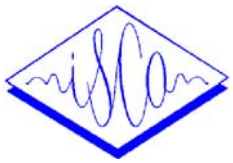
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INTERSPEECH 2004 - ICSLP
8th International Conference on Spoken Language Processing
ICC Jeju, Jeju Island, Korea
October 4-8, 2004

A Study on Nasal Coda Loss in Continuous Speech+

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Abstract

In this study, statistical analysis is used to investigate nasal coda loss in spoken Standard Chinese. In order to find out the factors that influence nasal coda loss, we take into account the segmental and supra-segmental features and their interactions. We find out that articulation manner, post nasal coda boundary and tone influenced the nasal coda loss significantly, the interaction between tone and stress, tone and post boundary, articulation manner and tone are significant too.

1. Introduction

In continuous speech, phonemes are influenced by others factors, we call this phenomenon sound change. In standard Chinese, there are several forms of sound change, which include phoneme deletion and other forms. (Changpei Luo, 1957).

In continuous speech, there are three forms of nasal coda, completely reserved, completely loss and form which can't be seen in the wave form and spectrogram but can be perceived. In speech synthesis which is base on rules, it is very important to make sure their actual forms in different circumstances for improving the naturalness of synthesized speech.

Forerunners' study showed two conditions subject to nasal coda loss: 1.the shorter the nasal coda duration is, the easier the nasal coda to lose; 2. the syllables bearing falling tone are easier to lose the nasal codas than in other tones.

Jianfen Liang(2001) investigated the nasal coda loss phenomenon in continuous speech. She found that nasal coda loss was influenced by three factors: the articulation manner of the initial of the next syllable, temporal distance between these two syllables, and the tone of the syllable.

M. Grazia Busà(2003) studied nasal loss in Italian. The results showed that voiceless fricatives are most conducive to nasal loss.

In our study, we suppose nasal coda N1 in syllable **C1V1N1**, having its pre-syllable C0V0(N0) and post syllable C2V2(N2), and two boundaries BI and BF between them, i.e. its context is as this: C0V0(N0) BI **C1V1N1** BF C2V2(N2). C is the initial and V(N) is the final and N is [n] or [Đ]. T1 is the tone of **C1V1N1.** We will find out which contribute most to N1 deletion, C2, BI, BF, T1 or their combinations.

2. Materials

The materials in this study are selected from the corpus ASSCD that was constructed by Phonetic Lab, Institute of Linguistics, CASS. The corpus is composed of 18 discourses with 300-500 syllables each, and read by 5 female and 5 male speakers. There are 9778 syllables and 2793 of them contain nasal coda. Prosodic and segmental annotations are made by using C-ToBI and SAMPA-C labeling conventions. We obey the following criterion on nasal coda annotation: 1. If there are obvious nasal coda in the spectrogram, we annotated the position of the nasal codas; 2. If there are no obvious nasal coda in the spectrogram, but we can hear the nasal murmur at the syllable coda, we just do nothing; 3. Else, we annotated nasal loss. Then we find out that there are 645 syllables which lose their nasal codas, 479 syllables which contain nasal murmur in the syllable coda but nasal murmur couldn't be seen in the spectrogram, and 1669 syllables whose nasal codas could be obviously seen in the spectrogram. In this study we just analyze the relationship between nasal coda loss and related factors.

+It was supported by National Social Science Foundation

3. Results

3.1 Relationship between articulation manner of C2 and nasal codas loss

In this study, we classify the initials C2 of the post nasal coda syllables C2V2(N2) into 12 classes according to their articulation manners. They are silence, voiced silence, stop, aspirated stop, affricatives, aspirated affricatives, fricative, voiced fricative, nasal and lateral. Numbers from 0 to 11 correspond to these classes respectively. The detail statistical results are shown in *Table1*. There are 832 silence patterns and 21% syllables, which are in front of them, lose their nasal codas. There are 115 voiced silence patterns and 0.87% syllables, which are in front of them, lose their nasal codas; 248 stop patterns and 2.82% syllables, which are in front of them, lose their nasal codas; 62 aspirated stop patterns and 1.61% syllables, which are in front of them, lose their nasal codas; 92 affricatives patterns and 1.09% syllables, which are in front of them, lose their nasal codas; 146 aspirated affricatives patterns and 6.16% syllables, which are in front of them, lose their nasal codas; 631 fricative patterns and 33% syllables, which are in front of them, lose their nasal codas; 67 voiced fricative patterns and 63% syllables, which are in front of them, lose their nasal codas; 264 semivowel patterns and 63% syllables, which are in front of them, lose their nasal codas; 30 vowels patterns and 80% syllables, which are in front of them, lose their nasal codas; 159 nasal patterns and 1.89% syllables, which are in front of them, lose their nasal codas; 147 lateral patterns and 4.08% syllables, which are in front of them, lose their nasal codas.

Table1. Statistical results of articulation manner

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
0	832	.21	.41	1.42E-02	.18	.24	0	1
1	115	8.70E-03	9.33E-02	8.70E-03	-8.53E-03	2.59E-02	0	1
2	248	2.82E-02	.17	1.05E-02	7.47E-03	4.90E-02	0	1
3	62	1.61E-02	.13	1.61E-02	-1.61E-02	4.84E-02	0	1
4	92	1.09E-02	.10	1.09E-02	-1.07E-02	3.25E-02	0	1
5	146	6.16E-02	.24	2.00E-02	2.22E-02	.10	0	1
6	631	.33	.47	1.88E-02	.29	.37	0	1
7	67	.63	.49	5.95E-02	.51	.75	0	1
8	264	.63	.48	2.98E-02	.57	.69	0	1
9	30	.80	.41	7.43E-02	.65	.95	0	1
10	159	1.89E-02	.14	1.08E-02	-2.51E-03	4.02E-02	0	1
11	147	4.08E-02	.20	1.64E-02	8.45E-03	7.32E-02	0	1
Total	2793	.23	.42	7.98E-03	.22	.25	0	1

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A one factor ANOVA pooled on all syllables indicates significant effect of articulation manner on nasal coda loss, $F(11, 1790) = 70.78$, $P = 0 < 0.05$. Then, we carry out the test of homogeneity of variance, and find the variances are not homogenous. So we chose T test method to execute the pairwise comparison, and find that the articulation manners belong to 4 different groups according to their effect on nasal coda loss. The first group contains voiced silence, stop, aspirated stop, affricative, aspirated affricative, nasal and lateral. The second group contains semivowel and voiced fricative. The third group only contains fricative. The fourth group only contains vowel. The difference between groups is significant. As shown in *Figure1*, effects of different articulation manners on nasal coda loss are quite different. It is vowel that has the most significant effect on nasal coda loss (about 80%), then is semivowel and voiced fricative (about 62%), then is fricative (about 33%). If we classify the articulation manners by vocal tract status, we will find that nasal coda tends to lose when vocal tract is not completely obstruent.

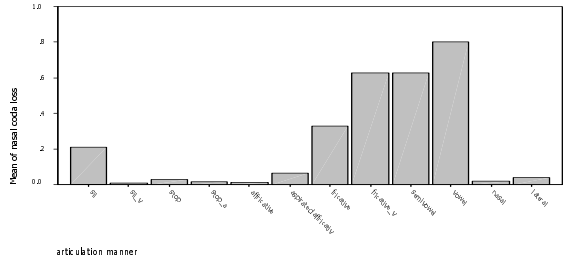


Figure1. Effect of articulation manner on nasal coda loss

3.2 Relationship between boundary and nasal coda loss

In this part, numbers from 0 to 4 correspond to syllable boundary, prosody word boundary, prosody phrase boundary, intonation group boundary respectively. So BI and BF has value from 0 to 4.

3.2.1 Relationship between BI and nasal coda loss

There are 2556 syllables with BI=0 and 23% of them lose their nasal codas; 221 syllables whose BI=1 and 24% of them lose their nasal codas; 16 syllables whose BI=2 and 31% of them lose their nasal codas. From the statistical results, we come to the conclusion that the syllables that contain nasal coda locate in the non-initial place of a prosody word.

A one factor ANOVA pooled on all syllables indicates non-significant effect of BI on nasal coda loss, $F(2, 2790) = 0.413$, $P = 0.65 > 0.05$. Then, we carry out the test of homogeneity of variance, and find the variances are homogenous. So we chose S-N-K test to execute pair-wise comparison, and found there were no significant difference between the three types of BI. As shown in *Figure2*, about 20% syllables lose their nasal codas.

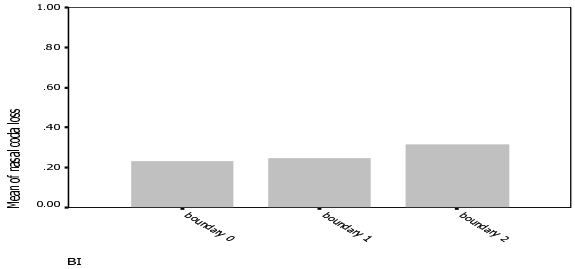


Figure2. Effect of front boundary on nasal codas loss

3.2.2 Relationship between BF and nasal coda loss

There are 2023 syllables with BF=0 and 22% of them lose their nasal codas; 333 syllables with BF=1 and 20% of them lose their nasal codas; 126 syllables with BF=2 and 13% of them lose their nasal codas, 198 syllables with BF=3 and 33% of them lose their nasal codas, 113 syllables with BF=4 and 44% of them lose their nasal codas. From the statistical results, we come to the conclusion that the syllables that contain nasal coda locate in the non-final place of a prosody word.

A one factor ANOVA pooled on all syllables indicates significant effect of BF on nasal coda loss, $F(4, 2788) = 12.374$, $P = 0 < 0.05$. Then, we carry out the test of homogeneity of variance, and find the variances are not homogenous. So we chose T test method to execute the pairwise comparison, and find that there are 3 different groups according to their effect on nasal coda loss. The first group contains boundary 0, boundary 1 and boundary 2, their effect on nasal coda loss is not significantly different. The second group only contains boundary 3. The third group only contains boundary 4. The difference between groups is significant. As shown in *Figure3*, the effects of BF on nasal codas loss are significantly different. It is boundary 4 who has the most significant effect on nasal coda loss (about 44%), then is boundary 3 (about 33%).

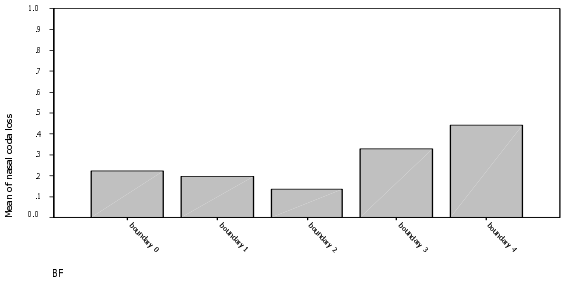


Figure3. Effect of back boundary on nasal codas loss

3.3 Relationship between stress and nasal coda loss

In this part, numbers from 0 to 3 correspond to non-stress, prosody word stress, prosody phrase stress, sentence stress. There are 2025 syllables which have no stress and 24% of them lose their nasal coda; 349 syllables which carry prosody word stress and 19% of them lose their nasal codas, 106 syllables which carry prosody phrase stress and 22% of them lose their nasal codas; 313 syllables which carry sentence stress and 24% of them lose their nasal codas. From the statistical results, we come to the conclusion that most syllables do not carry stress in our materials.

A one factor ANOVA pooled on all syllables indicates no significant effect of the stress on nasal coda loss, $F(3, 2789) = 1.074$, $P = 0.359 > 0.05$. Then, we carry out the test of homogeneity of variance, and found the variances were not homogenous. So we chose T test method to execute the pairwise comparison, and found that different types of stresses make no difference on nasal coda loss, as shown in *Figure 4*.

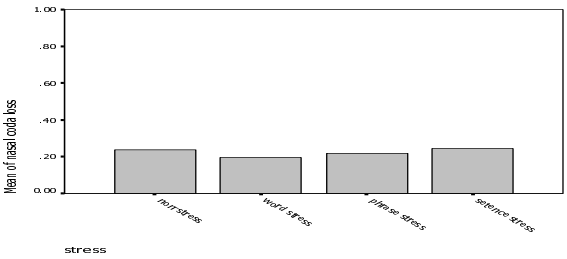


Figure4. Effect of stress on nasal coda loss

3.4 Relationship between tone and nasal coda loss

In this part, numbers from 0 to 4 correspond to neutral tone, high tone, rising tone, low tone and falling tone. There are 81 syllables which have neutral tone 36% of them lose their nasal codas; 805 syllables which have high tone and 17% of them lose their nasal codas; 845 syllables which has rising tone and 23% of them lose their nasal codas; 348 syllables who has low tone and 28% of them lose their nasal codas; 714 syllables which have falling tone and 28% of them lose their nasal codas. From the statistical results, we come to the conclusion that the corpus covers all the tones in standard Chinese.

A one factor ANOVA pooled on all syllables indicates significant effect of the tone on nasal coda loss, $F(4, 2788) = 9.109$, $P = 0 < 0.05$. Then, we carry out the test of homogeneity of variance, and found the variances were not homogenous. So we chose T test method to execute the pairwise comparison, and find that tones belong to 3 different groups according to their effect on nasal loss. The first group contains high tone and rising tone. The second group contains low tone and falling tone. The third group only contains neutral tone. The difference between groups is significant. As shown in *Figure5*, the effects of different tones on nasal codas loss are significantly different. It is neutral tone that has the most significant effect on nasal coda loss (about 36%), then is low tone and falling tone (about 27%).

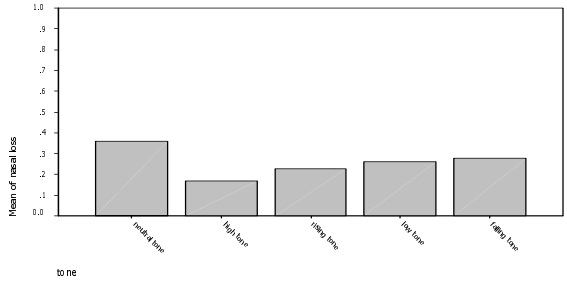


Figure5. Tone's effect on nasal coda loss

3.5 Interaction between related factors

In this part, we apply two-way ANOVA to analyze the interaction between articulation manner, tone, stress, front boundary, back boundary. We exclude the factor combination front boundary*back boundary which is obviously independent.

3.5.1 Interaction between articulation manner and tone

Articulation manner has significant effect on nasal coda loss, $F(\text{articulation manner}) = 42.717$, $P = 0 < 0.05$; tone does not has significant effect on nasal coda loss, $F(\text{tone}) = 1.584$, $P = 0.176$; the interaction between these two factors is significant, $F(\text{articulation manner*tone}) = 1.94$, $P = 0.00 < 0.05$. Then, we consider the quantity Eta^2, and find that $Eta^2(\text{articulation manner}) > Eta^2(\text{articulation manner*tone}) > Eta^2(\text{tone})$. So we conclude that articulation manner is the most significant factor of the three, then articulation manner*tone. Tone is the least significant factor. At last we consider the observed power of these factors, and find that the observed power of articulation manner and articulation manner*tone equals 1, so we do not need more articulation manner and articulation manner*tone samples; the observed power of tone equals 0.493, so we need more tone samples.

3.5.2 Interaction between articulation manner and BI

Articulation manner has significant effect on nasal coda loss, $F(\text{articulation manner}) = 14.104$, $P = 0 < 0.05$; BI dose not has significant effect on nasal coda loss, $F(\text{BI}) = 0.211$, $P = 0.81$; the interaction between these two factors is not significant, $F(\text{articulation manner*BI}) = 0.767$, $P = 0.741 > 0.05$. Then, we consider the quantity Eta^2, and find that $Eta2(\text{articulation manner}) > Eta^2(\text{articulation manner*BI}) > Eta^2(\text{BI})$. So we conclude that articulation manner is the most significant factor of the three, then articulation manner*BI. BI is the least significant factor. At last we consider the observed power of these factors, and find that the observed power of articulation manner equals 1, so we do not need more articulation manner samples, the observed power of articulation manner*BI equals 0.586, so we need more articulation manner*BI samples, the observed power of BI equals 0.083, so we need a large number of BI samples.

3.5.3 Interaction between articulation manner and BF

Articulation manner has significant effect on nasal coda loss, $F(\text{articulation manner}) = 19.441$, $P = 0 < 0.05$; BF has significant effect on nasal coda loss, $F(\text{BF}) = 26.412$, $P = 0 < 0.05$; the interaction between these two factors is not significant, $F(\text{articulation manner*BF}) = 0.956$, $P = 0.5 > 0.05$. Then, we consider the quantity Eta^2, and find that $Eta^2(\text{articulation manner}) > Eta^2(\text{BF}) > Eta^2(\text{articulation manner*BF})$. So we conclude that articulation manner is the most significant factor of the three, then BF. Articulation manner*BF is the least significant factor. At last we consider the observed power of these factors, and find that the observed power of articulation manner equals 1, so we do not need more articulation manner samples, the observed power of BF equals 1, so we do not need more BF samples, the observed power of articulation manner*BF equals 0.649, so we need a bit more articulation manner*BF samples.

3.5.4 Interaction between articulation manner and stress

Articulation manner has significant effect on nasal coda loss, $F(\text{articulation manner}) = 29.579$, $P = 0 < 0.05$; stress has significant effect on nasal coda loss, $F(\text{stress}) = 0.189$, $P = 0.904 > 0.05$; the interaction between these two factors is not significant, $F(\text{articulation manner*stress}) = 0.515$, $P = 0.99 > 0.05$. Then, we consider the quantity Eta^2, and find that $Eta^2(\text{articulation manner}) > Eta^2(\text{articulation manner*stress}) > Eta^2(\text{stress})$. So we conclude that articulation manner is the most significant factor of the three, then articulation manner*stress. Stress is the least significant factor. At last we consider the observed power of these datum, and find that the observed power of articulation manner equals 1, so we do not need more articulation manner samples, the observed power of articulation manner*stress equals 0.086, so we need a large number of articulation manner*stress samples, the observed

power of stress equals 0.556, so we need a bit more stress samples.

3.5.5 Interaction between tone and BI

Tone dose not have significant effect on nasal coda loss, F(tone) =1.936, P = 0.102 >0.05; BI does not have significant effect on nasal coda loss, F(BI) = 0.557, P = 0.573 >0.05; the interaction between these two factors is not significant, F(tone* BI) =0.807, P = 0.545 > 0.05. Then, we consider the quantity Eta^2, and find that Eta^2(tone) > Eta^2(BI) > Eta^2(tone*BI). So we conclude that tone is the most significant factor of the three, then BI. Tone*BI is the least significant factor. At last we consider the observed power of these factors, and find that the observed power of tone equals 0.558, so we need more tone samples, the observed power of tone*BI equals 0.294, so we need a large number of tone*BI samples, observed power of BI equals 0.149, so we need a large number of BI samples.

3.5.6 Interaction between tone and BF

Tone has significant effect on nasal coda loss, F(articulation manner) =9.457, P = 0 <0.05; BF has significant effect on nasal coda loss, F(BF) = 9.885, P = 0 <0.05; the interaction between these two factors is significant, F(tone*BF) =2.979, P = 0 < 0.05. Then, we consider the quantity Eta2, and find that Eta^2(tone*BF) > Eta^2(BF) > Eta^2(tone). So we conclude that tone*BF is the most significant factor of the three, then BF. Tone is the least significant factor. At last, we consider the observed power of these factors and find that the observed power of tone equals 1, so we do not need more articulation manner samples, the observed power of BF equals 1, so we do not need more BF samples, the observed power of tone*BF equals 0.998, so we do not need more tone*BF samples.

3.5.7 Interaction between tone and stress

Tone has significant effect on nasal coda loss, F(tone) =5.485, P = 0 <0.05; stress does not have significant effect on nasal coda loss, F(stress) = 2.318, P = 0.074 > 0.05; the interaction between these two factors is significant, F(tone*stress) =1.923, P = 0.032 < 0.05. Then, we consider the quantity Eta2, and find that Eta^2(tone*stress) = Eta^2(tone) > Eta^2(stress). So we think that tone*stress and tone are the most significant factors of the three, then stress. At last, we consider the observed power of these factors, and find that the observed power of tone equals 0.977, so we do not need more articulation manner samples, the observed power of tone*stress equals 0.898, so we do not need more back boundary samples, the observed power of stress equals 0.586, so we need more tone*back boundary samples.

3.5.8 Interaction between BI and stress

BI dose not have significant effect on nasal coda loss, F(BI) =2.436, P = 0.088 > 0.05; stress dose not have significant effect on nasal coda loss, F(BI) = 1.806, P = 0.144 > 0.05; the interaction between these two factors is not significant, F(BI*stress) =1.853 , P = 0.085 > 0.05. Then, we consider the quantity Eta2, and find that Eta^2(BI*stress) > Eta^2(BI) = Eta^2(stress). So we conclude that BI*stress is the most significant factor of the three, then BI and stress. At last, we consider the observed power of these factors, and find that the observed power of BI equals 0.492, so we need more articulation manner samples, the observed power of stress equals 0.473, so we need more stress samples, the observed power of BI*stress equals 0.698, so we need more BI*stress samples.

3.5.9 Interaction between BF and stress

BF has significant effect on nasal coda loss, F(BF) =6.084, P = 0 < 0.05; stress dose not have significant effect on nasal coda loss, F(stress) = 1.422, P = 0.234 > 0.05; the interaction between these two factors is not significant, F(BF*stress) =1.614 , P = 0.074 > 0.05. Then, we consider the quantity Eta^2, and find that Eta^2(BF) > Eta^2(BF*stress) > Eta^2(stress). So we conclude that BF is the most significant factor of the three, then BF*stress. Stress is the least significant factor of the three. At last, we consider the observed power of these factors, and find that the observed power of BF equals 1, so we do not need more BF samples, the observed power of stress equals 0.493, so we need more stress samples, the observed power of BF*stress equals 1, so we do not need more BF*stress samples.

4 Conclusion

In this study, we think that articulation manner is the most conductive factor to nasal coda loss. Tone, boundary and stress are the most conductive supra-segmental factors to coda loss.

Initial's articulation manner of the following syllables influenced nasal coda loss significantly. Then, if we classify the articulation manners by vocal tract status, we get two basic classes: 1. When the vocal tract is completely obstruent (including stop, aspirate stop, aspirated affricative, affricative, nasal and lateral), the percentage of nasal coda loss is very low; 2. When the vocal tract is not completely obstruent, the percentage of nasal coda loss increases significantly compared to the first class. So we come to the conclusion that nasal coda loss is related to the vocal tract stratus when articulation.

Some of the supra-segmental factors influence nasal coda loss significantly. Tone is one of these factors. Neutral tone does the largest contribution to nasal coda loss, then low tone and falling tone. High tone and rising tone have the least effect on nasal coda loss. Back boundary is the other supra-segmental factor. Boundary4 do the largest contribution to nasal coda loss, then boundary3. Boundary1, boundary2, and boundary0 have the least effect on nasal coda loss.

By applying two-way ANOVA, we got the following conclusion. The interaction between tone and stress, tone and back boundary, articulation manner and tone are significant. Others are not significant.

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