AN AERODYNAMIC STUDY OF THE NASALS AND NASALIZATION IN TAIWANESE MANDARIN

Yueh-chin Chang, Kai-yun Ou and Feng-fan Hsieh
National Tsing Hua University
Nasalization refers to sounds produced while the velum is lowered to allow the air to escape through the nose.

The phonetic implementation of vowel nasalization may depend on:
- the phonemic system of the language (whether nasality is phonemic)
- Direction of nasalization
  Carryover (NV) vs. Anticipatory (VN)
Vowel height

• High vowels are produced with higher velum and less velopharyngeal opening than low vowels. (cf. Moll, 1960; Ohala, 1971; Bell-Berti, 1973; ....)

→ low vowels tend to be more nasalized than high vowels

• Low vowels need a lower velum to be perceived as nasal (Beddor, 1993, ....)
INSTRUMENTS & TECHNIQUES
( KRAKOW AND HUFFMAN, 1993)

- Velum movement
  - X-ray
  - Ultrasound
  - Fiberoptics
  - Nasograph (Ohala, 1971; Clumeck, 1976)
  - Velotrace (Horiguchi and Bell-Berti, 1987)
Velum movement

- MRI
- Electromagnetic articulatory (Ushijima and Hirose, 1974; Amelot et al., 2006; Shosted et al., 2012; Carignan et al., 2011, 2012, 2015)
Acoustic measurements (Berger, 2007)

- Decrease in F1 amplitude
- The emergence of a spectral prominence above F1 at around 1000 Hz (House and Stevens, 1956)
- Another nasal resonance below F1 between 250 and 450 Hz (Hattori et al., 1958)
Acoustic measurements

- A1-H1 (Huffman 1990)
- B1 (bandwidth of the first formant),
- ✔ ✔ COG(1000): Center of Gravity in the low frequency spectrum (below 1000 Hz) (Glass 1984; Glass and Zue, 1985)
Acoustic measurements

✓✓ A1–P0 (P0: amplitude of the nasal formant below F1, 0 to 450 Hz) (Chen, 1996)

• A1–P1 (P1: amplitude of the nasal formant above F1, 800 to 1100 Hz) (Chen, 1996)

• As nasality increases, both A1–P0 and A1–P1 should decrease.
Airflow equipment

- Nasometer
- Pquirer

Nasalance: the ratio of nasal to nasal+oral acoustic energy output (Fletcher and Frost, 1974)
Perception of nasality

- $A_1$ needed to be reduced by 8 dB (House and Stevens, 1956)
- Both the average $A_1 - H_1$ and change in $A_1 - H_1$ over time contributed to the nasality judgment (Huffman, 1990)
• The introduction of the nasal peak above F1 (around 1000 Hz) (Maeda, 1982; Hawkins and Stevens, 1985)

• The other nasal peak below F1 (around 250-450 Hz) (Hattori et al., 1958; Maeda, 1982)

• Gating methodology (Bengali and English: Lahiri and Marlsen-Wilson, 1992; Hindi and English: Ohala and Ohala, 1995)
Taiwanese Mandarin has 5 vowels and 2 nasal coda /n/ and /ŋ/. The possible VN rimes are: 
\{/in/, /iŋ/, /əŋ/, /əŋ/, /yn/, /ɔŋ/, /an/, and /anŋ/\}

Taiwanese Mandarin speakers tend to realize


Aims

• This work is an aerodynamic study of nasal sounds and nasalization in Taiwanese Mandarin (TM).
  -- Progressive over anticipatory?
  -- Is nasality correlated with vowel height?
  -- Manner of articulation induces vowel nasalization?
  -- Merger: /in/ → /iŋ/? /iŋ/ → /in/?

• Also, we wanted to investigate whether nasalization is realized differently in Taiwanese Mandarin and Standard Chinese (SC).
PARTICIPANTS

• Ten (10) native speakers of TM (5 male and 5 female in their 20s) from the Greater Taipei Area.

• To minimize potential “L1” interference.
  • They do not speak any other Sinitic languages spoken in Taiwan, e.g., Taiwanese Southern Min and/or Hakka.
CORPUS

• All possible NV, NVN, CV and CVN syllables in Taiwanese Mandarin.

• Only real words are used (164 words)

• Tone 4 (high falling) is used; otherwise, Tone 1 (high level) is chosen if there is a tonetic gap.

• Intended for cross-linguistic comparison in the future…
METHOD

• The airflow data were collected with the help of Pcquirer 516 (Scicon R&D Inc.) in a soundproof room at phonetics lab, National Tsing Hua University.

• Data were analyzed by Praat scripts developed at phonetics lab, National Tsing Hua University (Y.-L. Hsieh 2011, Y.-L. Hsieh et al. 2011).
The onset of nasalization was determined as the time point at which nasal airflow crossed the zero level plus 10% of the maximum level of nasal airflow in vowel (Delvaux et al. (2008)).
TWO TYPES OF MEASUREMENTS ON THE AIRFLOW DATA (DELVAX ET AL. 2008)

(1) Percentage of nasalized time (NasalTime%)

\[ \text{NasalizedDuration} = \frac{\text{NasalizedDuration}}{\text{TotalVowelDuration}} \times 100\% \]

(2) Percentage of nasal flow volume (NasalFlow%)

\[ \text{NasalFlow(bleu)} = \frac{\text{NasalFlow(bleu)}}{\text{NasalFlow(blue)} + \text{OralFlow(Red)}} \times 100\% \]
EXPERIMENTAL RESULTS
RESULT (1): VOWELS

• NV vs. VN

The magnitude of progressive nasalization (NV) is significantly larger than that of regressive nasalization (VN) for both NasalFlow% and NasalTime%.

→ progressive > anticipatory
• NV vs. NVN

Interestingly, NV has more NasalFlow% than NVN does (p<0.001), due to the rapid velopharyngeal closure at the beginning of the vowel for NVN.
High vowels have more NasalFlow% in various contexts (p<0.05), but have shorter NasalTime% (p<0.05).
RESULT (3): THE ROLE OF ONSET ON CONTEXTUAL NASALIZATION

- Voiced fricative and liquid induce more NFL% and nasal onset than voiceless counterparts.

- Aspirated consonants have oral and nasal flow volume than unaspirated ones (p<0.05) and induce a marginally significant earlier nasal onset (p=0.06).

<table>
<thead>
<tr>
<th></th>
<th>Unasp. Stop</th>
<th>Unasp. Affricate</th>
<th>Asp. Stop</th>
<th>Asp. Affricate</th>
<th>Voiceless Fricative</th>
<th>Voiced Fricative</th>
<th>Liquid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oral Flow</td>
<td>0.206</td>
<td>0.194</td>
<td>0.306</td>
<td>0.292</td>
<td>0.208</td>
<td>0.149</td>
<td>0.157</td>
</tr>
<tr>
<td>Nasal Flow</td>
<td>0.082</td>
<td>0.080</td>
<td>0.102</td>
<td>0.094</td>
<td>0.083</td>
<td>0.066</td>
<td>0.083</td>
</tr>
<tr>
<td>NFL%</td>
<td>29.1%</td>
<td>29.3%</td>
<td>24.6%</td>
<td>24.2%</td>
<td>29.4%</td>
<td>32.3%</td>
<td>34.0%</td>
</tr>
<tr>
<td>NDur%</td>
<td>51.0%</td>
<td>51.3%</td>
<td>58.7%</td>
<td>56.5%</td>
<td>52.1%</td>
<td>56.6%</td>
<td>57.0%</td>
</tr>
</tbody>
</table>
**VOICING AND ASPIRATION**

- **Why voicing induces more nasal airflow:**
  - In CVN syllables, velum lowering starts from the closure phase or release phase for liquid, but after release phase for stops and fricatives (Moll and Danioff, 1971).
  - Our results lend support to this view.

- **What about aspiration?**
  - It has been noted in Matisoff (1973) that /h/ tends to trigger spontaneous nasalization in sound change (rhinoglottophilia).
  - More or less, aspiration = [h]
RESULT (4): THE ROLE OF CODA ON CONTEXTUAL NASALIZATION

• Codas /n/ vs. /ŋ/

Coda /ŋ/ induces “more nasalization” in the preceding vowels than /n/ does for both nasal airflow volume and nasal flow duration, but the difference is insignificant.

<table>
<thead>
<tr>
<th></th>
<th>NasalFlow%</th>
<th>NasalTime%</th>
</tr>
</thead>
<tbody>
<tr>
<td>/n</td>
<td>31.2%</td>
<td>58.9%</td>
</tr>
<tr>
<td>/ŋ</td>
<td>33.8%</td>
<td>59.9%</td>
</tr>
</tbody>
</table>
• Progressive nasalization (NV) > Anticipatory nasalization (VN).

• Nasality is positively correlated with vowel height.

• Similar results found in our previous study for Taiwanese Southern Min and French (Hsieh et al. 2011).

• But that is not consistent with some other languages, e.g. Hindi, whereby nasality is negatively correlated with vowel height.
• Voiced fricatives and liquid induce a larger nasal flow percent than their counterparts do.

• Aspiration is produced with more oral and nasal airflow and triggers an earlier nasal onset.

  → Rhinoglottophilia (Matisoff, 1975)

• Coda /ŋ/ induces more nasality in the preceding vowels than coda /n/ does. Similar results are also found in Taiwanese Southern Min (TSM) but not in Standard Chinese (SC).
Taiwan Mandarin (TM) vs. Standard Chinese (SC)

- Vowels have more nasality in SC than that in TM.
- Nasal coda’s duration is longer in TM than that in SC.
- /n/ is much shorter than /ŋ/ in SC than that in TM.
- Vowel preceding /n/ is more nasalized than /ŋ/ in SC, but not in TM and TSM.

<table>
<thead>
<tr>
<th></th>
<th>TM</th>
<th>SC</th>
<th>TSM</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>31.0%</td>
<td>51.0%</td>
<td>19.6%</td>
</tr>
<tr>
<td>ŋ</td>
<td>33.8%</td>
<td>50.3%</td>
<td>21.7%</td>
</tr>
</tbody>
</table>

NasalFlow% Nasal coda’s duration (in ms.)

- TM: 131 ms.
- SC: 154 ms.
- TSM: 81.00 ms.
- TM: 111.00 ms.
MORE ON NASAL CODAS IN TAIWANESE MANDARIN
Previous studies show that there is contextual place neutralization of nasal codas in TM, especially for the pairs /ən/ and /əŋ/, and /in/ and /iŋ/.

In our study, impressionistically speaking,

- all speakers distinguished between /an/ and /aŋ/
- 85%~89% of speakers distinguished between /ən/ and /əŋ/
- 74%~79% of speakers distinguished between /in/ and /iŋ/.
Due to the nature of the airflow experiment, it is oftentimes difficult to accurately identify the place of articulation of a coda nasal.

In our study, “N” is used to refer to the tokens that are not easily identifiable.

In this work, we focused on the following rimes:

/\an/ vs. /\aŋ/

/\eŋ/ vs. /\eŋ/

/\iŋ/ vs. /\iŋ/.
Our impressionistic results show that /in/ and /iŋ/ are most “confusables”, meaning that they are more likely to be transcribed as “N” (in average 23.5% for the coda /ŋ/ vs. 13% for the coda /n/).

<table>
<thead>
<tr>
<th>Coda identified as</th>
<th>n</th>
<th>ŋ</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>an</td>
<td>100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ən</td>
<td>89%</td>
<td></td>
<td>11%</td>
</tr>
<tr>
<td>in</td>
<td>79%</td>
<td></td>
<td>21%</td>
</tr>
<tr>
<td>aŋ</td>
<td></td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>əŋ</td>
<td></td>
<td>85%</td>
<td>15%</td>
</tr>
<tr>
<td>iŋ</td>
<td></td>
<td>74%</td>
<td>26%</td>
</tr>
</tbody>
</table>
Differences in Nasal Flow %

We measured the nasality and the duration of the nasal coda. If we don’t take the pair /an/ and /aŋ/ into consideration, /n/ and /ŋ/ have similar magnitude of nasal flow volume% (79.7% VS. 81.5%), and their magnitude is higher than that of /N/ (76.4%~77.4%).

<table>
<thead>
<tr>
<th>NasalFlow%</th>
<th>n</th>
<th>N(&lt;n)</th>
<th>NasalFlow%</th>
<th>η</th>
<th>N(&lt;η)</th>
</tr>
</thead>
<tbody>
<tr>
<td>an</td>
<td>71.0%</td>
<td></td>
<td>aŋ</td>
<td>58.7%</td>
<td></td>
</tr>
<tr>
<td>ən</td>
<td>78.5%</td>
<td>71.7%</td>
<td>əŋ</td>
<td>79.4%</td>
<td>72.3%</td>
</tr>
<tr>
<td>in</td>
<td>80.9%</td>
<td>81.1%</td>
<td>η</td>
<td>83.6%</td>
<td>82.4%</td>
</tr>
</tbody>
</table>
The coda /ŋ/ is significantly longer than the coda /n/ (157 ms. vs. 137 ms, p<0.05).
/N/ is shorter than /ŋ/ and /n/. (115 ms.~129 ms.)

<table>
<thead>
<tr>
<th>Duration</th>
<th>֧n</th>
<th>N(&lt;n)</th>
<th>Duration</th>
<th>֧ŋ</th>
<th>N(&lt;ŋ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>an</td>
<td>117</td>
<td></td>
<td>anη</td>
<td>149</td>
<td></td>
</tr>
<tr>
<td>֜n</td>
<td>130</td>
<td>109</td>
<td>֜ŋ</td>
<td>148</td>
<td>131</td>
</tr>
<tr>
<td>in</td>
<td>145</td>
<td>121</td>
<td>inŋ</td>
<td>166</td>
<td>127</td>
</tr>
</tbody>
</table>
Nasal flow induced

- Vowels followed by /ŋ/ are more “nasalized” than those followed by /n/ in nasal flow volume% (p>0.05).
- Vowels followed by /N/ have a degree of nasalization (32.8%~33.3%) less than those followed by /n/ (35.3%) and /ŋ/ (36.9%).

<table>
<thead>
<tr>
<th>NasalFlow%</th>
<th>n</th>
<th>N(&lt;n)</th>
<th>η</th>
<th>N(&lt;η)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>28.8%</td>
<td></td>
<td>&lt;33.7%</td>
<td></td>
</tr>
<tr>
<td>η</td>
<td>27.2%</td>
<td>26.7%</td>
<td>&lt;29.2%</td>
<td>27.5%</td>
</tr>
<tr>
<td>i</td>
<td>43.4%</td>
<td>38.8%</td>
<td>&lt;44.5%</td>
<td>39.1%</td>
</tr>
</tbody>
</table>
SUMMARY

• Coda [N] is different from [n] and [ŋ]:
  ✷ Coda duration: N < n < ŋ
  ✷ NasalFlow%: N < n < ŋ
  ✷ NasalFlow% induced in vowel : N < n < ŋ

• [N] can be regarded as an instance of “incomplete neutralization,” unlike previous studies.

• Further issue: Is [N] attributable to language contact (with Taiwanese Southern Min)?
ARTICULATORY CHARACTERISTICS
EMA DATA

Speaker M1:
/ŋ/ has both TT and TD gesture for /aŋ/ and /iŋ/

Speaker F1:
• /in/ > /iŋ/
• /əŋ/ has both TT and TD gesture
EMA DATA (CONT.)

Speaker M2:
//in// shows both TT and TD gestures in [in].

- There seems to be inter-speaker variation in the production of VN rimes.
EMA DATA
(STANDARD CHINESE)

- SC speaker: different articulatory gestures for /n/ and /ŋ/.
CONCLUSION

- Take-home messages:
  - Regarding /in/ vs. /iŋ/, we found that [iN] is different from [in] and [iŋ] with respect to airflow and duration (incomplete neutralization).
  - Articulatorily speaking, [N] may have two gestures, TT and TD.
ACKNOWLEDGEMENTS

• Special thanks go to
  Prof. Eric Zee,
  Prof. Wai-sum Lee
  Mr. Steven So
  Phonetics Lab, City University of Hong Kong
  for their hospitality and assistance!
Thank you!
Comments?