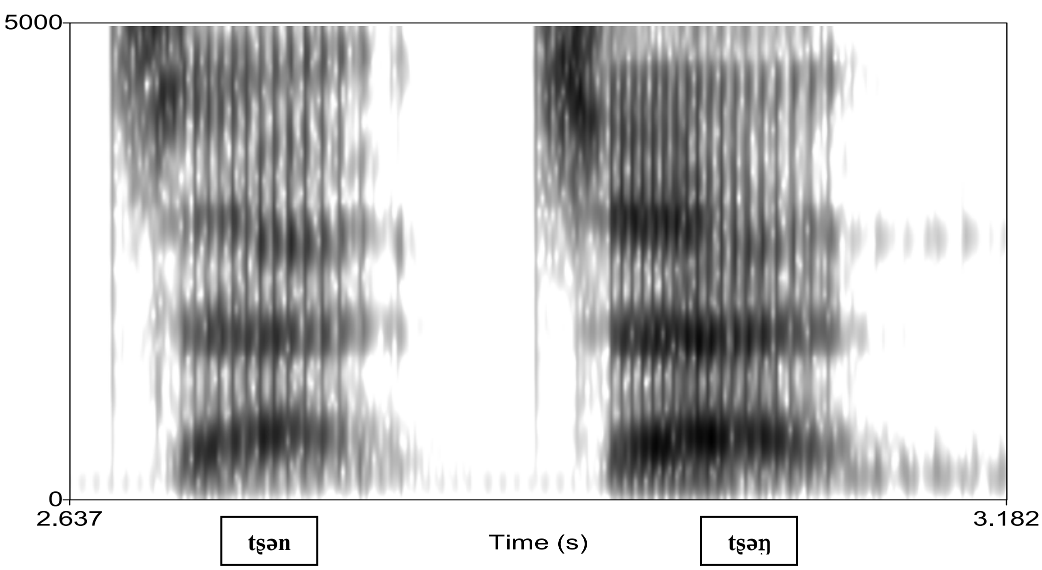


Figure 7. Spectrograms for [tʂən] and [tʂəŋ].

Syllables ending in /in/ and /iŋ/ are also not significantly different in the vowel formants preceding them. The only significant difference is found between the early points of F1 in careful style of reading ($p < .05$, $t = -2.255$, $df = 19$). F1 for [iŋ] is higher than [in] at the early point (361 Hz vs. 340 Hz). I attribute this bizarre difference to the effect of the onset consonant on F1 transitions rather than an effect related to the nasal endings. The average values of F1, F2, and F3 for [in] and [iŋ] (read in careful style) are plotted in Figure 8. The spectrograms for [tɕin] and [tɕiŋ] are given in Figure 9.

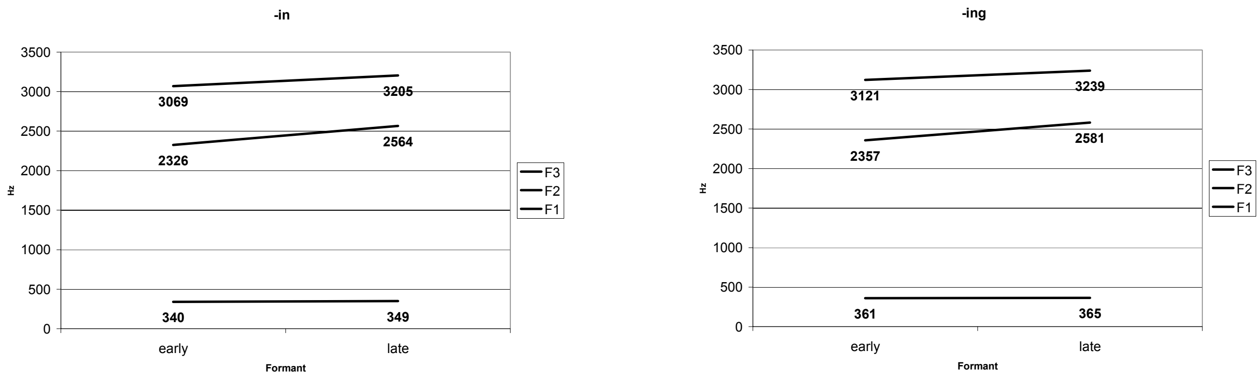


Figure 8. Average F1, F2, and F3 of syllables ending in [in] and [iŋ].

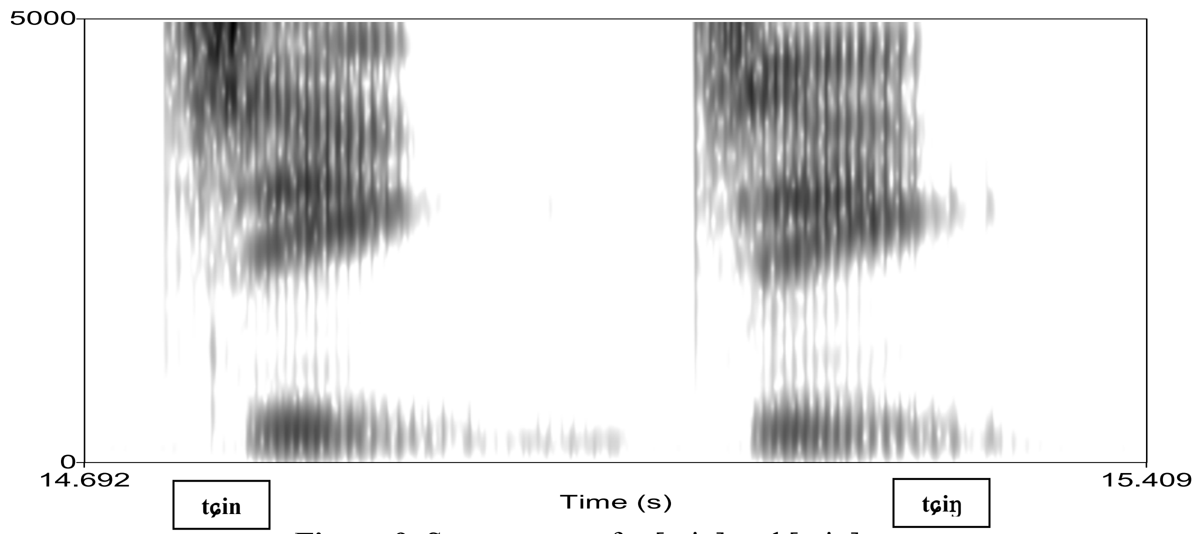


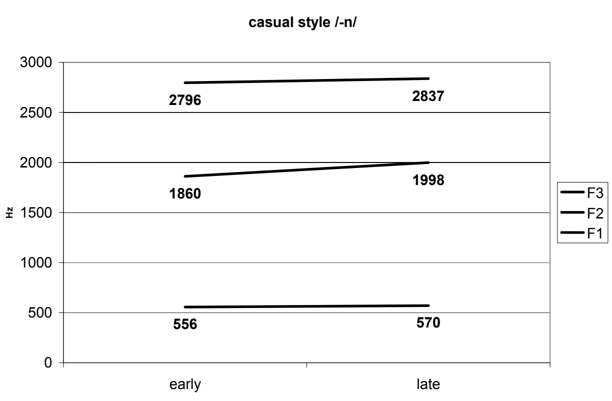
Figure 9. Spectrograms for [tɕin] and [tɕiŋ].

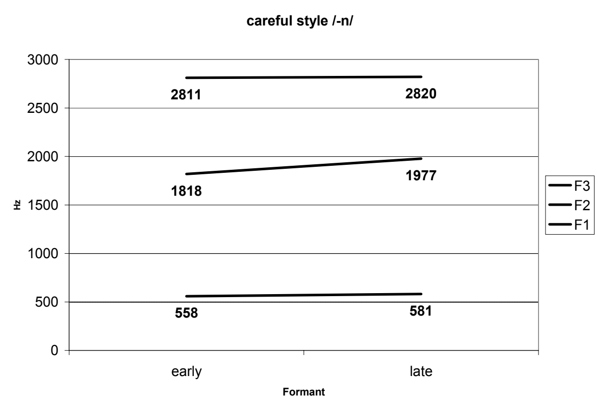
The results suggest that acoustically, [in] and [iŋ] are not distinguishable. At least by looking at the first three formants of the vowels, we cannot find significant differences between the pair. If there exists any difference between [in] and [iŋ], it is to be found elsewhere. The fourth formant, the duration of the nasal endings, and vowel durations may be the potential places to look for the differences between [in] and [iŋ] if there is any.

These possibilities remain to be explored in further research. However, since we have looked at the most likely place, it is very likely that there is just no difference any more.

As to speech styles, natural and careful ways of reading do not influence the vowel quality in terms of F1, F2, and F3. Paired-sample *t*-tests show no significant differences in all but one condition: the early points of F2 in syllables that end in [-n] are significantly higher for natural speech (1860 Hz) than for careful speech (1818 Hz) ($p < .05$, $t = 2.86$, $df = 55$). It is possible that this significant difference results from the diversity of formant transitions between the onset consonants and vowels. Figure 10 shows the average values of F1, F2, and F3 in /-n/ and /-ŋ/ endings in natural and careful speech styles.

These results suggest that nasal endings do not show different patterns in casual and careful reading tasks. A person does not adjust his nasal endings significantly differently towards the prescriptive pronunciations to make casual and careful speech different.





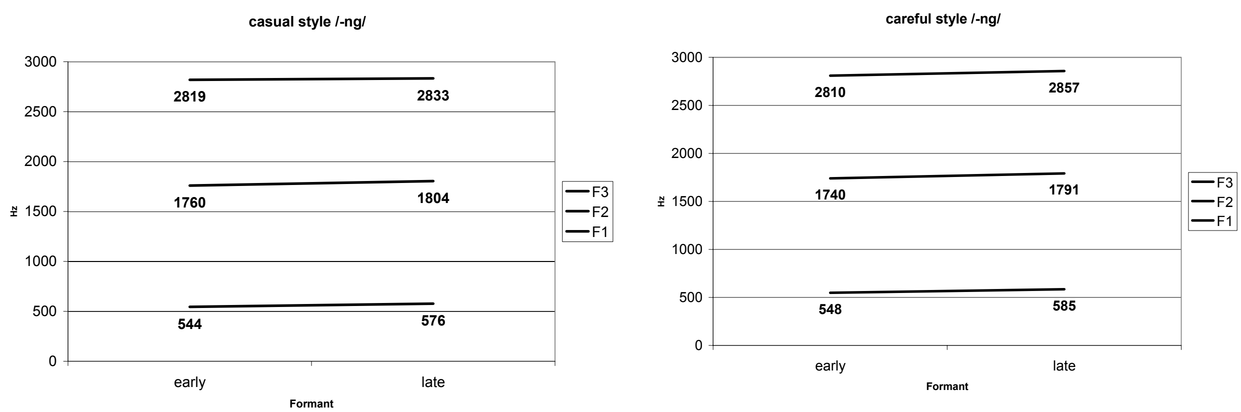


Figure 10. Average F1, F2, and F3 of syllables ending in /-n/ and /-ŋ/ in casual and careful reading styles

3.2. *Experiment II: Perception tasks*

3.2.1 *Subjects*

Three subjects (two males & one female; at the age of 28, 30, and 35) that did not participate in the first experiment participated in the perception tasks. The subjects were all residents of Taipei since birth, and speak Taiwan Mandarin as their native language. English was a second language that they did not learn until age 7.

3.2.2 *Material*

The materials were made of 56 minimal pairs and 4 filler pairs, taken from the target items produced by one of the speakers (under the condition of careful speech) in Experiment I. The items (60 in total) were randomly distributed into 6 lists, each comprising 10 test items. The filler pairs were added in order to make subjects feel that the same character could appear more than once. Therefore, having heard an item once does not guarantee that it would not appear again.

3.2.3 *Procedure*

The subjects were asked to listen to the test items played out from a speaker at a comfortable volume. They were instructed to pick the character that they heard out of the minimal pairs presented on the questionnaire. Subjects were told that the same character may appear more than once. This ensured that subjects paid attention to each test item without relying on expectations (based on probability of items). Ten items were played consecutively as a list, with an interval of 1500 milliseconds. The frequencies of the responses were calculated according to the intended pronunciations and the actual perceptions.

3.2.4 *Results and discussion*

The perceptual difference between [æn] and [aŋ] is robust as shown in Table IV. Subjects were 100% correct in deciding whether they heard [æn] or [aŋ]. The acoustic differences in F2 that we found in Experiment I seemed to serve as very reliable cues for the subjects to make correct identifications.

TABLE IV. The perception of [æn] and [aŋ].

Prescribed pronunciation / Perceived sounds	[æn]	[aŋ]
[æn]	**30 (100%)**	0
[aŋ]	0	**30 (100%)**

The perception of [ən], [əŋ], and [ɔŋ] showed diverse results (see Table V). As one would expect, [ən] and [ɔŋ] are easily distinguishable because of the apparent vocalic differences. These acoustic differences reside in F2 as suggested by the results of Experiment I. Subjects were 100% correct identifying [-ɔŋ] syllables. However, they showed great confusion between [ən] and [əŋ]. They predominantly identified what they heard as [ən]. This shows a trend for Mandarin nasal endings [-əŋ] to be merging into [ən]. At least perception-wise, subjects tended to identify both [ən] and [əŋ] as a sound closer to [ən]. There are several possible stories to tell: It is possible that Mandarin speakers in Taiwan now pronounce [əŋ] as [ən], or as something similar to [ən]; therefore, listeners perceive both sounds as [ən]. It is also possible that both [ən] and [əŋ] underwent phonetic change, merging into a sound that is more [ən]-like. Since no distinction was made in production, there is no way listeners could distinctively perceive the sounds when they appear in isolation. A third (yet less likely) possibility is that [ən] and [əŋ] are actually produced as distinct sounds. Our acoustic analysis of vowel formants was not sensitive enough to mark the distinction. Neither were subjects able to perceive the differences when these syllables appeared in isolation. If this is the case, our question should be whether it makes sense to maintain acoustic differences when speakers no longer perceive them. However, this is very unlikely to be the case, as children need to be able to perceive in order to acquire linguistic differences.

TABLE V. The perception of [ən], [əŋ], and [ɔŋ].

Prescribed pronunciation / Perceived sounds	[ən]	[əŋ]	[ɔŋ]
[ən]	**22 (83%)**	**12 (80%)**	0
[əŋ]	2 (17%)	3 (20%)	0
[ɔŋ]	0	0	**9 (100%)**

There was also significant confusion between [in] and [iŋ], but direction of merging was interestingly different from the case of [ən] and [əŋ]. As shown in Table VI, subjects perceived both [in] and [iŋ] as [iŋ] or as a sound that is more [iŋ]-like. The pair of nasal endings [in] and [iŋ] is losing distinction and merging into [iŋ]. Speculations similar to those of [ən] and [əŋ] could be made to account for the findings. It is possible that [in] is pronounced more like [iŋ] in contemporary Mandarin spoken in Taiwan. It is also possible that both [in] and [iŋ] have undergone phonetic change, arriving at a sound that is somewhat closer to [iŋ]. It may also be the case that the distinction between [in] and [iŋ] becomes too minute to capture in our acoustic analysis as well as in subjects' perception of the syllables in isolation.

TABLE VI. The perception of [in] and [iŋ].

Prescribed pronunciation / **Perceived sounds**	[in]	[iŋ]
[in]	6 (20%)	6 (20%)
[iŋ]	**24 (80%)**	**24 (80%)**

4. General discussion

In sum, this research finds differences in the production and perception of nasal endings in relation to different vowels preceding them. The question is not so simple as whether there is still distinction between /-n/ and /-ŋ/. It is, rather, how different vowels interact with the nasal endings, together bringing forth phonological assimilation and phonetic change. The production tasks in this research show that assimilation of the vowels towards the places of articulation of nasal endings is common.[3] In so doing, the minimal pairs are kept further apart, making it easy to draw distinctions in perception. In cases where assimilation does not take place, the /-n/ vs. /-ŋ/ distinction is no longer kept. It is found that /in/ becomes [iŋ]-like and that /əŋ/ becomes [ən]-like.

Let us now answer the questions proposed in the introduction:

[3] In this paper, we have seen /an/ becoming [æn] and /əŋ/ becoming [ɔŋ] among others that I have not included in this research.

- *Are the prescribed nasal endings /-n/ and /-ŋ/ distinguished in Standard Mandarin spoken in Taiwan? If yes, how are they distinguished acoustically? If not, when (following which vowels) is the distinction lost? What do they become?*

  In certain cases (e.g. /an/ vs. /aŋ/) where the vowels undergo assimilation, the distinction between /n/ and /ŋ/ is kept. This distinction is found in F2. In others (e.g. /ən/ vs. /əŋ/, /in/ vs. /iŋ/), when the vowels remain relatively the same, no significant acoustic distinction has been found.

- *Do natural speech and careful speech show the same patterns?*

  Natural reading and careful reading of the materials do not show significant differences.

- *Do listeners distinguish between /-n/ and /-ŋ/ in perception tasks? When are they and when are they not distinguished?*

  Consistent with the reading data, in cases (e.g. /an/ vs. /aŋ/) where there is significant difference in production, subjects could easily make accurate distinctions. In cases (e.g. /ən/ vs. /əŋ/, /in/ vs. /iŋ/), where no distinction in production has been found, subjects also found it difficult to make correct identifications. True minimal pairs (i.e. minimal pairs that differ only in nasal endings as [n] or [ŋ]) have not been found. Nasal endings /n/ and /ŋ/ are either distinguished along with distinct vowels preceding them or not distinguished at all. Namely, they are in complimentary distribution.

- *Do the acoustic cues found in production help listeners distinguish /-n/ from /-ŋ/? Are listeners able to distinguish /-n/ and /-ŋ/ when the acoustic analyses of* *production show no significant distinction? That is, are there other cues not captured in this research that facilitate the distinction in perception?*

Answers to these questions are embedded in previous answers. Acoustic cues (e.g. F2) found in production tasks are useful in helping listeners distinguish between certain /-Vn/ /-Vŋ/ pairs. Subjects were not able to distinguish between pairs that did not show significant acoustic distinctions.

- *What does listeners' perception tell us about the direction of phonetic change among nasal endings?*

  It is shown that /in/ and /iŋ/ merged into/iŋ/, and that /ən/ and /əŋ/ merged into /ən/. The finding about /in/ and /iŋ/ is consistent with the converging formants (F2 and F3) shown in Figure 9. We could see the formant transitions into velar consonants in the spectrograms of /in/ and /iŋ/.

A further interesting question to pursue is why [ən]/[əŋ] and [in]/[iŋ] showed different directions of merging in perception. What role does the preceding vowel play in the direction of nasal merging?

The perceptual similarities between [n] and [ŋ] motivate the minimal pairs to merge in production. My hypothesis is that in -VN syllables, language speakers either modify the vowels for assimilation or keep the vowels as they are. When the vowels undergo assimilation, the [-Vn] syllables become dissimilated from corresponding [-Vŋ] syllables in the minimal pair, making perceptual difference relatively obvious and easy. When the vowels remain the same, the nasal endings [n] and [ŋ] undergo neutralization or merging. However, merging does not go freely in any direction. The preceding vowels condition the direction of merge. A natural tendency is for [in] to become more [iŋ]-like, and for [əŋ] to become more [ən]-like. I speculate that it is a universal tendency (that is physiologically grounded) for high front vowels to push the nasal endings towards the velum in order to keep the vocal tract narrow and long. For production reasons, therefore, [ŋ] appears more naturally with high front vowels, while [n] is usually preceded by nonhigh vowels. The English inflectional ending *–ing* [iŋ] becoming *–in* [ən], changing both the nasal ending and vowel quality, is another example that supports this account.

The present study confirms the direction of nasal merging found by Chen (1991). This research differed from the research of Chen, in that we tried to find acoustic distinctions between the nasal endings and empirically tested subjects' perception of the differences. There are several potential directions remaining for further research. First, increasing the number of subjects will increase the accountability and credibility of current analysis. Besides, one could collect data from subjects of different ages to show diachronic directions of phonetic change. Thirdly, in order to test the universality of nasal merging in relation to vowel quality, it will be useful to look into the nasal changes and nasalization in other languages. Contrastive analyses of nasal merging in different Chinese dialects will be helpful. As /n/-/ŋ/ distinction is better maintained in the Standard Mandarin spoken in Mainland China (particularly in Peking Mandarin), it will be interesting to do a contrastive analysis in Mainland Mandarin, and conduct cross-group perception tasks—asking Taiwanese subjects to listen to Mainland /n/-/ŋ/ minimal pairs, and vice versa. Another possible direction is to look at the nasal endings in naturally-occurring speech that appear in settings of various degrees of formality. It will be interesting to find any social meanings conveyed by the distinction of /n/ and /ŋ/ in certain contexts. Lastly, as mentioned in previous sections, it is possible that the distinction has not been observed by looking at vowel formants in this research. Therefore, future research could try to look for acoustic differences in other dimensions such as vowel duration, nasal duration, etc.

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APPENDIX: Materials used in Experiment I, the reading tasks.

/an/

1. 晚上回家吃飯 wan shang hui jia chi **fan**
2. 現在時間八點半 xian zai shi jian ba dian **ban**
3. 浪子回頭金不換 lang zi hui tou jin bu **huan**
4. 相約台北車站 xiang yue tai bei che **zhan**
5. 夏天吹電扇 xia tian chui dian **shan**
6. 考試別偷看 kao shi bie tou **kan**
7. 阿保有點散 a bao you dian **san**
8. 這案子很難判 zhe an zi hen nan **pan**
9. 色情氾濫 se qin fan **lan**
10. 一月一號是元旦 yi yue yi hao shi yuan **dan**

/aŋ/

1. 東西別亂放 dong xi bie luan **fang**
2. 你說我棒不棒 ni shuo wo bang bu **bang**
3. 到我店裡晃一晃 dao wo dian li huang yi **huang**
4. 有些老人走路用枴杖 you xie lao ren zou lu yong guai **zhang**
5. 有一支筆在桌上 you yi zhi bi zai zhuo **shang**
6. 叫他別反抗 jiao ta bie fan **kang**
7. 失敗別沮喪 shi bai bie ju **sang**
8. 美環有點胖 mei huan you dian **pang**
9. 乘風破浪 cheng fong po **lang**
10. 教室空蕩蕩 jiao shi kong dang **dang**

/ən/

1. 做人不能太過分 zuo ren bu neng tai guo **fen**
2. 不要過度興奮 bu yao guo du xing **fen**
3. 晚風一陣又一陣 wan fong yi zhen you yi **zhen**
4. 不需要你來陪襯 bu xu yao ni lai pei **chen**
5. 小心謹慎 xiao xin jin **shen**
6. 精神不振 jin shen bu **zhen**
7. 他去醫院洗腎 ta qu yi yuan xi **shen**
8. 土雞又油又嫩 tu ji you you you **nen**

/əŋ/

1. 中國的吉祥物是龍與鳳 zhong guo de ji xiang wu shi long yu **fong**
2. 這是我一個月的薪俸 zhe shi wo yi ge yue de xin **fong**
3. 行得直 坐得正 xin de zhi zuo de **zheng**
4. 我的星座是天秤 wo de xin zuo shi tian **cheng**
5. 小明很好勝 xiao ming hen hao **sheng**
6. 人人都怕得癌症 ren ren dou pa de ai **zheng**
7. 我的這一票很神聖 wo de zhe yi piao hen shen **sheng**
8. 梅花三弄 mei hua san **nong**

/in/

1. 不過十年 他已白了雙鬢 bu guo shi nian ta yi bai le shuang **bin**
2. 一天一封信 yi tian yi fong **xin**
3. 性相近 xin xiang **jin**
4. 心心相印 xin xin xiang **yin**
5. 我最愛樹蔭 wo zui ai shu **yin**
6. 非請勿進 fei qin wu **jin**
7. 違反宵禁 wei fan xiao **jin**
8. 他渾身是勁 ta huen shen shi **jin**
9. 同歸於盡 tong gui yu **jin**
10. 吝於付出 **lin** yu fu chu

/iŋ/

1. 牙痛不是病 ya tong bu shi **bing**
2. 先生貴姓 xian sheng qui **xing**
3. 如入仙境 ru ru xian **jing**
4. 他的命很硬 ta de ming hen **ying**
5. 他沒有反應 ta mei you fan **ying**
6. 禪修講求心靜 chan xiu jiang qiu xin **jing**
7. 我得學習以人爲鏡 wo dei xue xi yi ren wei **jing**
8. 王老師很受人尊敬 wang lao shi hen shou ren zun **jing**
9. 家裡保持乾淨 jia li bao chi gan **jing**
10. 軍人要服從命令 jun ren yao fu cong ming **ling**

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