THE PHONETIC VARIANTS OF TAIWANESE "VOICED" STOPS: AN AIRFLOW STUDY

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Abstract: As in other languages with "voiced" stops, the phonetic realization of Taiwanese /b/ and /g/ is highly variable from one context to another. Zhang (1983) even claims that they are replaced by homorganic nasals [m] and [ŋ] when the syllable is closed by a nasal. The positional variants were examined using oral and nasal airflow recordings. Three types of syllable structures were chosen with initial voiced stops in CV, CVN, and CVC. The target syllables are placed in utterance initial position and in medial positions after nasals, vowels, and voiceless stops. Utterance initially, there is a voiceless prenasalization, although its occurrence is strongly speaker-dependent. When preceded by nasals, the prenasalized voiced stops alternate with post-stopped nasals. When preceded by vowels, the prenasalization was found only in nine out of 630 tokens.

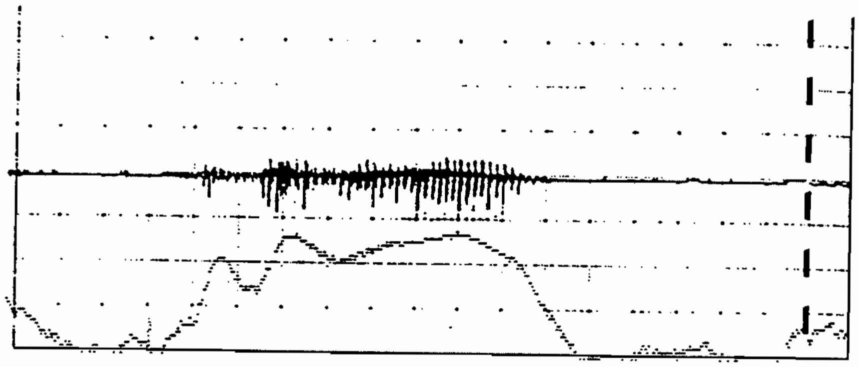
Introduction

As in other languages with "voiced" stops, (e.g. Spanish where the voiced stops show up as spirants) the phonetic realization of Taiwanese /b/ and /g/ is highly variable from one context to another. For example, in utterance initial positions, they are said to be "prenasalized" as well as prevoiced, and the prenasalization is voiceless (Chan, 1987; Zhang, 1983). That is /b/ here is [$^{\text{m}}$b] (or [$^{\text{m̥}}$b]) and /g/ is [$^{\text{ŋ}}$g] (or [$^{\text{ŋ̊}}$g]). /l/ will be included here, because /l/ fill the systematic position where one would expect and /d/. However, the prenasalization is not easily observed in the acoustic data collected here (e.g. Figure 1), nor could it be noted in the fiber-optical study done by Iwata et al.(1979), since they looked at glottal width not velo-pharyngeal opening width. In order to analyze the prenasalization, an air flow study is necessary. In an airflow study any air flowing out of nose and mouth are recorded independently, regardless of whether the air causes vocal folds to vibrate or not. Therefore, an air flow study is most efficient in picking up voiceless nasal articulation with low amplitude, such as the prenasal segments here.

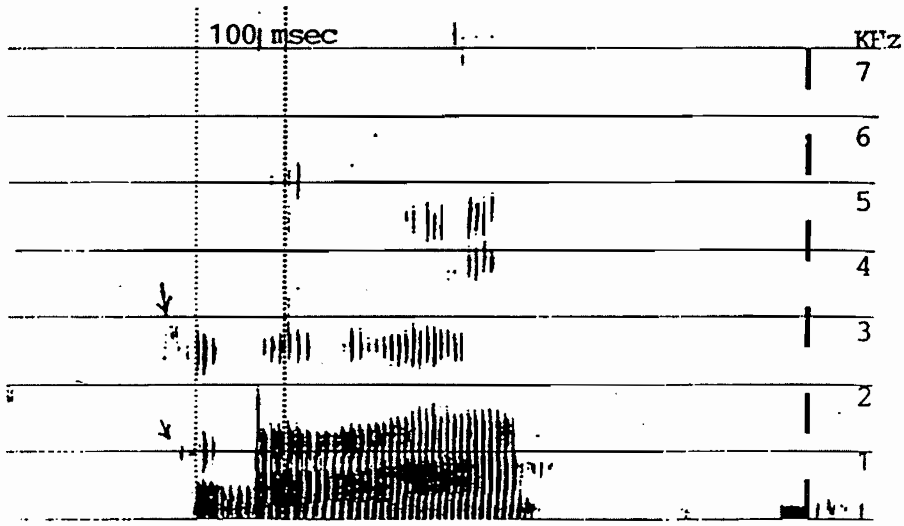
The airflow data are used to address two issues: first , the precise distribution of initial (prenasalized) voiced stops and initial nasals with regards to following segmental environments. The relationship between Taiwanese initial voiced stops and initial nasals is a controversial one. Historically, Taiwanese initial voiced stops came from initial nasals. Many studies influenced by the diachronic relationship between the two series, proposed an allophonic relationship between the two. According to Zhang, Taiwanese voiced stops change into homorganic nasals when the syllables are closed by nasals.

/b, l, g/ -----> [m, n, ŋ] / ________ ṽ, VN.

However a counterexamples such as /gɔŋ˧˥/ [gɔŋ˧˥] 'dizzy' was found by Pan (1994), as shown in Figure 2. This counterexample raise doubts to the rule. What challenges the validity of the rule even more is that the rule does not mention anything about /bŋ ˧˥/ [məŋ˧˥] 'door' (Figure 3), If Taiwanese initial voiced stops and nasals are indeed in an allophonic relationship, then CN syllable structure should definitely be mentioned in Zhang's rule. Therefore air flow data is brought in to test the phonological rule Zhang proposed.

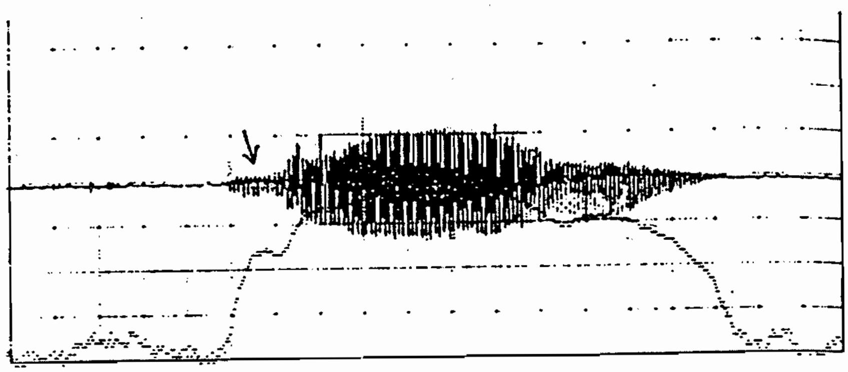


(a) waveform

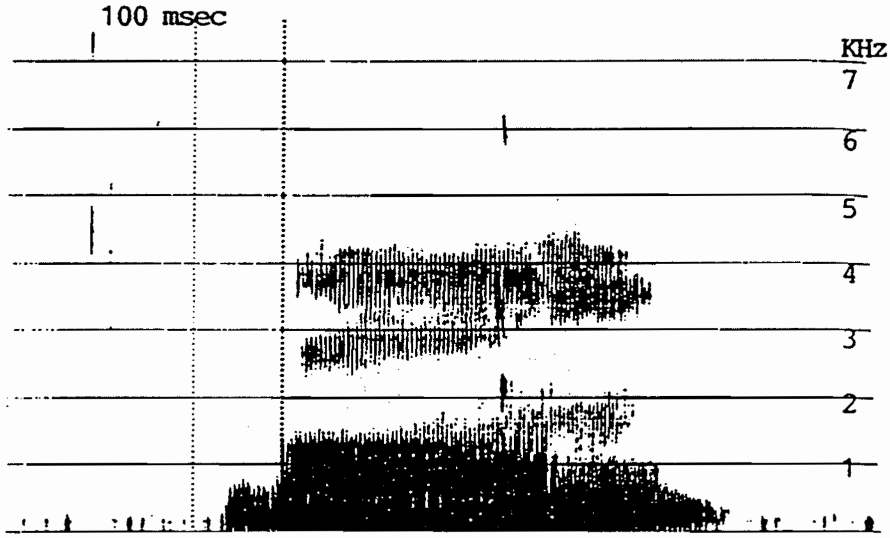


(b) Spectrogram

Figure 1 (a) waveform, (b) spectrogram, Taiwanese /bo˧/ [ᵐ̥bo˧] 'hat'

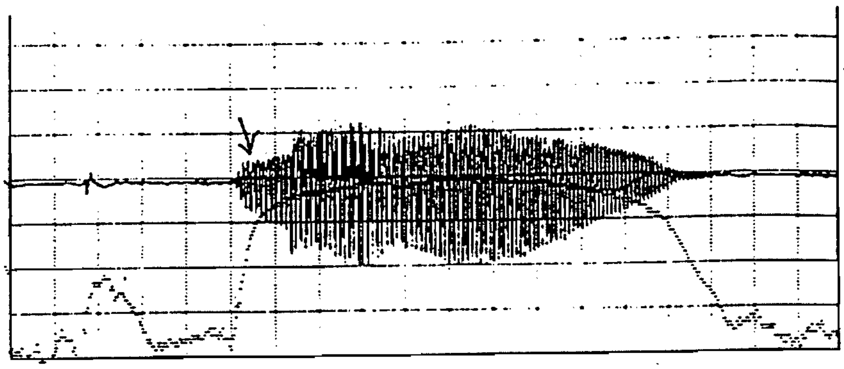


(a) waveforms

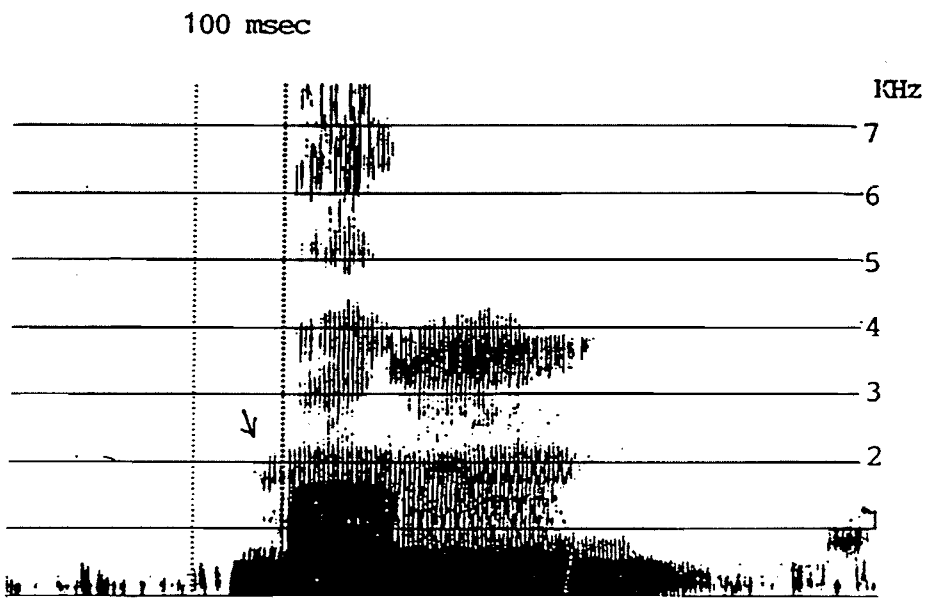


(b.) Spectrogram

Figure 2 (a) waveform, (b) spectrogram /gɔŋ˧˥/ [gɔŋ˧˥] 'dizzy'



(a) Waveform



(b.) Spectrogram

Figure 3 (a) waveform, (b) spectrogram /bəŋ˦˥/ [məŋ˦˥] 'door'

The second issue addressed is to find out the actual phonetic variants of Taiwanese voiced stops in utterance initial position and other positions not usually elicited in field studies such as Zhang's (1983).

Method of Air Flow Study

Instrumentation

An oral and nasal dual channel Rothenberg air flow mask was used to collect airflow. The airflow signals were recorded by digitizing directly to the hard drive of a 80486 PC. The signals were digitized at 10 kHz using Cspeech version 4.0. There is a 10 ms delay in the nasal air flow due to the 30 Hz filter used. The response time and delay of this filter are both about 10 ms.

Subjects

Seven male native Taiwanese speakers from the graduate school of The Ohio State University participated voluntarily in the experiment. They are all tri-lingual speakers of Taiwanese, Mandarin, and English. CF, YF, and BH all grew up in Tainan (Southern Taiwan). HJ is the only speaker from Taichung (Central Taiwan). LK is from Pingtong (Southern Taiwan). WS and CC are from Taipei (North Taiwan). The dialectal differences of Taiwanese spoken in South, Central, and North Taiwan are not relevant to the study here.

Corpora

Morphemes with target initial consonants were recorded in three separate contexts --- citation form, phrase initial position, and phrase medial positions following vowels, voiceless consonants, and nasals.

Table 1 shows the fifteen Taiwanese morphemes with three different syllable structures, CV, CVN, and CV+[voiceless stops], in the citation forms. Taiwanese initial /l/ was also included, since it shows the same distributional pattern relative to

Table 1 The fifteen citation form morphemes in the three different syllable structures.

CV:		CVN	CV+[voiceless stops]
labial			
/ba˦˥ /	'numb'	/baĩ˥˧/ 'mosquito'	/baʔ˧˨/ 'meat'
		/ban˧/ 'slow'	/bak˥˧/ 'eye'
dental			
/la˧/	'stir'	/laĩ˦˥/ 'human'	/lak˥˧/ 'six'
		/lan˥˧/ 'we, us'	/lap˥˧/ 'pay'
velar			
/gia˦˥/	'centipede'	/giam˦˥/ 'strict'	/get˥˧/ 'evil'
		/gen˥˧ /'study'	/giap˧˨/ 'press'

the nasals as /b/ and /g/ do. Table 2 shows the same fifteen morphemes embedded in phrase initial position. The 45 phrases with morphemes embedded in phrase-medial position are shown in Table 3. The segments preceding the chosen morphemes included vowels, voiceless stops, and nasals. All tokens were randomized. There are two repetitions for most items in the corpus. Due to copying mistakes in making the lists, some items were repeated only once, while others were repeated three times. There are all together six such list-making mistakes. However, this should not affect the interpretation of the results, since there is large number of samples (154 tokens)

Table 2 The phrases with the target morphemes embedded in initial position.

CV		CVN	
/ba˧bi˧˨/	'paralysis'	/baŋ˥a?˥˧/	'mosquito'
/la˧˨təŋ˥/	'stir soup'	/ban˧fun˥/	'(train, airplane) delay'
/gia˧kaĩ˥/	'centipede'	/lan˥ta˧e˦˥/	'we'
		/laŋ˧baʔ˧˨/	'human flesh'
		/giam˧gek˥˧/	'strict'
		/gen˥kiu˧˨/	'research'
CV+voiceless stops			
/baʔ˥˧wan˦˥/	'meat ball'		
/bak˧˨tçiu/	'eye'		
/lak˧˨siaĩ˥/	'six pairs'		
/lap˧˨s^wey˧˨/	'pay tax'		
/giap˥˧aʔ˥˧/	'tong'		
/giat˧˨tsu˥˧/	'disobedient child'		

Table 3 Examples of phrases with target morphemes embedded in the phrase medial position after vowels, voiceless stops, or nasals (The preceding context segment and target voiced stops are in bold face.)

A. Preceded by vowels

<u>-V + CV</u>

/sio˥dz**i**˧˥**b**a˧pi˨˩/ 'polio'

<u>-V + CVN</u>

/**ɔ**˧**b**aŋ˥a˥˧/ 'black mosquito'

<u>-V + CV[voiceless stops]</u>

/l**ɔ**˥**b**aʔ˥˧pəŋ˧/ 'pork stew on rice'

B. Preceded by nasals:

<u>-N + CV</u>

/la**ŋ**˧**b**a˧pi˨˩/ 'paralyzed person'

<u>-N + CVN</u>

/hu**n**˧**b**aŋ˥a˥˧/ 'kill mosquito with smoke'

<u>-N + CV[voiceless stops]</u>

/ku**n**˧**b**aʔ˥˧so˨˩/ 'simmer ground meat'

C. Preceded by voiceless stops

<u>-[voiceless stops]+CV</u>

/tau˧kʰa**k**˨˩**b**a˧pi˨˩/ 'brain paralysis'

<u>-[voiceless stops] + CVN</u>

/pʰa**ʔ**˥˧**b**aŋ˥a˥˧/ 'kill mosquito'

<u>-[voiceless stops]+CV[voiceless stops]</u>

/tɕia**ʔ**˥˧**b**aʔ˥˧piã˥˧/ 'eat meat patty'

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for each subject, and the results are discussed in terms of percentages, instead of absolute numbers.

Procedure

Each subject was recorded in a sound booth holding an air flow mask against his or her own face while reading the corpus. The experimenter was outside of the booth controlling Cspeech to record the airflow data.

The recording consisted of three sessions. In the first session, subject were instructed to produce phrases with chosen morphemes embedded in medial position.

In the second session, phrases with chosen morphemes in initial position were produced. In the third session, subjects were instructed to produce individual morphemes in citation form.

Data analysis

Data were displayed and analyzed with Cspeech 4.0. See sample displayed in Figure 4. The oral and nasal airflow were compared to determine the presence of prenasalization, and the two positions were marked, as shown in the figure. Cursor A was placed at the point where the nasal air flow ceases. Cursor B was placed at the point where the oral air flow of vowel starts, as shown in Figure 4. In utterance initial position, to avoid including subjects' breathing as the prenasalization of voiced stops, 50 ms is used as the cut-off point. If the duration between A and B is less than 50 ms, then the token is judged to be prenasalized. Any trace of nasal airflow that are more than 50 ms prior to the onset of voicing is judged to be breathing. When in phrase medial position, if the duration between point A and B is less than 10 ms, then the voiced stop is judged to be fully nasalized. The reason why 10 ms was used here as a cut off point is because there is a 10 ms delay in the nasal air flow due to the 30 Hz filter used.

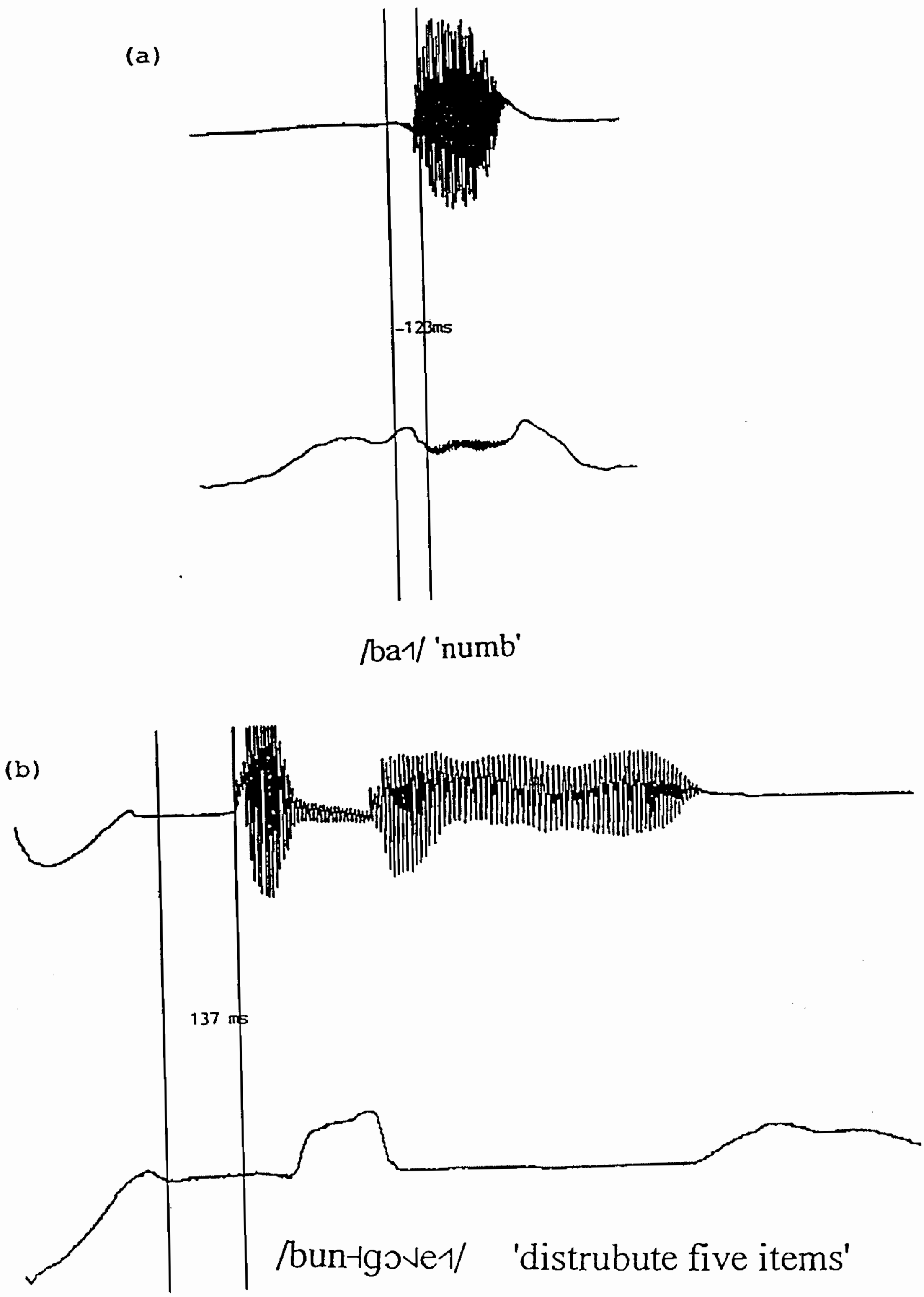


Figure 4. Example of air flow analysis. (a) /ba˥/ 'numb' (b) /bun˧gɔ˧˩e˥/ 'distribute five items'. The upper channel is oral airflow. The lower channel is nasal airflow.

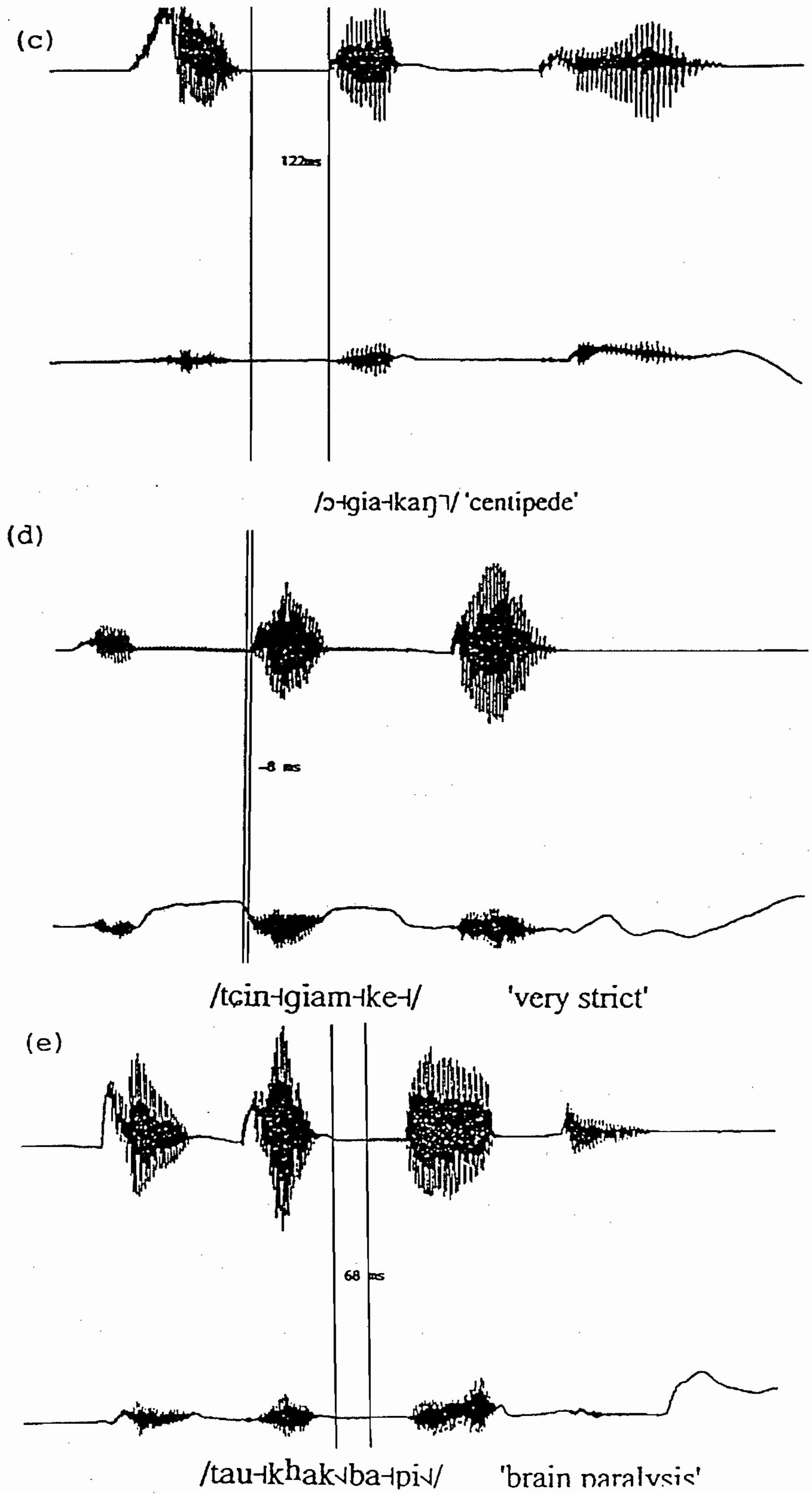


Figure 4 (Continued) (c) /ɔ˧gia˧kaŋ˥/ 'black centipede' (d) /tɕin˧giam˧ke˧/ 'very strict' (e) /tau˧kʰak˩ba˧pi˩/ 'brain paralysis'

Results of Adult Air Flow Study

The results of airflow data will be discussed according to the three types of contexts: (1) citation form (2) phrase-initial position, and (3) phrase-medial position after (3) vowels, (4) nasals, and (5) voiceless stops.

Citation form

Table 4 and 5 shows the percentage of prenasalized voiced stops in citation form and phrase-initial position. Although tokens in citation form and phrase-initial position were recorded in different sessions, they are essentially in the same utterance initial position. Therefore the results are discussed together. For voiced stops in citation form, there does not seem to be any uniform pattern across speakers for the presence of prenasalization. The occurrence of prenasalization was very speaker-dependent. While subject CF, WS, and BH had low percentages of prenasalization for voiced stops in citation forms, YF, LK, HJ, and CC had high percentages of prenasalization. There was also no consistent pattern of differences across the syllable types, either.

The results from morphemes placed in phrase-initial position are also shown in Table 5. Again, there was no uniform pattern for the presence of prenasalization. Whether a token shows nasal air flow during the early part of the closure or not seems to be arbitrary. While some subjects, like YF, LK and HJ, had high percentage of prenasalization for the voiced stops, others like CF and WS had low percentage of prenasalization. Again, the occurrence of prenasalization is very speaker-dependent

Phrase medial position

The results of voiced stops embedded in phrase-medial position are shown in Table 6. For those voiced stops preceded by vowels, prenasalization was found only in nine tokens and all these cases were due to the existence of alternate

Table 4 Percentage of prenasalized voiced stops produced in citation form:

Subjects	Syllable Structures [voiced stops]+V	 [voice stops]+V+[stops]	 [voiced stops] + V+ N
CF	25.00% (3/12)	16.67% (2/12)	10.00% (1/10)
YF	100.00% (12/12)	91.67% (11/12)	100.00% (10/10)
LK	100.00% (12/12)	100.00% (12/12)	100.00% (10/10)
HJ	75.00% (9/12)	75.00% (9/12)	70.00% (7/10)
WS	58.33% (7/12)	33.33% (4/12)	40.00% (4/10)
BH	33.33% (4/12)	75.00% (9/12)	70.00% (7/10)
CC	100.00% (12/12)	83.33% (10/12)	60.00% (6/10)

Table 5 Percentage of prenasalized voiced stops produced in phrase-initial position:

Subjects	Syllable Structure		
	[voiced stops]+V	[voiced stops]+V+[stops]	[voiced stops] + V+ N
CF	37.5%	76.15%	66.67%
	(3/8)	(10/13)	(6/9)
YF	100.0%	92.31%	100.0%
	(8/8)	(12/13)	(9/9)
LK	87.5%	92.31%	100.0%
	(7/8)	(12/13)	(9/9)
HJ	100.0%	100.0%	88.89%
	(8/8)	(13/13)	(8/9)
WS	62.5%	61.54%	33.33%
	(5/8)	(8/13)	(3/9)
BH	87.5%	92.31%	77.78%
	(7/8)	(12/13)	(7/9)
CC	87.5%	84.62%	77.78%
	(7/8)	(11/13)	(7/9)

pronunciations for the preceding or target words. For example, the word 'hair' can be /tʰau˧mɔ˧/ or /tʰau˧məŋ˧/. The prenasalization occurred when the subjects produced nasals instead of vowels to precede the voiced stops. For example instead of /tʰau˧m ɔ˧**g**iap˨a˥˧/ CF, YF, and WS produced four tokens of /tʰau˧m**əŋ**˧**g**iap˨a˥˧/ 'hair pin'. In another case, CF and HJ produced three tokens of /sio˥dzi˦**m**ã˧pi˨/ instead of /sio ˥dzi˦**ba**˧pi˨/ 'polio'. That is , they used an alternate form of the target morpheme with a nasalized vowel and hence produced a nasal /m/ rather than the targeted /b/ for the initial. CF and YF also produced two tokens of /hue˥tɕ**ia**˥**man**˨hun˥/ instead of /hue˥tɕ**ia**˥**ban**˨hun˥/ 'train delay'. In all of these cases, the subjects did not produce a vowel + voiced stop sequence as directed. After excluding these cases, no other prenasalized voiced stops preceded by vowels were found.

When the voiced stops are preceded by voiceless stops, the nasalization was found in only three cases, as shown in Table 6. In HJ's case, because of alternative pronunciation in the same dialect, he produced /tau˧kʰ**ak**˥**ba**˧pi˨/ as /tau˧kʰ**ak**˥**ma**˧ pi˨/ . YF, on the other hand, produced a homorganic nasal instead of the target stop, e. g. /tɕia**ʔ**˧**ma**ʔ˥pia˥˧/, instead of /tɕia**ʔ**˧**ba**ʔ˥pia˥˧/ 'eat meat patty'. However, in the second repetition of the same item, CF and YF produced voiced stops as instructed, and the voiced stop was not prenasalized. Apparently when preceded by voiceless stops, the voiced stops are not prenasalized.

For the voiced stops preceded by nasal consonants, almost 100% of the tokens were fully nasalized, as shown in Table 6. According to the airflow data, the voiced stops changed into nasals when preceded by nasals. However, the spectrogram of these voiced stops indicated that the plosive quality was somehow still preserved.

When the segment preceding the voiced stops is a nasal, the nasalization of the preceding nasal extends all the way through the voiced stop closure, as shown in the air flow data of Figure 5.

From the first glance of the air flow data it seems that the voiced stop is assimilated to become a nasal when preceded by a nasal. If this is indeed the case, then the only distinction between phrases such as, /saŋ˥˩bi˥˩/ 'send rice' (Figure 6), which has nasal airflow extending all the way into the voiced stops, and /saŋ˥˩mĩ˧/ 'send noodles' (Figure 7) is the nasalization or lack of it on following vowel. However, acoustic spectrographic data revealed acoustic differences in the closure portion, as shown in Figure 6.

When comparing /saŋ˥˩bi˥˩/ ' send rice' (Figure 6) with /saŋ˥˩mĩ˧/ 'send noodles' (Figure 7) three acoustic characteristics differentiate /b/ from /m/. First is the gap in low-frequency energy at the end of the /b/, immediate preceding the vowel; second is a strong burst release found at the onset of vowel following /b/; third is the strong attack and immediate rise in energy in the oral flow at the onset of vowel following /b/ suggested for a post-stopped nasal. This strong burst of energy is similar to the oral release of the Zhongshan post-stopped nasal (Chan & Ren, 1987). Post-stopped nasals are composed of a nasal segment with a strong burst release at the end. Zhongshan is one of several other Chinese dialects that has been reported to have nasal+stop segments, but instead of prenasalized stops, Zhongshan is said to have post-stopped nasals. Of the Chinese dialects with complex nasal+stop segments, Taiwanese represents an unique case of a prenasalized stop in which the stop is the more dominant element than the nasal (Chan & Ren, 1987). Most of other nasal + stop segments of Chinese dialects are post-stopped nasals, in which the nasals are more prominent than the stop components. However, judging from the result of acoustic and air flow data, it is likely that Taiwanese prenasalized stops change into post-stopped nasals when preceded by nasals.

Table 6. Percentage of prenasalized voiced stops produced in phrase-medial position:

Subjects	Preceding Segments		
	V	/p/,/t/,/k/,/ʔ/	N
CF	9.375%	0.0%	100.0%
	(3/32)	(0/27)	(31/31)
YF	9.375%	3.70%	100.0%
	(3/32)	(1/27)	(31/31)
LK	0.0%	0.0%	96.78%
	(0/32)	(0/27)	(30/31)
HJ	6.25%	3.70%	100.0%
	(2/32)	(1/27)	(31/31)
WS	3.125%	0.0%	96.78%
	(1/32)	(0/27)	(30/31)
BH	0.0%	0.0%	100.0%
	(0/32)	(0/27)	(31/31)
CC	0.0%	0.0%	100.0%
	(0/32)	(0/27)	(31/31)

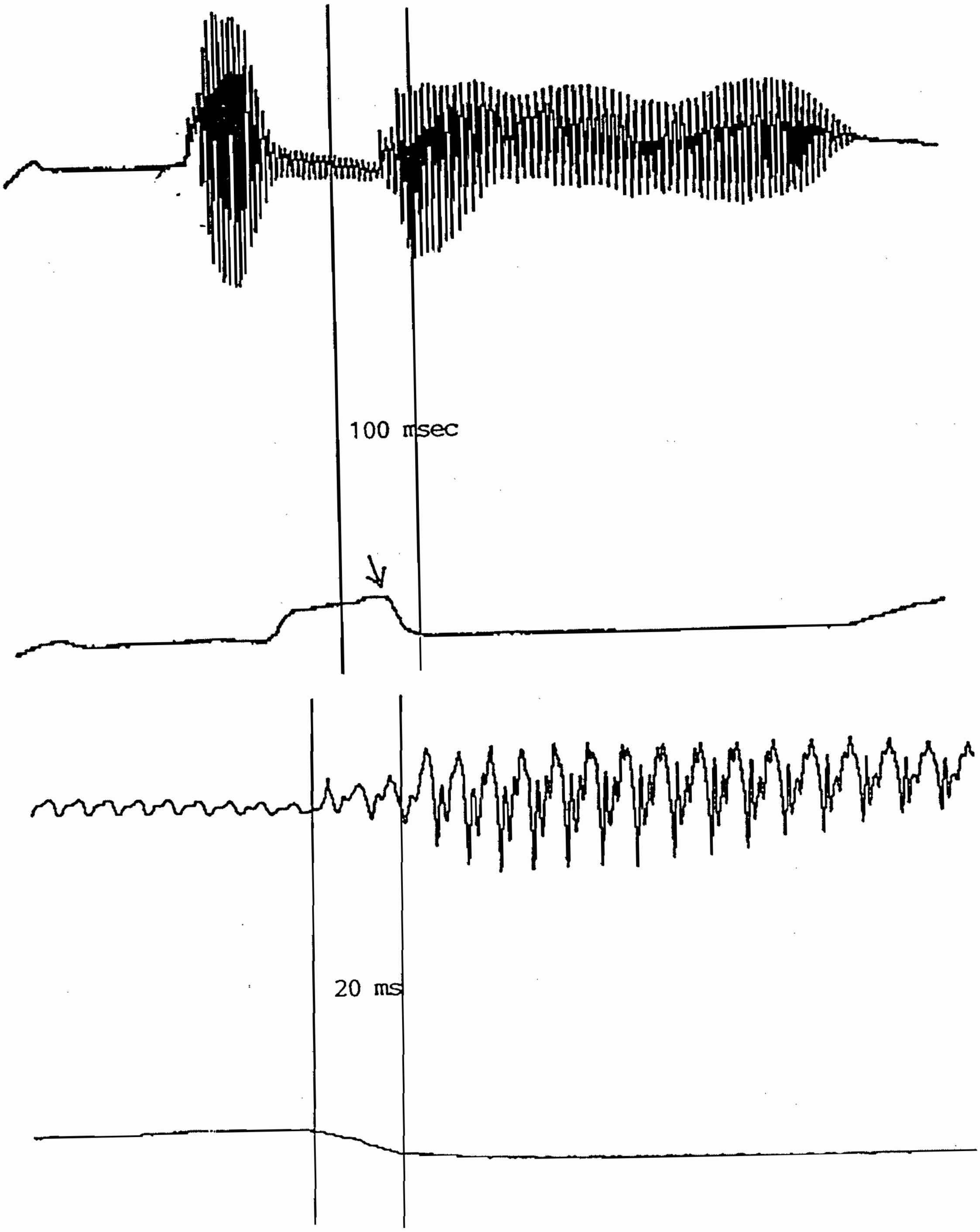
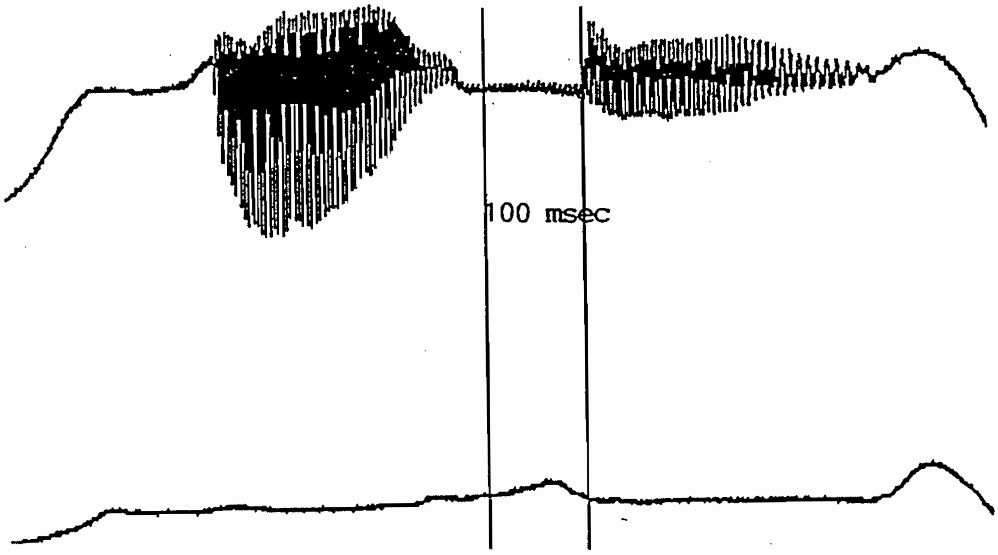
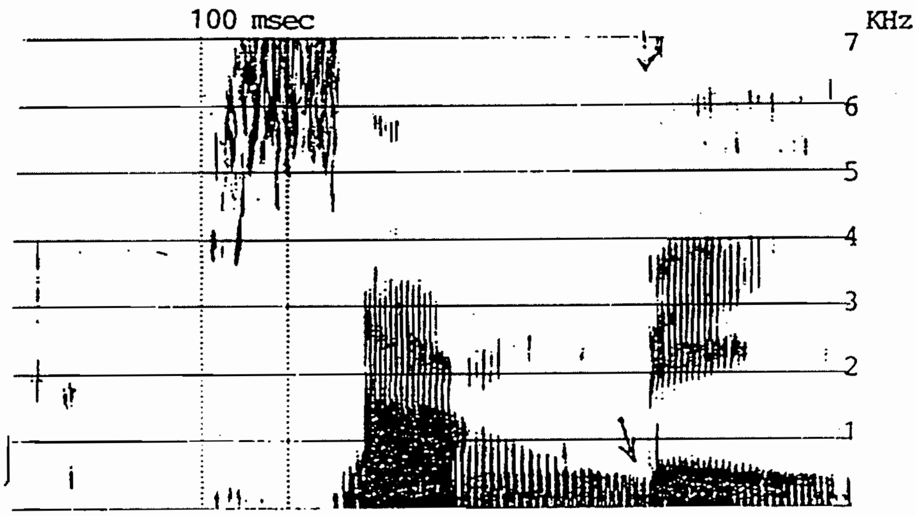


Figure 5. **Air flow data of Taiwanese voiced stop preceded by a nasal. (a) /bun˧gɔ˨˩e˧˥/ 'distribute five items' (b) zoom in of the 100 ms in (a) The upper channel is the oral air flow. The lower channel is the nasal air flow.**

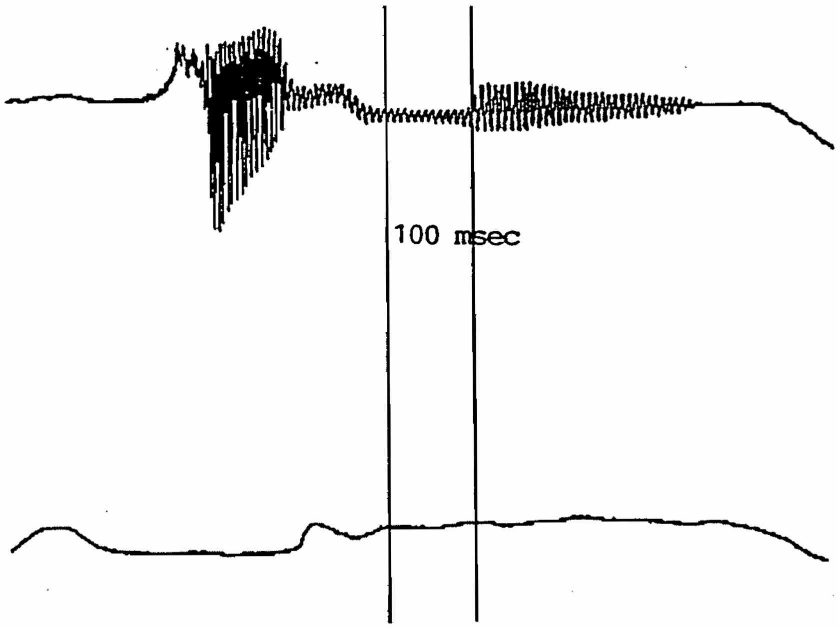


(a) Air flow: the upper channel is oral air flow, the lower channel is nasal air flow

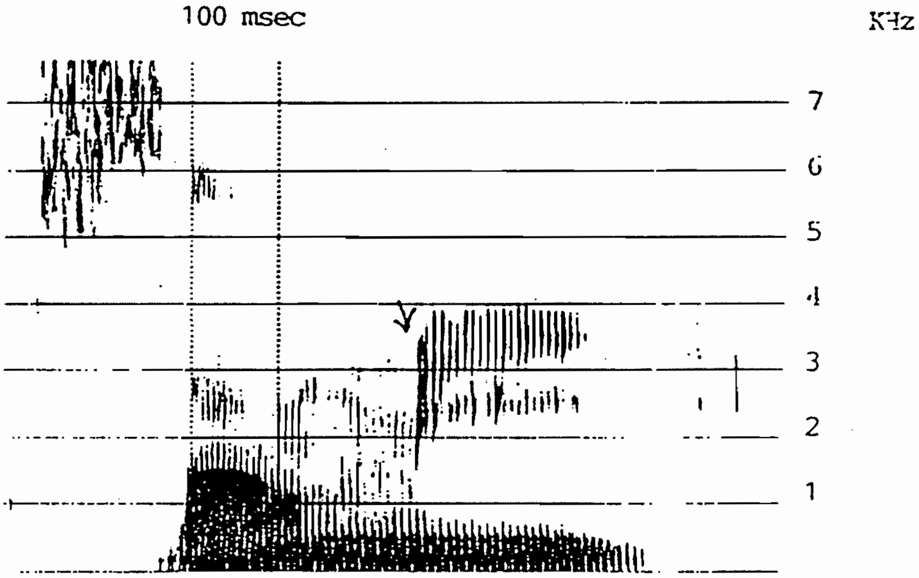


(b.) Acoustic data: spectrogram

Figure 6. (a) Air-flow and (b) acoustic data of a Taiwanese voiced stop preceded by a nasal /saŋ˥bi˥˩/ 'send rice'. The tokens in (a) and (b) are not the same, but the speaker is the same. The release gap in low frequency energy by the lower arrow, and the strong burst by the higher arrow.



(a) Air flow: the upper channel is oral air flow, the lower channel is nasal air flow



(b.) Acoustic data: spectrogram

Figure 7 (a) Air-flow and (b) acoustic data of a Taiwanese nasal preceded by a nasal /saŋ˥˩mĩ˧/ 'send noodles'. The speaker is the same as for Figure 3.11. The tokens in (a) and (b) are not the same, but the speaker is the same. Note the lack of a gap or strong burst at the arrow.

Summary

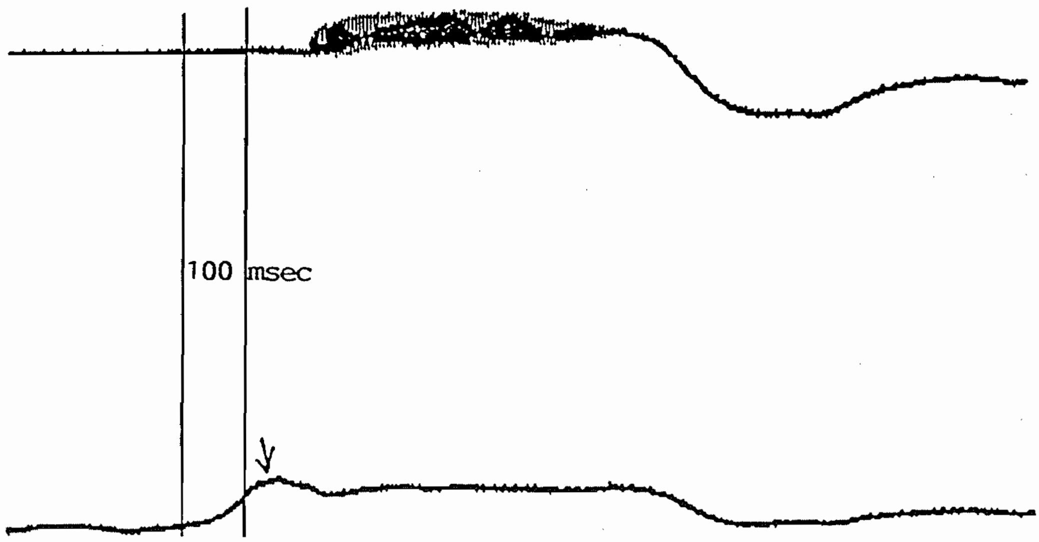
The phonetic variants of Taiwanese prenasalized voiced stops are not only influenced by the following segments, as proposed by Zhang's (1983) allophonic rule. They are also influenced by preceding segments. The prenasalization is lost when preceded by vowels, or voiceless stops. When preceded by nasals the prenasalized voiced stops change into post-stopped nasals. Only in utterance-initial positions do prenasalized voiced stops occur, but their occurrence varies in an speaker-dependent manner.

CONCLUSION

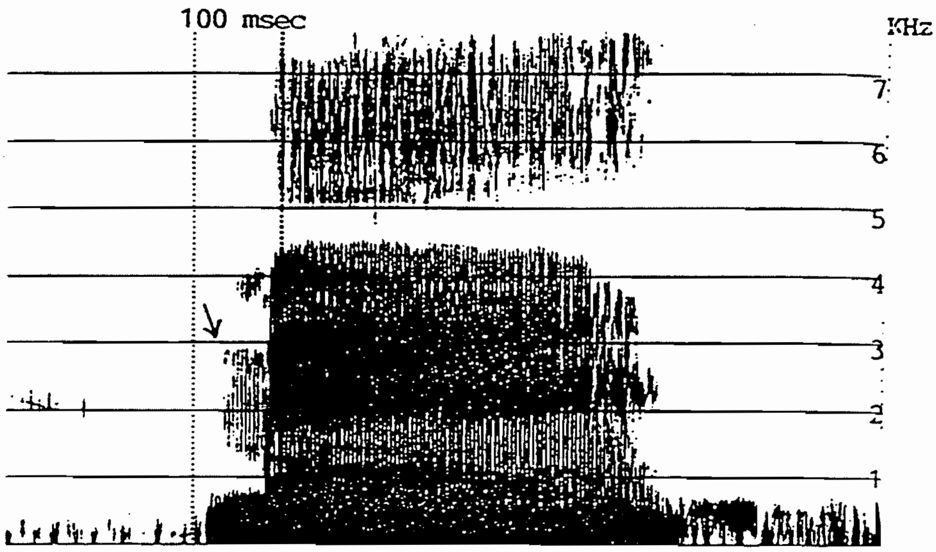
Relationship Between Initial Voiced Stops and Nasal

Zhang (1983) proposed a phonological rule relating Taiwanese initial voiced stops in forms such as /be˥˧/ ' horse' with initial nasals in forms such as /mẽ˧/ ' scold' (Figure 8). That is, noting a complementary distribution between voiced stops and nasals in initial position and citation form, he categorized the two types of sounds together as voiced stop phonemes claiming that Taiwanese initial voiced stops change into homorganic nasals when the syllable is closed by a final nasal or a nasalized vowel. In other words, he claims initial [m] is an allophone of /b/ and initial [ŋ] an allophone of /g/ before nasalized vowels and rhymes closed with nasals. However, the subjects in this study produced /b/ in /ban/ 'slow' as [b], not [m] as Zhang (1983) predicted (Figure 9). There are no extra nasal formants above 100 kHz in the initial consonants portion. The segmental environment proposed in Zhang's (1983) allophonic rule does not describe what happen here.

It is unclear whether the two series are indeed in an allophonic relationship, or whether there is a natural gap such that initial voiced stops occur before unnasalized vowel, while nasals occur before nasalized vowels, and nasals. Since there are no

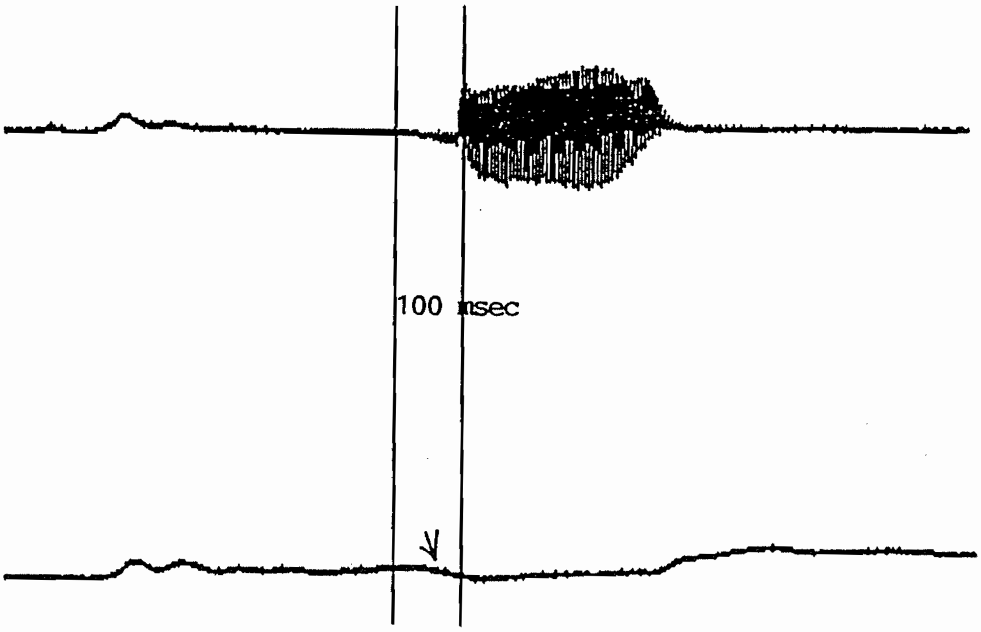


(a) Air flow: the upper channel is oral air flow, the lower channel is nasal air flow

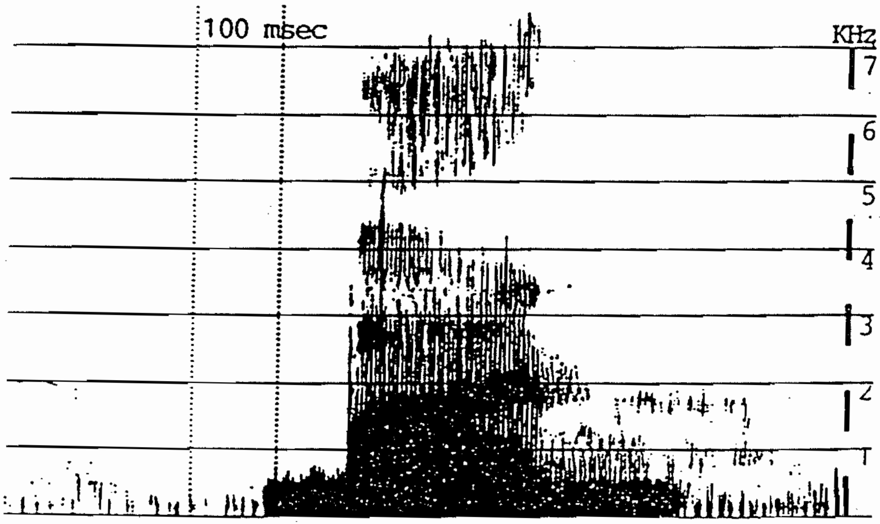


(b.) Acoustic data: spectrogram

Figure 8. (a) air flow and (b) acoustic data of Taiwanese voiced stops followed by nasalized vowels /mẽ˧/ [mẽ˧] 'scold'. The time scales of (a) and (b) are different. The tokens in (a) and (b) are not the same, but the speaker is the same.



(a) Air flow: the upper channel is oral air flow, the lower channel is nasal air flow



(b.) Acoustic data: spectrogram

Figure 9. (a)Air-flow and (b) acoustic data of Taiwanese voiced stops followed by a vowel and a final nasal /ban˧/ [ᵐbanˀ˧] 'slow'. The time scales of (a) and (b) are different. The tokens in (a) and (b) are not the same, but the speaker is the same.

morphological alternations supporting the identification of the two sets of initials as coming from a common underlying form. Further psychological studies, such as a perception test, are necessary to investigate native speakers' intuitions. complementary distribution alone is not merely enough to support for an allophonic relationship. Therefore, before any further psychological studies are done, no further claim will be made as to the relationship between the two series.

Phonetic Variants of Taiwanese Voiced Stops.

The results of the previous airflow study showed that when the voiced stops are in citation forms or other phrase-initial position, the presence of prenasalization was highly speaker-dependent. Some speakers tend to prenasalize utterance initial voiced stops more than others.

The only consistent phonetic patterns observed across subjects were in the three phrase-medial positions, when the voiced stops were preceded by segments such as vowels, nasals, and voiceless stops. It was discovered that when preceded by vowels or voiceless stops, no prenasalization occurred and the sounds are simply voiced stops. When preceded by nasals, the voiced stops change into post-stopped nasals.

Summarizing from the results of the airflow and acoustic measurement we can conclude that the so-called Taiwanese prenasalized voiced stop only appears in utterance-initial position, but its appearance is very speaker-dependent. This prenasalization is lost when the stop is preceded by vowels or voiceless stops. When preceded by a nasal, the prenasalized voiced stop changes into a post-stopped nasals, phonetically.

REFERENCES

Chan, M., & Ren, H. (1987) "Post-stopped nasals in Chinese: An areal study," *UCLA Working Papers in Phonetics*, **68**, 73-120.

Chan, M. (1987) "Post-stopped nasals in Chinese: An acoustical investigation," *UCLA Working Papers in phonetics*, **68**, 121-131.

Iwata, R. et al., (1979) "Laryngeal adjustments of Fukienese stops, initial plosives and final applosives,". *Annual. Bulletin. Research Institute Logopedics Phoniatircs* **13**, 61-81.

Pan, H. (1994) "The voicing contrasts of Taiwanese (Amoy) initial stops: Data from adults and children," The Ohio State University, Ph. D. dissertation.

Zhang, Z. (1983). *Taiwan Minnan Fangyan Jilue*, [A brief description of the Southern Min dialects in Taiwan]. Taipei: Wen Shi Tse Chubanshe.