UNIVERSITY OF CALIFORNIA

Los Angeles

A Phonetically-Based Optimality Theoretic Account of Consonant Reduction in Taiwanese

A thesis submitted in partial satisfaction of the requirements for the degree Master of Arts in Linguistics

by

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1995

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University of California, Los Angeles

1995

To my family

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ACKNOWLEDGMENTS

My most sincere gratitude goes to my committee members Patricia Keating, Donca Steriade, and Bruce Hayes for their support and confidence in my abilities.

Many thanks to Bruce Hayes for first suggesting the topic of Taiwanese lenition to me. Many ideas in this thesis were developed in a term paper written for his phonology class during the first year of my graduate studies. The present thesis has benefitted immensely from his many careful readings and many invaluable comments.

Thanks so much to my advisor and thesis committee co-chair Donca Steriade. She has been my phonology teacher since I became a linguistics student, during the final year of my undergraduate studies at UCLA. Her scholarship and passion for linguistics have always been an inspiration to me. It is her encouragement that convinced me to continue my work on the subject of Taiwanese lenition. She has read every version of my thesis, taking care not to allow me to neglect any point that requires a *why*.

Thanks so much to my committee co-chair Pat Keating. The many phonetics classes I have taken from her have shown me how exciting and friendly phonetics is; they have given me courage and confidence to seek answers to my questions in phonetic experimentation. The oral pressure experiment as presented here in Section 4 benefitted greatly from her guidance. She has been there throughout every step of the experiment, from the initial design of the pilot study to the final write-up.

I would also like to thank Henry Tehrani for his technical assistance during the oral pressure experiment, and to Rob Hagiwara for helping me with my endless computer inquiries, and for giving me a crash course on Mac Graphics.

I would like to thank all of my subjects of the oral pressure experiment for their time and patience. Thanks also to the audience in Pat Keating's Winter 1995 aerodynamics Proseminar who heard and commented on an earlier version of Section 4 of this thesis.

I would also like to thank Jongho Jun for discussing the methods employed in Silverman and Jun (1994) on Korean and English consonant co-production; the methods in Section 4 are modelled after their work. I would also like to thank Sun-Ah Jun for discussion of Korean language data. Finally, I would like to thank Shu-hui Peng for discussing the results of her electropalatography experiments, which will be part of her dissertation on Taiwanese.

ABSTRACT OF THE THESIS

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University of California, Los Angeles, 1995
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This thesis provides a <u>phonetically-based</u> Optimality Theoretic account of the behavior of Taiwanese stop consonants. It assumes that speech production represents a compromise between two opposing goals: <u>Ease of articulation</u> demands gestural reduction; <u>ease of perception</u> demands gestural preservation. The behavior of Taiwanese stops is argued to be the result of a particular compromise between these goals; the compromise is captured in a set of ranked Optimality Theoretic constraints.

The investigation begins with the observation that in intervocalic position, word-final stops are lenited; this contrasts with word-initial stops which do not lenite in the same environment. Next, we observe that word-final stops are frequently reduced pre-consonantally; this may lead to the perception of place assimilation.

The generality of word-final reduction in Taiwanese is accounted for by proposing a general reduction constraint. A more specific preservation constraint which requires the

preservation of word-initial consonants is proposed to be relevant in Taiwanese; this constraint outranks the reduction constraint, and therefore inhibits lenition of word-initial stops.

Next, it is observed that the frequency or magnitude of reduction depends on the place of articulation. It is also observed that intervocalic lenition is more frequent and consistent than pre-consonantal reduction in Taiwanese. These frequency asymmetries are explained by the fact that the vowel-consonant-vowel co-articulatory pressure is different for the active articulators involved in the production of different consonants, and in different prosodic environments.

1. Introduction

It has often been suggested (Martinet 1952, Lindblom 1990, among others) that speech represents a compromise between two opposing goals: ease of articulation, which requires the minimization of effort during speech production, and ease of perception, which demands maximization and preservation of contrasts. In their discussion of phonetic universals in the structure of consonant systems, Lindblom and Maddieson (1988) arrive at the generalization in (1) after surveying phoneme inventories of the 317 languages in UPSID[1]:

> 1. "Consonant inventories tend to evolve so as to achieve maximal perceptual distinctiveness at minimum articulatory cost" (p. 72, their (6)).

In other words, small inventories will consist only of "phonetically natural" articulations. As the inventory size increases (i.e., more contrasts are implemented), the more difficult articulations will be recruited to ensure sufficient perceptual distinctiveness of the segments, but only after the phonetically natural articulations have been saturated.

Similar strategies as stated in (1)--maximizing perceptual distinctiveness at minimum articulatory cost--can be observed between subsets of a language's consonant inventories. For example, Taiwanese has the word-initial consonants in (2a) and the non-word-initial consonants in (2b) (adapted from Lin 1989: 248-249 and Zhang 1983 : 7):

[1] UPSID stands for "UCLA Phonological Segment Inventory Database." The languages in UPSID are selected "so as to approximate 'a properly constructed quota sample on a genetic basis of the world's extant languages' (Maddieson 1984: 5)" (Lindblom and Maddieson 1988: 63).

2. Taiwanese Consonant Inventory
   a. Word-initial consonants:

b/m[2]	l/n	(dz)[3]	g/ŋ	
p	t	ts	k	
p^h	t^h	ts^h	k^h	
		s		h

   b. Word-final (= non-initial) consonants: (unreleased; see text for discussion)

P	T		K	ʔ
m	n		ŋ	

At a first approximation, the inventories in (2a) and (2b) certainly attest to the generalization in (1): The inventory in (2b) is about half the size of the inventory in (2a), and accordingly, the "less natural" articulations such as aspiration and voicing in obstruents are found only in the larger inventory in (2a). However, there is one important asymmetry between Taiwanese word-initial and word-final consonants the inventories in (2) fail to suggest: While the word-initial consonants are realized fairly consistently across prosodic environments as the IPA symbols in (2a) correctly imply, non-word-initial consonants are articulatorily (and acoustically) more variable, hence my use of the (non-IPA) symbols /P, T, K/: Pre-pausally, /P, T, K/ are unreleased and glottalized, yielding the percept of voiceless unaspirated stops[4]. Intervocalically, they are voiced and lenited. Pre-consonantally, they are optionally (perceptually) assimilated in place (and/or manner) to the following consonant (Zhang 1983: 22-23), and the voicing is variable. Implicit in the choice of the symbols /P, T, K/ is also the desire to remain agnostic as to what the "basic"

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2 The voiced oral stops and nasal stops are allophones: voiced "oral" onset stops are phonetically (weakly) prenasalized, and occur before an oral vowel; nasal onsets occur before a nasal vowel. Nasality is contrastive in vowels. For example, [i] 'he/she' vs. [ĩ] 'institution', [si] 'yes' vs. [sĩ] 'to marinate'.

3 /dz/ has merged with /l/ in some dialects. In the dialects which retain /dz/, it occurs only before high vowels, but is still contrastive with /l/, for example, [lip] 'to erect' vs. [dzip] 'to fill' (Tung 1957: 241).

4 Note that articulatorily, the percept of a voiceless unaspirated stop results from very different laryngeal (and perhaps supraglottal) configurations in onsets and pre-pausal codas: Voiceless unaspirated onset stops are produced with an open glottis during oral closure (voicelessness), and upon release of the stop closure, the glottis has closed and vocal fold vibration commences (no aspiration). Utterance-final stops, on the other hand, achieve the percept of voicelessness and absence of aspiration due to glottalization, which prevents vocal fold vibration, the articulatory correlate of [voice]; glottalization during the consonantal release also prevents an audible burst, hence the lack of aspiration.

allophone should be, in view of the phoneme's articulatory variability. I also refrain from choosing a basic allophone for the word-initial voiced stops.

Interpreting this articulatory variation particular to the non-word-initial position as imprecision of the articulation, we find Kohler's statement appropriate in accounting for this asymmetry in the degree of articulatory invariance of Taiwanese word-initial and word-final consonants: Kohler (1991) states that the "word-initial position has a higher signalling value for a listener and must therefore be given a more precise articulation by a speaker.... What is not very distinctive for a listener anyway may be reduced by a speaker more easily to yield to the principle of economy of effort" (Jun 1995: 37, citing Kohler 1991: 189). In addition, it has often been suggested (for example, in Brown and McNeill 1966) that the word-initial position plays an important role in lexical access in speech production. Thus, in Taiwanese, only the perceptually less salient non-initial positions allow ease-of-articulation considerations to override the ease-of-perception principle, yielding variable articulations across prosodic environments. The smaller, ease-of-articulation-governed non-initial inventory and the larger, contrast-preservation-governed word-initial inventory of Taiwanese can thus be said to conform to Lindblom and Maddieson's generalization in (1): In non-word-initial positions, where preservation of contrasts is a relatively low priority, articulatory effort is minimized; in the word-initial position, where preservation of contrasts is a relatively high priority, more articulatory effort is invested to maximize the ease of perception.

Based on the assumption that speech production represents language-specific compromises between ease of articulation and ease of perception, this paper will provide an account of final consonant lenition in Taiwanese, focusing on supraglottal gestural reduction in /P, T, K/. The claim put forth in the present paper is that word-final reduction is a general process in Taiwanese, with the aim of effort minimization. I will argue that the intervocalic coda lenition is the consequence of a general process of gestural reduction, driven by ease of articulation considerations. The place assimilation facts in Taiwanese documented by Zhang (1983) will follow naturally from a claim advanced by Jun (1995), that gestural reduction of the word-final stop (plus compensatory lengthening of the following word-initial consonant) is the articulatory mechanism responsible for perceived place assimilation.

I will argue that the lack of (perceptual) gestural reduction of pre-pausal stops is due to final glottal fortition, which enhances the percept of stophood. Furthermore, the failure of word-initial stops to spirantize suggests the presence of a constraint forbidding the weakening of word-initial segments, a constraint presumably motivated by the perceptual considerations introduced above.

In Section 2, I will briefly outline some assumptions about Taiwanese phonology adopted in this paper, and summarize the facts I propose to account for in the present study. Section 3 reviews the parts of Jun (1995) relevant to the current study. Section 4 describes a series of oral pressure experiments which provide evidence of pre-consonantal lenition in Taiwanese. Section 5 proposes an account of lenition in Taiwanese, within the framework of Phonetically-Based Optimality Theory.

2. Some Aspects of Taiwanese Phonology

2.1 Syllables

Taiwanese syllables allow maximally one consonantal onset and one consonantal coda, but neither onsets nor codas are obligatory. This means that all consonant sequences <u>CC</u> are necessarily heterosyllabic, with <u>C1</u> being the coda and <u>C2</u> being the onset. Furthermore, in a <u>VCV</u> sequence, the intervocalic consonant may be an onset (<u>V.CV</u>) or a coda (<u>VC.V</u>); the latter syllabification is the result of vowel-initial suffixation.

As is the case of most Chinese languages, each word in Taiwanese is a syllable, and each syllable is a word, with the exception of the suffixes /-a/[5] and /-e/[6] which are bound morphemes assumed here to be onsetless syllables.

2.2 The Realization of Taiwanese Word-initial and Word-final Stops

This section will summarize the observations about Taiwanese this paper proposes to account for, with the focus on the supraglottal articulations of consonants. Although the discussion mentions only the codas /P, T, K/, similar assumptions about the supralaryngeal stricture can be made about the nasal codas /m, n, ŋ/.

Intervocalic Position:

In Taiwanese, word-final /P, T, K/ lenite in intervocalic position, with the reduced /T/ most often perceived as a flap/tap, and the others as continuants:

3. aP a[7]	->	aβ̞a	'little box'
kʰuT a	->	kʰuɾ̞a	'little hole'
tiK a	->	tiɣ̞a	'bamboo'

The degree of intervocalic lenition is variable (as my use of the lowering diacritic [̞] suggests), and is always accompanied by voicing. Moreover, while word-final lenition consistently occurs before vowel-initial suffixes (/-e/, /-a/), it is more variable before vowel-initial words, which sometimes acquire an initial glottal stop /ʔ/ in slower, more careful speech, accompanied by glottalization of the preceding (unreleased) word-final stop. In (4), the word /aP/[8] stands for 'box':

[5] The suffix /-a/ has several meanings. For example, it may be a diminutive marker, as in /ap a/ 'little box (*lit.*, box A)'; it may be suffixed to familiar objects, as in /kam a/ 'oranges (*lit.*, orange A)'; it may also mark a pejorative tone, as in /kiŋ tsat a/ 'the (little) cops (*lit.*, police A)'.

[6] Like /-a/, the suffix /-e/ also has many usages. It can be used as a general counter/classifier, as in /tsit e laŋ/ 'one person (*lit.*, one E person)'; it is an agentive marker, as in /li e tsʰeʔ/ 'your book (*lit.*, you E book)'; it may be used as a relativiser, as in /li koŋ e ue/ 'what you have said (*lit.*, you say E speech)'; it is also a nominalizer, as in /aŋ sik e/ 'the red one (*lit.*, red color E)'.

[7] Tones will not be indicated in this paper, as they are irrelevant for the present study.

4.	tsap^{ʔ} ʔaP	~	tsaβaP	'ten boxes'
	tsit^{ʔ} ʔaP	~	tsiɾaP	'one box'
	lak^{ʔ} ʔaP	~	laɣaP	'six boxes'

Intervocalic lenition is particular to word-final position. Word-initial stops never show the alternation between non-continuants and continuants in the intervocalic environment. Focusing on the intervocalic word-initial consonants below, (5) and (6) show that voiceless stops undergo neither spirantization nor voicing in the intervocalic environment; (7) shows that voiced stops also do not undergo spirantization in the same environment:

5.	pe paʔ	[pe paʔ]	'eight hundred'	*[pe ɸaʔ]	*[pe βaʔ]
	pe tã	[pe tã]	'eight stands'	*[pe ɾ̥ã]	*[pe ɾã]
	pe kaʔ	[pe kaʔ]	'eight hectare'	*[pe χaʔ]	*[pe ɣaʔ]
6.	pe p^{h}a	[pe p^{h}a]	'eight lights'	*[pe ɸa]	*[pe βa]
	pe t^{h}aʔ	[pe t^{h}aʔ]	'eight stacks'	*[pe ɾ̥aʔ]	*[pe ɾaʔ]
	pe k^{h}a	[pe k^{h}a]	'eight players'	*[pe χa]	*[pe ɣa]
7.	pe ba	[pe ba]	'eight yards'	*[pe βa]	
	li li	[li li]	'twenty-two'	*[li ɾi]	
	li gɔ	[li gɔ]	'twenty-five'	*[li ɣɔ]	

Place Assimilation:

Word-final stops optionally assimilate in place to the following consonant, while word-initial stops never undergo progressive place assimilation:

8.	/tsaP pɔ/	[tsappɔ]	'ten steps'	
	/tsaP te/	[tsapte] ~ [tsatte]	'ten pieces'	*[tsappe]
	/tsaP k^{h}ɔ/	[tsapk^{h}ɔ] ~ [tsakk^{h}ɔ]	'ten dollars'	*[tsapp^{h}ɔ]
	/ts^{h}iT pɔ/	[ts^{h}itpɔ] ~ [ts^{h}ippɔ]	'seven steps'	*[ts^{h}ittɔ]
	/ts^{h}iT te/	[ts^{h}itte]	'seven pieces'	
	/ts^{h}iT k^{h}ɔ/	[ts^{h}itk^{h}ɔ] ~ [ts^{h}ikk^{h}ɔ]	'seven dollars'	*[ts^{h}itt^{h}ɔ]
	/laK pɔ/	[lakpɔ] ~ [lappɔ]	'six steps'	*[lakkɔ]
	/laK te/	[lakte] ~ [latte]	'six pieces'	*[lakke]
	/laK k^{h}ɔ/	[lakk^{h}ɔ]	'six dollars'	

8 The word for box is /aʔ/ in some dialects. This variation will not be relevant in the present discussion.

Place assimilation is not limited to consonants preceding a stop; it occurs also before nasals and sibilants: /la<u>K m̃ĩ</u>/ 'six tokens' [la<u>km̃ĩ</u>] ~ [la<u>mm̃ĩ</u>]; /la<u>K s</u>ɤ/ 'Six-Keys' [la<u>ks</u>ɤ] ~ [la<u>ss</u>ɤ][9].

It is my impression that coronal codas are the most likely to undergo place assimilation, while labial codas are the least likely to undergo place assimilation. This observation is supported by the frequency of the documented assimilated codas in Zhang (1983: 22-23).

<u>Pre-pausally</u>:

Pre-pausal codas undergo glottalization, and lenition is not (perceptually) attested in this environment. Here, pre-pausal position includes utterance-final position and utterance-medial but pre-pausal positions in careful speech.

<u>Word-initially</u>:

Finally, I would like to re-iterate that word-initial stops never undergo lenition; supraglottal closure always obtains whether the stop occurs in phrase-initial or phrase-medial positions.

<u>Consistency in intervocalic lenition</u>:

Note from the previous discussion of word-final consonants that lenition is consistent in the pre-vocalic position, but more variable in the pre-consonantal position.

In sum, word-final reduction appears to be a rather general phenomenon in Taiwanese, occurring (at least) in all phrase-/utterance-medial positions. I suggest that Jun's (1995) Optimality Theoretic analysis of place assimilation can be extended to account for reduction in Taiwanese. The next section will review the parts of Jun (1995) relevant to the analysis of Taiwanese.

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[9] The continuancy feature of C1 is also assimilated by C2 in this example.

3. Jun (1995)

This section will provide a partial summary of Jun (1995), a reduction-based account of place assimilation. Both articulatory and perceptual factors are considered in his study, and the opposing demands of articulation and perception are reconciled within the framework of Optimality Theory.

3.1 Articulatory Correlate of Place Assimilation

Like Jun, we will focus here only on the optional, casual-speech gradient regressive place assimilation in coda-onset clusters. This place assimilation can be represented as the perceptual deletion of the target place (C1) and the compensatory lengthening of the trigger place (C2):

9. Regressive Place Assimilation: C1C2 -> C2C2

It has been suggested by Browman and Goldstein (1986; 1989; 1990; 1992; cited in Jun 1995: 29) within the framework of Articulatory Phonology that casual-speech place assimilation may be due to either temporal overlap of the coda gesture by the onset gesture, or the spatial-temporal reduction of the coda gesture. In order to isolate the particular contributions of these two articulatory mechanisms--overlap and reduction--in the perceptual loss of C1 place cues in place assimilation, Jun (1995) conducted a series of production and perception experiments on English and Korean, which differ in the range of place assimilations observed.

Adopting the methodologies and interpretations developed in Silverman and Jun (1994), Jun (1995) monitored the pressure build-up behind the lips[10] during the articulation of (Korean and English) utterances containing /pt/ and /pk/ clusters. He found that while the labial gesture [p] never reduces before [t], labial reduction sometimes obtains before [k] in Korean, but not in English. The results so far parallel the observation that /pt/

[10] A more thorough discussion of the inferences of the oral pressure readings will be provided in Section 4.

never undergoes place assimilation in both English and Korean, and that /pk/ may optionally undergo place assimilation in Korean only, in which case the cluster is perceived as [kk].

Follow-up perceptual experiments showed that whether listeners heard /p/ as assimilated in /pk/ clusters depended on whether the /p/ was reduced: Only in case of a reduced /p/ did the place cues of the labial coda remain undetected in /pk/. That is, place assimilation in /pk/ obtains if and only if the labial coda is reduced; otherwise, [pk] is perceived, irrespective of the degree of p-k overlap. Jun (1995) concludes that gestural reduction, and not overlap, plays the decisive role in perceptual assimilation.

Finally, he concludes with Barry (1992) and Nolan (1992) that gestural reduction in casual speech place assimilation is speaker-controlled, that is, gestural reduction in gradient place assimilation does not arise as the consequence of vocal tract constraints (p. 135).

3.2 Typological Generalizations

Based on a more extensive typological survey of place assimilation, Jun (1995) corroborates Mohanan's (1993) cross-linguistic generalization[11] that if non-coronals undergo place assimilation, so do coronals. Moreover, based on the place assimilation patterns in Korean and the assimilation patterns in the Inuktitut dialects surveyed in Dorais (1986), he elaborates on Mohanan's generalization by suggesting that if velars are targets of place assimilation, so are labials, and if labials are targets of place assimilation, so are coronals (p. 92), i.e., coronals are more likely to undergo place assimilation than labials, which are in turn more likely to undergo place assimilation than velars. Note that in Taiwanese, although /P, T, K/ may all undergo place assimilation, and thus conform to Jun's (1995) implicational statements, labials are *less* likely than velars to be targets in

[11] Mohanan's (1993) generalizations are based on attested place assimilation patterns in English, Korean, Hindi, and Malayalam (Jun 1995: 40).

assimilation, which appears to be a counter-example to the statement that velar targets implies labial targets, i.e., velars are less likely targets than labials in place assimilation.

Jun's generalization is based on the observation that in Korean, both coronal and labial codas may be targeted in place assimilation, while velars never undergo place assimilation. Furthermore, many of the languages surveyed only allow coronal codas[12] to undergo place assimilation (e.g., Catalan, English, German, Toba Batak, Yakut (p.82)). While there are languages which allow all (unreleased) codas (/p, t, k/) to be targets in place assimilation (e.g., Diola Fogny, Japanese, Malay, Nchufie, Yoruba (p.82)), no language targets non-coronals in place assimilation to the exclusion of coronals. Similarly, no language targets velars in place assimilation to the exclusion of labials (and coronals).

3.3 Analysis

3.3.1 Theoretical Assumptions

In explaining the varying degree of likeliness of place assimilation targets, Jun (1995) assumes the Production Hypothesis suggested by Steriade (1993) and Byrd (1994):

> 10. Production Hypothesis (Jun 1995: 35, his (35)):
> Speakers make more effort to preserve the articulation of speech sounds with powerful acoustic cues, whereas they relax in the articulation of sounds with weak cues.

That is, the most favored targets in place assimilation are such because they have the weakest acoustic cues even in their non-reduced forms. Jun argues that the relative likelihood of coda targets reflects the relative robustness of their perceptual cues in a consonant cluster. In a stop (nasal or oral) consonant cluster <u>CC</u>, <u>C1</u> is usually unreleased (i.e., the release or stop burst of <u>C1</u> is inaudible) due to overlap by <u>C2</u>. In the case of an unreleased <u>C1</u>, identification of its place relies solely on the V-to-C transition, which is significantly less salient than the acoustic cues present in C-to-V transitions. Moreover, the place cues of <u>C1</u> in V-to-C transitions may be influenced by <u>C2</u> (p. 153, citing Byrd 1992,

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[12] Jun's (1995) generalizations include both oral and nasal codas.

Zsiga 1992), especially upon considerable overlap by a slow C2 gesture (e.g., non-coronal C2).

Assuming that unreleased coronals have weaker place cues than unreleased non-coronals, and further, unreleased labials have weaker place cues than unreleased velars (See Jun 1995, Section 4.2.1.2: 149-151 for a detailed discussion), Jun proposes that the coronal gesture is the least likely to be preserved under unrelease; labials are the next least likely candidate of preservation; and finally, unreleased velar codas are the most likely to be preserved as a stop. Moreover, he assumes this tendency to be universal. Below, I will provide his formalization of this tendency after briefly reviewing the formal framework of Optimality Theory which both Jun (1995) and the present paper employ.

In Optimality Theory (Prince and Smolensky 1993, McCarthy and Prince 1993), the phonology is composed of a set of universal constraints. Unlike in other constraint-based theories, these constraints are violable, and they are ranked. The constraint ranking is language-specific. Thus, cross-linguistic variations result from variations in constraint ranking, and not variations in the constraint composition: The constraint ranking determines the possible outputs of a grammar. For each given input form, an infinite number of outputs are generated. In determining the winning form, these outputs are evaluated against the strictly-ranked constraint hierarchy. An output which violates a higher-ranked constraint is always disfavored to one which violates a lower-ranked constraint. (See Prince and Smolensky 1993 for a more comprehensive discussion of the procedure of output evaluation.)

Using Jun's (1995) constraints as an illustration, assume the following subset of constraints in regressive assimilation. I will only focus here on the reduction of C1 in a CC cluster, and assume that highly ranked constraints ensure the compensatory lengthening by

C2 as C1 reduces, as well as the absence of progressive place assimilation (i.e., reduction of C2 plus compensatory lengthening by C1):

11. Reduction Constraint (p. 143, his Chapter 2, (2)):
    RED: Conserve articulatory effort.

12. Preservation Constraint (generalizing his Chapter 4, (6), p. 151):
    Pres(pl(X˺)): Preserve the place cues of an unreleased articulation X˺, where X ranges among the places dorsal, labial, and coronal.

The reduction constraint RED requires that a consonantal gesture be reduced, or lenited[13], while the preservation constraint Pres(pl(X˺)) requires that the cues for the place of articulation X be preserved; for an unreleased pre-consonantal coda, this means the articulatory gesture giving rise to the place cues for X must be unreduced: These two constraints clearly encode opposing demands. Now assume two hypothetical languages L1 and L2 which contrast in the relative ranking of these two constraints. In L1, RED outranks Pres(pl(X˺)), i.e., reduction is favored. In L2, Pres(pl(X˺)) is ranked higher than RED, i.e., preservation is favored. These two partial grammars are represented in (13), where the notation ">>" reads "outranks":

13 a. L1: RED >> Pres(pl(X˺))

b. L2: Pres(pl(X˺)) >> RED

The tableaux in (14) and (15) evaluate the relevant competing output forms of L1 and L2. In the tableaux below, the input form is indicated on the top left cell, and the relevant candidates are indicated in the left-most column, where C1C2 represents an unreduced C1, and C2C2 represents a reduced C1[14]. The notation "→" is placed next to the winning candidate. The top row lists the constraints, with the convention that the constraint to the

[13] Gestural deletion is an extreme form of reduction. In Jun (1995), deletion is the result of a separate, highly-ranked constraint DEL (p. 144), which requires maximal conservation of articulatory effort. Thus, I follow Jun in assuming that while the constraint RED demands gestural reduction, it cannot force gestural deletion.

[14] Recall that we are only concerned with the reduction of C1, and neither the product of progressive assimilation (C1C1) nor the result of C1 reduction with no compensatory lengthening of C2 (ØC2) are deemed possible (better) outputs.

left outranks the constraint to the right. Each "*" in the cell records one violation of the constraint indicated at the top of the column for the corresponding candidate output. The notation "!" is placed before the crucial violation which leads to the candidate's demise. We are now ready to examine the tableaux below:

14. L1 (Place Assimilation)

/VC1C2V/	RED	Pres(Pl(X'))
VC1C2V	!*	
→ VC2C2V		*

15. L2 (No Place Assimilation)

/VC1C2V/	Pres(Pl(X'))	RED
→ VC1C2V		*
VC2C2V	!*	

Before we examine the two grammars L1 and L2 separately, note first that given the same input /VC1C2V/, the outputs commit the same number of violations of the same constraints in both languages: Focusing on the realization of the coda (C1), the output VC1C2V commits one violation of RED by failing to reduce[15], but satisfies Pres(Pl(X')) in doing so. In contrast, the output VC2C2V satisfies RED by reducing C1, but violates Pres(Pl(X')) in doing so.

Now turning our attention to the language-internal rankings in (14) and (15), we see that the constraint ranking in L1 means that the output VC1C2V violates a more highly-ranked constraint than does VC2C2V; hence, the latter candidate is the optimal one. In contrast, (15) shows that the constraint ranking in L2 means the candidate VC1C2V violates a more lowly-ranked constraint than VC2C2V, thus emerging as the optimal candidate. Optimality Theory thus provides an explicit framework within which the language-specific interaction of the conflicting demands of production and perception can be formalized.

[15] Notice that the onset C2 also commits one violation of reduction which I do not indicate here.

3.3.2 A Formal Account of the Place Assimilation Typology

Returning to the formalization of the place assimilation typology in Jun (1995), two families of constraints are relevant for determining the realization of targets in place assimilation. The first family of constraints is driven by minimization of effort considerations, embodied in the constraint RED repeated in (16):

16. RED: Conserve articulatory effort

The second family of constraints is driven by perceptual considerations. He proposes a universal ranking based on the acoustic salience of the place cues, assuming the Production Hypothesis. The ranking is provided in (17), in which the set of individual constraints is an instantiation of my generalized constraint in (12):

17. Universal ranking for target places (p.151, his Chapter 4, (6)):
 Pres(pl(dor˺)) >> Pres(pl(lab˺)) >> Pres(pl(cor˺))

The universal constraint hierarchy in (17) indicates that unreleased velars are more likely to be preserved than unreleased labials and unreleased coronals. Moreover, unreleased labials are more likely to be preserved than unreleased coronals, where preservation of place cues may be interpreted to mean resistance to reduction.

Using the universal constraints and constraint hierarchy in (16) and (17), Jun (1995) accounts for the attested cross-linguistic patterns of place assimilation. Again, I focus here only on the gestural reduction of C1 in the cluster C1C2. The interaction of (16) and (17) predicts four possible patterns:

Pattern 1: **RED** >> Pres(pl(dor˺)) >> Pres(pl(lab˺)) >> Pres(pl(cor˺))

This ranking predicts that all codas (velars, labials, coronals) may be targeted in place assimilation, since RED outranks the entire range of preservation constraints which deter reduction. This pattern is attested in Diola Fogny, Japanese, Malay, Nchufie, and Yoruba. Taiwanese also seems to fall under this ranking. However, I will argue in

Section 5 that the hierarchy as stated here only captures part of the place assimilation typology facts.

<u>Pattern 2</u>: Pres(pl(dor˺)) >> **RED** >> Pres(pl(lab˺)) >> Pres(pl(cor˺))

This ranking predicts that labial and coronal codas may be targeted in place assimilation, but velar codas never will, since its preservation constraint outranks the reduction constraint. This pattern is unambiguously attested in Korean. See Jun (1995), Section 4.3.3 (pp. 171-177) for a detailed discussion of Korean place assimilation.

<u>Pattern 3</u>: Pres(pl(dor˺)) >> Pres(pl(lab˺)) >> **RED** >> Pres(pl(cor˺))

This ranking predicts that only coronal codas will undergo place assimilation, since the reduction constraint is outranked by the constraints preserving the place cues of unreleased velars and unreleased labials. This pattern is unambiguously attested in Catalan, English, German, Toba Batak, and Yakut. See Jun (1995), Section 4.3.2 (pp. 166-170) for a detailed discussion of place assimilation in English.

<u>Pattern 4</u>: Pres(pl(dor˺)) >> Pres(pl(lab˺)) >> Pres(pl(cor˺)) >> **RED**

Finally, this ranking predicts that place assimilation will never occur, since the reduction constraint is outranked by the entire range of preservation constraints. Although Jun (1995) does not discuss this case, we can tentatively assume that all languages which disallow place assimilation of unreleased codas share this constraint hierarchy[16].

In conclusion, interaction of the reduction constraint in (16) with the universal preservation constraint hierarchy in (17) generates all and only the attested place assimilation typology surveyed by Jun (1995).

[16] However, we conjecture that a close examination of cross-linguistic casual-speech data will reveal that such a language does not exist. That is, gestural reduction of pre-consonantal codas is expected to occur cross-linguistically in fast speech.

With these background assumptions in mind, we now return to the case of Taiwanese. We propose that the observations about intervocalic lenition and place assimilation can receive a unified Junnian account of gestural reduction. However, before we embark on an Optimality Theoretic analysis of Taiwanese, we must first confirm our hypothesis that coda reduction indeed occurs pre-consonantally. Section 4 describes an experiment which establishes that lenition obtains in the pre-consonantal position in Taiwanese. Section 5 provides a formal account of word-final reduction in Taiwanese.

4. Experiment: Aerodynamic Evidence of Pre-consonantal Reduction in Taiwanese

4.1 Objective of the Experiment

Regressive place assimilation has been documented by Zhang (1983: 22-23) for Taiwanese and by Tung (1975: 239) for Xiamen, a closely related dialect. I have also observed optional casual-speech place assimilation in the speech of a number of Taiwanese speakers. Drawing from the conclusions of Jun (1995), we predict that the percept of place assimilation in casual speech is an indication of gestural reduction of the coda plus compensatory lengthening by the following (unreduced) onset; place assimilation is therefore related to intervocalic reduction. The goal of this experiment is to determine whether coda reduction indeed obtains in Taiwanese[17]. An affirmative answer to this question would suggest that word-final lenition is part of a more general phenomenon in Taiwanese, i.e., lenition is not limited to the intervocalic environment.

4.2 Hypothesis

In Taiwanese, pre-consonantal codas may be lenited in casual speech. This hypothesis is suggested by the percept of place assimilation and Jun's (1995: 139)

[17] This experiment does not investigate the correlation between the presence/absence of gestural reduction and the perception of place assimilation, as we are only focusing here on the former variable, and not in a correlation of the two.

conclusion that "gestural reduction plays the decisive role in the perceptual loss of the target in [casual-speech] place assimilation[18]."

4.3 Methodological Assumptions

The basis of this experiment is the observation that air flowing via the glottis into the oral cavity will result in pressure build-up in the cavity if the incoming air cannot be (sufficiently) vented, as in the case of a supra-laryngeal stop closure. Section 4.3.1 discusses some expected oral pressure patterns, considering factors such as the presence or absence of incoming flow, the presence or absence of supra-laryngeal stop closure(s), and the consequences of oral cavity expansion and compression. Section 4.3.2 summarizes the methods and interpretations developed in Silverman & Jun (1994), which the present experiment adopts.

4.3.1 Relevant Factors in the Interpretation of Oral Pressure Data

The figures below provide schematic diagrams of the oral cavity. In *Figures 1* and *2*, Points A and B correspond to different places of constriction: the lips and the glottis, respectively. $\underline{P_A}$ denotes the pressure behind constriction point A, or the pressure inside the cavity enclosed by constriction points A and B. In *Figures 1a* and *1b*, the glottis is open, and air flows via the glottis into the oral cavity. When the lips are open, as schematized in *Figure 1a*, no pressure will accumulate in the oral cavity, and the pressure behind constriction point A ($\underline{P_A}$) approximates the atmospheric pressure (to the left of point A), conventionally zero. If the lips are closed, as in *Figure 1b*, the incoming air flow will result in a pressure build-up behind constriction point A: I will represent the positive increase in pressure as $\underline{+p}$.

[18] Note that reduction is limited to the pre-consonantal position in Korean, but occurs both pre-consonantally and pre-vocalically in Taiwanese. This difference will be addressed in Section 5.

Figure 1a: glottis open; lips open

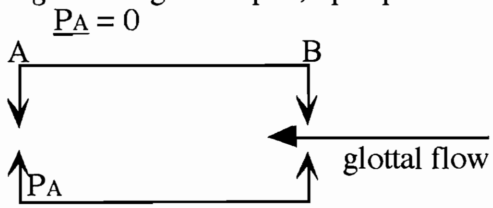
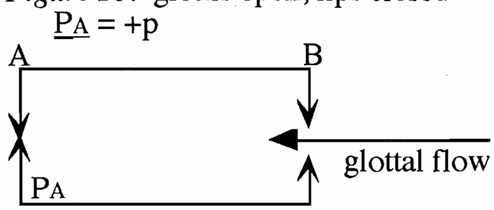


Figure 1b: glottis open; lips closed



In *Figures 2a* and *2b*, the glottis is closed, for example, during the glottal stop [ʔ] or the glottalized consonant [ˀp]. Assume the stop constriction is first formed at point B, and that the size of the cavity between A and B remains constant (for example, neither active expansion by larynx lowering nor active compression by larynx raising). In both cases, the pressure behind constriction point A is essentially zero, even when a stop closure is formed at A; this is because the glottal closure reduces glottal flow to zero, thereby removing the source of pressure build-up in the oral cavity.

Figure 2a: glottis closed, lips open

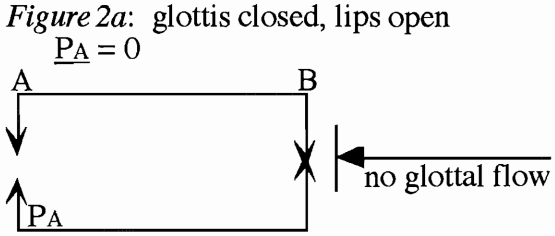
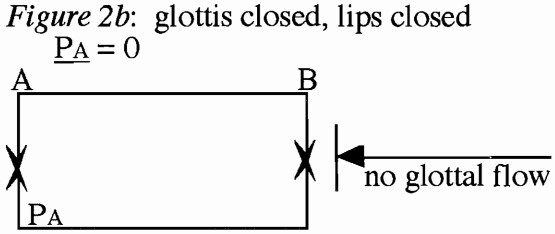


Figure 2b: glottis closed, lips closed

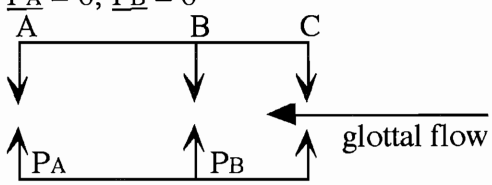


Next, consider the cases of articulatory overlap, where two supralaryngeal constrictions are formed, such as during an overlapped pk cluster. Only the cases with open glottis will be considered, since only these will be relevant for the present discussion. In the remainder of this section, the constrictions at A and B refer to the labial and velar places of articulation, respectively, while C refers to the glottis.

Figure 3 represents an oral cavity with two sub-cavities, one between points A and B, and one between points B and C. In *Figure 3*, all three places of constriction are open (i.e., neither labial, nor velar, nor glottal closure): Air flows into the oral cavity and through points B and A (relatively) freely; no pressure builds up behind either point A or point B.

Figure 3: no labial closure, no velar closure; open glottis

$\underline{P_A} = 0$, $\underline{P_B} = 0$



Figures 4a and *4b* schematize the situations with one supralaryngeal closure (during articulatory overlap of a stop plus a lenited stop), alternating the stop closure between points A and B. In *Figure 4a*, labial closure is achieved, but not velar closure. This is similar to *Figure 1b*. If pressure measurements were taken behind points A and B, both should detect positive pressure, since both $\underline{P_A}$ and $\underline{P_B}$ represent the pressure in the cavity enclosed by points A and C. In contrast, the two sub-cavities in *Figure 4b* have different oral pressure types. In *Figure 4b*, velar closure is achieved, but not labial closure. In this case, the cavity between A and B will have zero pressure, as in *Figure 2a*, since there is no air flow into the cavity (and the lips are open); the cavity between B and C will have positive pressure, as in *Figure 1b*, since there is continuous air flow into the cavity which has no vent.

Figure 4a: labial closure, no velar closure; open glottis

$\underline{P_A} = +p$, $\underline{P_B} = +p$

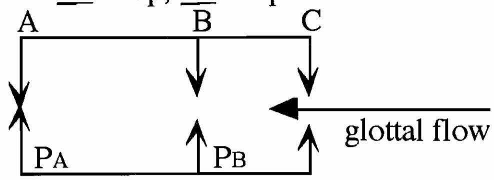
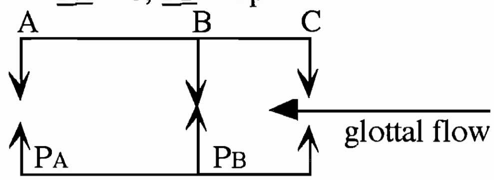


Figure 4b: no labial closure, velar closure; open glottis

$\underline{P_A} = 0$, $\underline{P_B} = +p$



Now consider simultaneous closures at points A and B in *Figure 5a*. If closure at A is achieved before B, both $\underline{P_A}$ and $\underline{P_B}$ will be positive, although $\underline{P_A}$ might be lower than (maximal) $\underline{P_B}$, if closure at B is formed before glottal flow ceases. If, however, velar closure is achieved before labial closure, the pressure in the cavity between B and C will be positive while the pressure in the cavity between A and B will be at or near zero, since there is no incoming air after the formation of labial stop.

Figure 5a: labial closure, velar closure; open glottis

P_A = +p or 0, P_B = +p

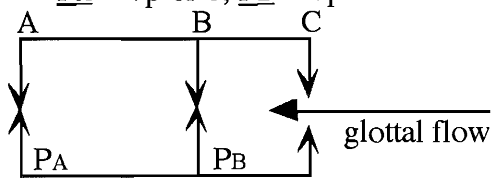


Figure 5b: labial closure, velar closure; open glottis
tongue dorsum fronting

$P_A \uparrow$, $P_B \uparrow$ (slower)

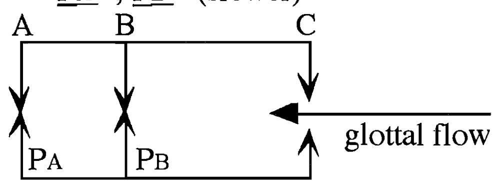
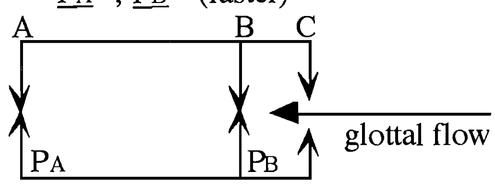


Figure 5c: labial closure, velar closure; open glottis
tongue dorsum backing

$P_A \downarrow$, $P_B \uparrow$ (faster)



Consider now the dynamic pressure changes in the two subcavities above the glottis in *Figures 5b* and *5c*. In *Figure 5b*, the constriction at B has moved forward from the starting position in Figure 5a, due to co-articulation of a back-front vowel sequence. This articulator movement results in a compression of the cavity sealed at points A and B; consequently, P_A increases. In the absence of glottal flow, the accompanying expansion of the cavity between B and C (due to tongue dorsum fronting) will result in pressure rarefaction, i.e., a decrease in P_B is expected. However, since *Figure 5b* indicates that there *is* continuous incoming glottal flow to contribute to pressure build-up, an increase in P_B is still expected, provided the rate of pressure rarefaction due to cavity expansion is less than the rate of pressure increase due to glottal flow. Assuming this to be the case, the net effect of cavity expansion and glottal flow will result in a(n initially) slower increase in P_B than in *Figure 5a*, where no cavity expansion obtains.

In *Figure 5c*, the cavity sealed at constriction points A and B expands due to tongue retraction during the articulation of a flanking front-back vowel sequence. As a consequence, the enclosed air column rarifies, resulting in a decrease in $\underline{P_A}$. The reduced volume between B and C will see a faster pressure increase than would be expected from glottal air flow alone, due to the cavity compression resulting from tongue retraction.

Although I have only considered the oral pressure dynamics during labial and velar constrictions, the discussions above on multiple supralaryngeal constrictions may be extended to cover the alveolar place of articulation at constriction point B (or A).

There exist two more relevant factors to be considered: nasal opening and voicing. Although the above discussions have assumed a raised velum (i.e., no nasal leakage) and a spread glottis (i.e., considerable glottal flow) as the conditions during glottal flow, similar oral pressure consequences can be assumed during voicing (low glottal flow) and nasalization (lowered velum). However, both conditions will result in a slower supralaryngeal pressure build-up: Voicing means a dramatically reduced rate of air flowing into the oral cavity; nasalization has the same effect of reducing the net flow into the oral cavity, by the nasal vent. Less flow will result in a slower pressure build-up.

4.3.2 Silverman & Jun (1994)

Silverman and Jun (1994) showed that oral pressure (henceforth Po) measurements taken behind the lips during unreduced labial+velar stop sequences may serve as good diagnostics for gestural overlap when the consonant sequence is flanked by vowels of varying backness, and that the presence or absence of overlap is especially clear when the vowel environment is front-back. In ipku, an overlapped sequence will show a positive-then-negative change in Po (*Figure 4a* - *Figure 5c* - *Figure 4b*); in ikpu, an overlapped sequence will show a negative-then-positive change in Po (*Figure 4b* - *Figure 5c* - *Figure 4a*). In both cases, the positive change in Po is the result of pressure building up behind the labial closure, while the negative change in Po results from pressure rarefaction due to tongue retraction occurring while both the labial and velar closures are maintained (i.e., when there is articulatory overlap). Furthermore, Silverman and Jun interpreted an absence of Po change during the articulation of pk as evidence of labial reduction: In the absence of labial closure, the pressure behind the lips is expected to equal the atmospheric pressure, or zero in the metrics employed (See the discussion of ***Figures 1a, 4b***). Silverman and Jun (1994) were able to establish the validity of their methods because pharyngeal pressure was recorded concurrent with the Po traces; the pharyngeal pressure traces allowed them to interpret their Po data convincingly by enabling them to directly identify the duration of velar closure (as the period of positive pharyngeal pressure change).

Adopting the methods and interpretations of Silverman and Jun (1994), Jun (1995) extended the test tokens to include Korean pt clusters in addition to pk clusters; both pt and pk were preceded by the front vowel [i], and followed by a back vowel from the set [u,o,a]. In addition to being good indications of articulatory overlap during unreduced ipku, Po data is also a good diagnostic for labial reduction. In his Po trace interpretations of both pk and pt, a positive Po was taken as indication of labial closure, while a flat Po trace during the CC duration was interpreted to mean labial reduction. No conclusions were drawn from the Po data regarding the overlap of unreduced pt, based on the assumption that tongue dorsum retraction during a front-back vowel sequence will show no (significant) effect on the articulation of the coronal [t], i.e., the tongue blade will not retract along with the tongue body.

I have applied this method in assessing the presence of coda reduction in Taiwanese consonant clusters. This experiment considered non-homorganic, heterosyllabic CC sequences where either C1 or C2 was labial. In labial-initial clusters, the overall change in Po was taken to be a reliable indication of whether the coda gesture had undergone reduction. In labial-final clusters, reliable interpretation of coda reduction depended on considerable overlap of the two CC gestures, since only in this case can a meaningful interpretation of the status of the non-labial coda be inferred from the Po readings taken behind the lips; fortunately, this turned out to be the case almost all of the time.

We are now equipped with the necessary information for the understanding of the Taiwanese oral pressure experiment, to be described in the following sections.

4.4 Method

4.4.1 Subjects

Six paid native speakers (4 male, 2 female) of Taiwanese participated in this study. With the exception of one female speaker who was an undergraduate student at UCLA, all the subjects were UCLA graduate students. All of them were born and raised in Taiwan as bilingual speakers of Taiwanese and Mandarin, and left Taiwan after age 23. None of them had been abroad for more than 5 years at the time of this study, and Taiwanese is the language in the home for all of the speakers. I will refer to these speakers as "m1," "m2," "m3," "m4," "f1," and "f2," where "m1" is Male Speaker 1, and "f1" is Female Speaker 1, etc.

None of the subjects in this experiment were linguists, and all of them were naive about the purpose of the study, as well as about Taiwanese phonetics and phonology.

4.4.2 Speech materials

All the relevant sequences were placed in a phrase-medial position, where a fairly constant subglottal pressure (i.e., maximum potential Po) may be assumed. The phrases employed for this experiment are provided in Appendix A, with the relevant sequences underscored. There are two parts to this data set:

Part I: Word-initial versus word-final stops

It is clear from perception that word-final stops, but not word-initial stops, lenite intervocalically. Based on this assumption, Po data of intervocalic word-initial and word-final /p/ and /m/ are compared to ensure that lenition is unambiguously reflected in the Po traces. The phrases used for this part of the experiment correspond to Utterances 1~4 in Appendix A. The relevant (utterance-medial) VCV sequences are summarized in Table 1, with the word-boundary indicated by a period:

Table 1. Intervocalic Word-initial versus Word-final C

	Word-Initial	Word-Final
/p/	a.pa	ap.e
/m/	a.ma	am.e

As discussed in Section 4.3.1 in regard to *Figures 2a* and *2b*, glottalization will result in no (substantial) Po build-up if labial closure is achieved after glottal closure. Since no oral flow data is recorded (which would allow us to ascertain the presence of labial reduction plus an open glottis, in which case positive oral flow will be detected) when zero Po is detected, we must rely on the acoustics: Presence of voicing may be used as evidence against glottal closure whether or not the supra-laryngeal constriction is reduced.

The Po effect is expected to be more robust for /p/ than for /m/, since the positive Po build-up during /m/ will be low, if at all, due to the lower rate of glottal flow during voicing and the presence of the nasal vent which reduces the net flow into the oral cavity. It is therefore important to test what kinds of Po patterns can be used reliably as the diagnostic for the presence or absence of labial reduction.

Part II: Labial + C Clusters

Po data of the utterance-medial sequences listed in Table 2 are examined for evidence of gestural reduction of C1. Due to the limitations of the methodology, only non-homorganic stop clusters containing a labial constituent are employed. Both oral and nasal word-final stops are included in the data set. These correspond to Utterances 5 ~ 12 in Appendix A.

Table 2. Labial + Non-labial Clusters

	C1 = Labial		C2 = Labial	
	C2 = velar	C2 = coronal	C1 = velar	C1 = coronal
C1 = oral	iPku	iPtu	iKpu	iTpu
C1 = nasal	imku	imtu	inpu	inpu

4.4.3 Data-collecting Procedures

Each subject was fitted with a Rothenberg mask connected to pressure/flow transducers. The pressure tube consists of two segments: The first part is 5 3/4 inches (≈ 14.5 cm) in length, and has a 5 mm inside diameter; this is connected to the pressure transducer at one end, and to the second tube at the other. The second part is 3/4 inches (≈ 2 cm) in length, and has a 3 mm inside diameter. The smaller-diametered tube is used to minimize the disruptiveness of the experimental apparatus for the subjects. The longer, larger-diametered tube is required by the design of the mask and the transducer; it also gives a better frequency response than a narrower tube would. The tubes, after being connected together, measure about 6 inches in length.

The subjects were asked to hold the mask, and insert the narrower end of the tube in the corner of the mouth between the lips[19]. They were instructed to not allow the end of the tube to come in contact with their teeth. When the smaller tube is held between the lips, its (opening) end is probably perpendicular to the major direction of flow; oral pressure measured in this way reduces the potential for artifacts in pressure record.

The subjects were provided with twelve Taiwanese phrases, read to them one at a time by the experimenter. After the experimenter read each phrase, the subject was instructed to repeat the phrase eight times in their normal, conversational speech style.

Two signals were recorded on the Kay Elemetrics Computerized Speech Lab (CSL)

[19] See Jun 1995: 99, Figure 2 for a diagramatic representation of the method of measuring oral pressure.

in the UCLA Phonetics Laboratory: audio and oral pressure (behind the lips). The first and eighth repetitions of each test phrase were discarded. Flow[20] was not captured because a tight fit of the mask could not be achieved for any of the speakers.

The oral pressure trace was not calibrated because we are interested here only in the qualitative pattern of Po change. Also, we present below the unfiltered Po trace; this allows us to identify the periods of voicing as the regular oscillations in the Po waveforms.

4.5 Results and Analysis

4.5.1 Word-final Oral Stops

Part I: Intervocalic consonants

The Data

Figures 6a and *6b* provide representative Po traces of intervocalic word-initial /p/ and word-final /P/. All the tokens (6 repetitions per token x 6 speakers) examined displayed the same pattern.

In each figure, the top waveform corresponds to the audio signal, and the bottom is the Po trace. The vertical axis represents pressure, while the horizontal axis represents time in seconds. A phonemic transcription for the utterance is provided below the audio waveform; morpheme boundaries are indicated by a period ".". I have marked off the relevant segment (underlined in the transcription) in each waveform by the vertical lines labeled A and B. Point A corresponds to the acoustic onset of the consonant, and was located from an expanded waveform by marking the end of the vowel (complex wave). Point B corresponds to the release (offset) of the consonant, and was located from the waveform by marking the stop burst in the case of unreduced consonants, or by marking the beginning of the following vowel (complex wave in the case of a reduced labial).

[20] As mentioned earlier, oral flow data is helpful in the word-final, intervocalic position in disambiguating between glottalization and labial reduction with no glottalization, both of which will result in no pressure build-up behind the lips, but only the latter will yield positive oral flow. In addition, flow data is helpful in identifying the interval of oral closure in consonant clusters (= the interval of no oral flow).

Figure 6a contains two instances of Po rise during an intervocalic word-initial /p/[21]; I have only marked off one instantiation below:

Figure 6a: Word-initial /p/ in a.pa

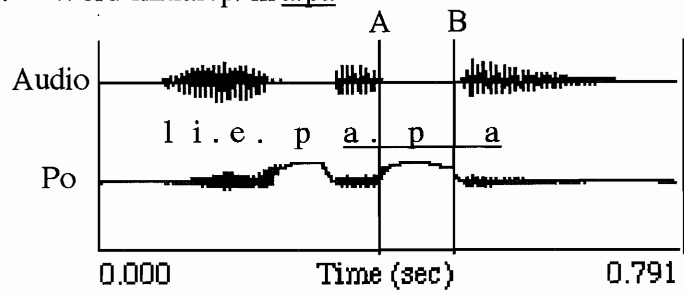
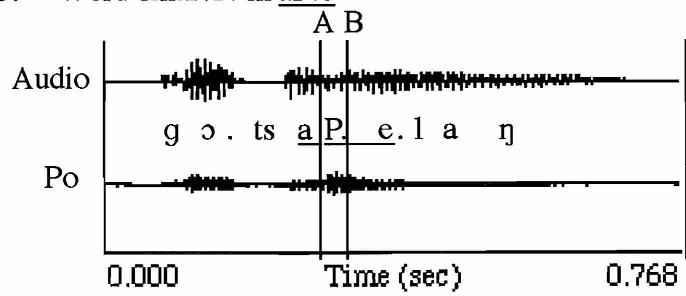


Figure 6b: Word-final /P/ in aP.e



Figures 6a and *6b* are representative of the intervocalic /p/ and /P/ examined. We observe from a comparison of *Figures 6a* and *6b* that positive Po is detected during intervocalic word-initial /p/, where no reduction is perceived, while no overall Po rise is detected during intervocalic word-final /P/, where labial reduction is expected. An additional observation is that word-initial /p/ is significantly longer than word-final /P/.

Notice that in *Figure 6b*, although a voiceless closure presumably obtained during the affricate /ts/, no positive Po rise is detected. This is because the current method will only detect Po (immediately) behind the lips; the Po accruing behind the coronal constriction is not detectable by the present methodology.

[21] I consider the string /pa pa/ 'Dad' to be a reduplicated form of the vocative /pa/ 'Dad,' which is also well-formed. Both /p/s in /pa pa/ are therefore word-initial.

Discussion

Po data unambiguously showed that consistently across 6 speakers, word-initial /p/ was unreduced while word-final /P/ was reduced: A significant pressure rise was detected during the production of word-initial /p/ (*Figure 6a*), as predicted in the discussion of *Figure 1b*, while no (significant) overall Po change was detected during word-final /P/ (*Figure 6b*), as predicted in the discussion of *Figure 1a*. Furthermore, the intervocalic Final /P/ duration showed sinusoidal oscillation on the audio waveform indicative of voicing; the absence of Po rise is therefore not the consequence of glottalization (i.e., *not* the scenario diagrammed in *Figures 2a* or *2b*). Finally, although it might be argued that the lack of positive Po in /P/ is *not* due to lenition, but is due to a combination of reduced glottal flow (voicing) plus short duration, it is clear from the percept (roughly, IPA [β]) that intervocalic /P/ was always reduced. Thus, in interpreting Po of CC clusters, *I will consider a positive Po similar to that in a.pa as indication of unreduced labial closure, while an absence of (significant) overall Po change during /P/ or /p/ (accompanied by voicing) such as in ap.e. as indicating labial reduction.*

Part II: Consonant clusters

Summary of attested Po patterns during CC

I use the following notations to qualitatively categorize the Po traces:

AP: All-Positive; positive Po was detected throughout the CC duration.

PN: Positive-then-Negative; positive Po was detected, followed by negative Po.

PZ: Positive-then-Zero; positive Po was detected during (roughly) the first half of the CC duration, followed by zero Po during the remaining CC duration.

AZ: All-Zero; no change in Po (zero) was detected throughout the CC duration.

Figures 7 to *10* exemplify these Po patterns. As in the previous figures, the top waveform in each figure below is the audio, and the bottom is the oral pressure measured behind the lips. The vertical axis measures pressure, while the horizontal axis measures time. The vertical lines labeled A and B demarcate the duration of the consonant cluster CC, where either C1 or C2 is a labial consonant. Point A is determined from the expanded waveform as the point where the vowel [i] (complex waveform) ends. Point B corresponds to the burst of C2, or the release of the stop closure. A phonemic transcription is provided below the audio waveform; the relevant consonant cluster is underlined, and the morpheme boundaries are indicated by a period ".".

Figure 7: AP (All-Positive)
/iK.pu/. The example is taken from Speaker m1.

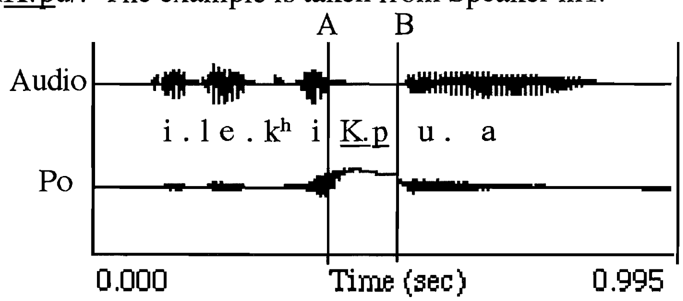


Figure 8: PN (Positive-then-Negative) Two examples are shown: P.k and P.t.

Figure 8a: /iP.ku/. The example is taken from Speaker m1.

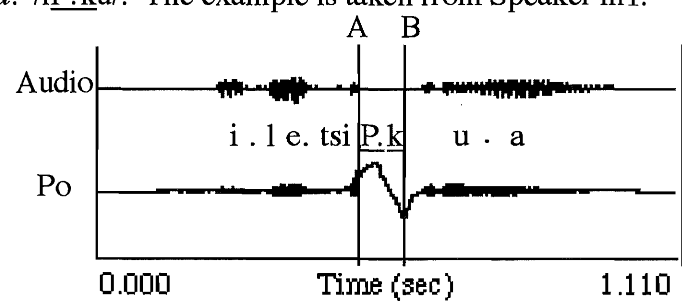


Figure 8b: /iP.tu/. The example is taken from Speaker f1.

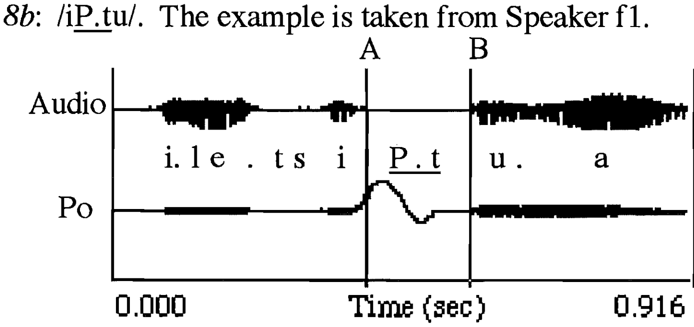


Figure 9: PZ (Positive-then-Zero)
/iP.ku/. The example is taken from Speaker m4.

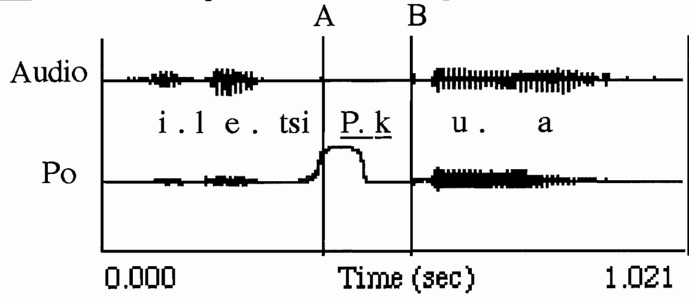


Figure 10: AZ (All-Zero).
/iP.ku/. The example is taken from Speaker f2.

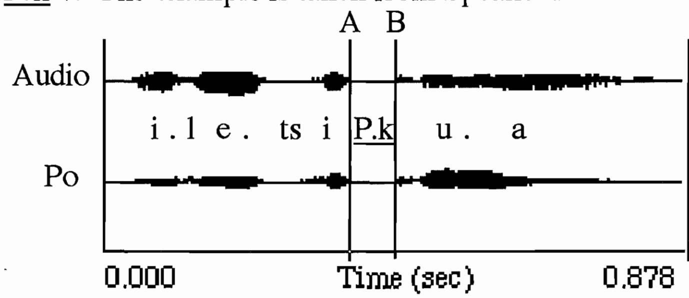


Table 3 summarizes the number of times (out of 36 repetitions) each pattern was attested during the consonant sequences (flanked by the vowels i-u) listed in the far left column. The patterns are indicated on the first row, not in any significant order. To facilitate the reading of this table, I have shaded the boxes for which zero results were obtained. Thus, the remaining unshaded boxes report only positive (non-zero) results.

Table 3. Summary of Results by Po Patterns

	AP	PN	PZ	AZ
iP.ku		15	12	9
iP.tu		5	23	8
iK.pu	36			
iT.pu	36			

Appendix B presents the (same) results by speaker.

Interpretation of the Po data

The results in Table 3 are interpreted based on the following assumptions:

i. An AP pattern indicates complete labial closure throughout the entire duration of CC. Moreover, no other (significant) consonantal constriction was formed during the labial closure (See discussion of *Figure 4a* in Section 4.3.1). In the case of a labial C1, this would mean progressive place assimilation by the labial C1 plus gestural reduction of the non-labial C2. In the case of a labial C2, this would mean regressive place assimilation by the labial C2 plus gestural reduction of the non-labial C1. An alternative interpretation is gestural overlap of CC plus lenition of the non-labial consonant. As we might expect, this pattern never arises in the labial-C1 clusters, i.e., word-initial lenition plus compensatory lengthening by the preceding coda is unattested in Taiwanese.

ii. As discussed in Silverman and Jun (1994), a PN pattern indicates simultaneous closure by a labial C1 and a non-labial C2, or, gestural overlap plus the absence of lenition at both places of articulation; the rarefaction is due to tongue body retraction which expands the sealed cavity (See discussion of Figure 5c in Section 4.3.1). Thus, the pattern is attested only in labial-C1 clusters. In addition, as exemplified in *Figures 8a* and *8b*, both iP.ku and iP.tu may yield this pattern, contrary to the assumption in Jun (1995) that front-back vowel co-articulation on an overlapped labial-coronal cluster will have no significant effect (of pressure rarefaction) on the Po measured behind the lips.

iii. A PZ pattern indicates labial closure during the first part of the CC duration only. Furthermore, no significant gestural overlap by the non-labial occurred during labial closure. Not surprisingly, this pattern is only attested in the labial-C1 clusters.

iv. An AZ pattern indicates that no labial closure was formed throughout the CC closure. In the case of no gestural overlap, this would either mean a lenited labial C1 or a lenited labial C2 (*Figure 1a*). Although no Po will be detected behind the lips if the labial closure is formed after the non-labial closure (i.e., [kp] or [tp]), all else being equal, the design of the present experiment will yield a NP Po pattern due to co-articulation of the front-back flanking vowels. It is thus not surprising that this pattern is attested only for the labial-C1 clusters, since, based on perception, we do not expect to find evidence of word-initial reduction.

To summarize, the results in Table 3 are interpreted based on the following criteria:

i. C1 is interpreted as unreduced in P.C2 if either positive-then-zero (PZ: no overlap of Pk, *Fig.9*) or positive-then-negative (PN: overlap of P.C2, *Figs. 8a,b*) Po patterns were detected during the CC duration. C1 is interpreted as reduced in P.C2 (*Fig. 10*) if no change in Po (AZ) was detected.

ii. For Pt sequences, no conclusion is drawn regarding the degree of gestural overlap from an absence of negative pressure, assuming, according to Jun (1995), that rarefaction will not necessarily be detectable in overlapped, unreduced iP.tu sequences.

iii. C1 reduction is interpretable in C1.p only when C1.p was highly overlapped, and a non-zero Po was detected throughout the duration of C1.p. In such case, an all-positive (AP) Po pattern is interpreted as indicating gestural reduction in C1 (*Fig. 7*), while a negative-then-positive (NP) Po is interpreted as no reduction in C1 (*Fig. 12*); the latter pattern never arose in the oral C1.p clusters.

Summary of reduction in C1 and gestural overlap in CC

The numbers indicated in Tables 4a and 4b are derived from the results summarized in Table 3. The denominators in each cell indicate the total number of unambiguous repetitions from the experiment; the maximum number is 36 in each case (6 speakers x 6 repetitions for each token). The sum of the denominator (counted once for each token) and the number of inconclusive tokens should equal 36. In the tables below, I have shaded the boxes for which no unambiguous data may be obtained. The reasons for the choice of the shaded box(es) are as follows:

i. iP.tu, no overlap: Reliable evidence for the non-overlap of Pt is obtainable only when the labial is unreduced (since both an overlapped and unoverlapped [βt] sequence are expected to register zero pressure behind the lips). Assuming this to be the case, non-overlapped Pt should exhibit a positive-then-zero (PZ) Po trace. However, Jun (1995) suggested that the same Po trace may result from an overlapped Pt in the i-u environment, since it is not clear that the tongue-body retraction need necessarily result in the rarefaction of the air in the cavity sealed by the lips and the tongue blade[22], assuming that the tongue blade will not always retract in a front-back vowel environment. Although some instances of PN patterns have been obtained during iP.tu sequences, thereby providing unambiguous evidence of gestural overlap, in the absence of pharyngeal pressure data, I will assume that the PZ Po pattern during iP.tu has an ambiguous interpretation between non-overlap and overlap.

Table 4a: Word-final (C1) Reduction in CC

	iP.ku	iP.tu	iK.pu	iT.pu
reduction	9/36	8/36	36/36	36/36
no reduction	27/36	28/36	0/36	0/36
inconclusive	0	0	0	0

I infer from Table 4a that word-final reduction may occur for all places of articulation. Moreover, non-labials are more likely to reduce than labials. More

[22] That negative pressure was obtained at all for labial-t sequences (5 for iptu, 16 for imtu) suggests one of three possible mechanisms of cavity expansion (pressure rarefaction):

i. The tongue blade retracts along with the tongue body due to vowel co-articulation.
ii. The tongue blade does not retract, but the retraction of the tongue body "stretches" out the anterior part of the tongue, causes the curvature of the blade to go from a concave down configuration to a concave up configuration, thus expanding the cavity sealed by the tongue tip and the lips.
iii. The lips protrude in anticipation of the rounded vowel to follow (suggested by P. Keating).

The pressure rarefaction may reflect one of these articulatory possibilities, or any combination thereof.

specifically, in the present data corpus, labials reduce before [k, t] about 25% of the time, and non-labials reduce before [p] 100% of the time.

Table 4b: Gestural Overlap in CC

	iP.ku	iP.tu	iK.pu	iT.pu
overlap	15/27	5/5	36/36	36/36
no overlap	12/27		0/36	0/36
inconclusive	9	31	0	0

I infer from Table 4b that both labial-C1 and labial-C2 clusters may overlap. Moreover, I generalize that labial-C2 clusters are more likely to overlap than labial-C1 clusters. More precisely, the present corpus offers unambiguous evidence of no overlap in some tokens of iP.ku and unambiguous evidence of overlap in some tokens of iP.ku and iP.tu; all instances of iK.pu and iT.pu are interpreted to be (unambiguously) overlapping.

Conclusion

This portion of the experiment supports the hypothesis that C1 may reduce in CC. Keeping in mind that C2 is not constant in these test tokens, we can also generalize that either labials reduce less readily than velars and coronals, or that labials are more likely than velars and coronals to trigger reduction of the preceding C, or both. Put another way, this experiment has established that it is more likely for non-labials to reduce before labials than for labials to reduce before non-labials in Taiwanese (stop) consonant clusters. Note that the present oral pressure experiment is unable to show directly that Labials are less likely to reduce than Velars, since the design of the experiment cannot provide evidence of the tongue dorsum activity in a CC sequence where C1 is /k/ and C2 is /t/[23]. Also, the oral pressure experiment will only detect consonantal weakening if the extent of the weakening

23 Similarly, while electropalatography (EPG) will be able to shed light on the tongue dorsum activity in the sequence K.t, it cannot also provide comparable information on the labial activity in the sequence P.t. An EPG study, or a combination of EPG and Po study will thus still be unable to establish the relative likelihood of word-final /P/ reduction and /K/ reduction, since while EPG data may provide gradient evidence of articulatory reduction, Po data will only provide categorical evidence of (continuant-yielding) articulatory reduction.

results in the absence of stop closure. In this view, it is possible that the degree of lenition is the same at all places of articulation, but "more" lenition needs to obtain in labials than in non-labials for reduction to be reflected in Po data, since the Po data can only distinguish between presence and absence of closure.

In addition, at least with respect to word-final labials, the results of this experiment showed that while labial reduction *sometimes* occurs before a following (non-homorganic) stop, lenition *always* obtains before a following vowel.

This experiment also showed that in Taiwanese, gestural overlap in non-homorganic consonant sequences is more common in labial-final clusters than in labial-initial clusters.

To conclude, the results of this experiment support the prediction based on the attested place assimilation and Jun's (1995) conclusion that gestural reduction is responsible for the perceptual loss of the target place in casual speech place assimilation: Word-final stops may reduce before a following consonant. The hypothesis that non-word-initial lenition is a more general process, occurring before vowels and consonants alike, is supported.

Section 4.4.2 is a similar experiment which assesses word-final reduction in nasals. Similar conclusions regarding reduction and overlap are reached.

4.5.2 Word-final Nasal Stops

Part I: Intervocalic consonants

The Data

Figures 11a and *11b* provide representative Po traces of intervocalic word-initial and word-final /m/. All the tokens (6 repetitions per token x 6 speakers) examined displayed the same pattern.

In each figure, the top waveform corresponds to the audio signal, and the bottom is the Po trace. The vertical axis represents pressure, while the horizontal axis represents time. A phonemic transcription for the utterance is provided below the audio waveform; morpheme boundaries are indicated by a period ".". I have marked off the relevant segment (underlined in the transcription) in each waveform by the vertical lines labeled A and B. Point A corresponds to the acoustic onset of the consonant, and was located from an expanded waveform by marking the end of the vowel (complex waveform) duration. Point B corresponds to the release of the consonant, and was located from the waveform by marking the beginning of the following vowel (complex waveform).

Figure 11a contains two instances of Po rise during an intervocalic word-initial /m/; I have only marked off one instantiation below:

Figure 11a: Word-initial /m/ in a.ma

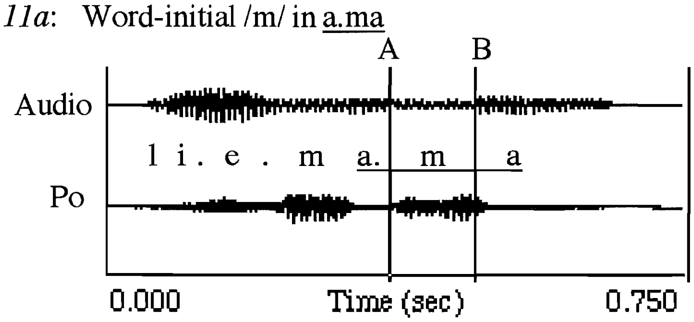
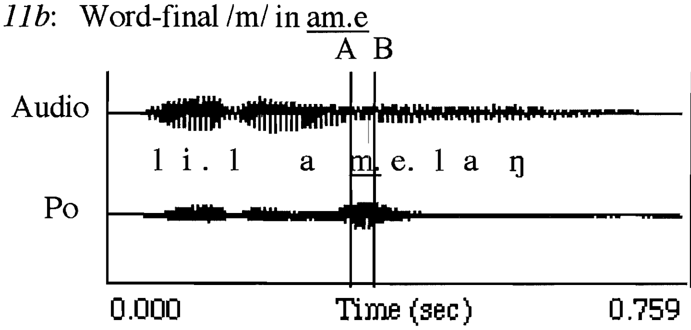


Figure 11b: Word-final /m/ in am.e



Figures 11a and *11b* are representative of the intervocalic word-initial and word-final /m/ examined. We observe from a comparison of *Figures 11a* and *11b* that no significant Po rise is observed in either word-initial or word-final intervocalic /m/, even

though labial reduction is expected only in the latter. An additional observation is that word-initial /m/ is significantly longer than word-final /m/; the same contrast in segment duration was found in the oral consonants.

Discussion

In contrast to the oral consonants, Po data is unable to distinguish the degree of oral constriction/reduction between intervocalic word-initial /m/ (*Figure 11a*) and word-final /m/ (*Figure 11b*); both showed no (or very slight) overall Po change, consistent across 6 speakers. Assuming the labial closure was complete in word-initial /m/ (as in word-initial /p/), the absence of positive Po during /m/ is likely due to a combination of the voicing configuration of the glottis (i.e., less air flowing into the vocal tract) and nasal leakage. I conclude that this lack of asymmetry between the Po data of word-initial versus word-final /m/ makes m.C2 clusters (or more generally, clusters containing a nasal coda) less appropriate for the current investigation. I have nonetheless included NC clusters in the data set since any instance of positive (or negative) Po during the nasal duration must necessarily be interpreted as indicating an unreduced labial closure, and, in the case of labial C2 clusters, temporal overlap of NC constrictions plus a reduction of N. In interpreting Po of CC clusters, *I will consider a non-zero Po as indication of unreduced labial closure, while an absence of Po change during the duration of /m/ is inconclusive evidence for labial reduction.*

Part II: Consonant clusters

Summary of attested Po patterns during CC

In addition to the notations AP, PN, PZ, and AZ, introduced in Section 4.5.1, the following notations are used in the qualitative categorization of the Po traces in this section:

NP: Negative-then-Positive; negative Po was detected, followed by positive Po.

ZP: Zero-then-Positive; zero Po was detected during the first half of the CC duration, followed by positive Po during the remaining CC duration.

ZN: Zero-then-Negative; zero Po was detected during the first half of the CC duration, followed by negative Po during the remaining CC duration.

Figures 12, *13*, and *14* instantiate these Po patterns. In each figure below, the top waveform is the audio, and the bottom is the oral pressure measured behind the lips. The vertical lines labeled A and B demarcate the duration of the consonant cluster CC, where either C1 or C2 is a labial consonant. Point A is determined from the expanded waveform as the point where the vowel [i] (complex waveform) ends. Point B corresponds to the onset of the vowel [u] (complex waveform). A phonemic transcription is provided below the audio waveform; the relevant consonant cluster is underlined, and the morpheme boundaries are indicated by a period ".".

Figure 12: NP (Negative-then-Positive)
/iŋ.pu/. The example is taken from Speaker f1.

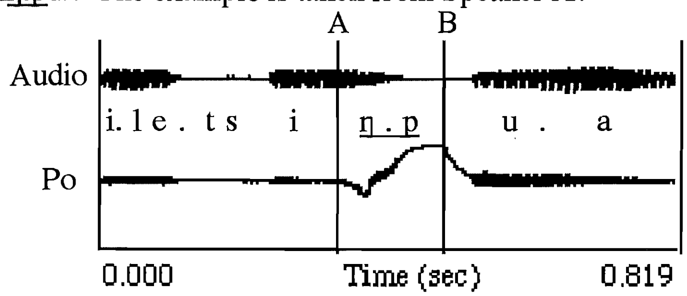


Figure 13: ZP (Zero-then-Positive)
/in.pu/. The example is taken from Speaker m2.

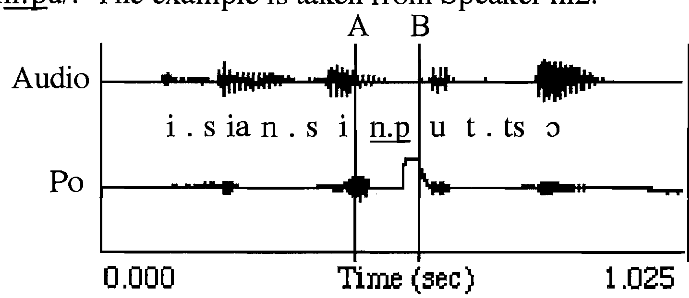
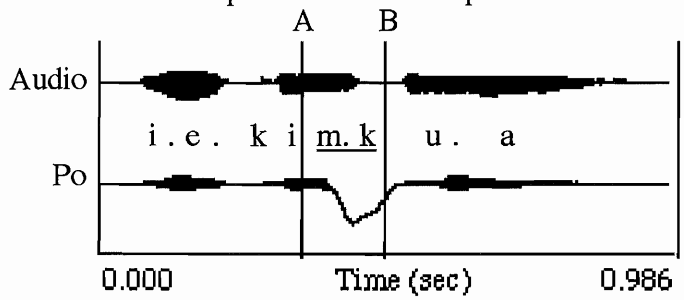


Figure 14: ZN (Zero-then-Negative)
/im.ku/. The example is taken from Speaker f2.



There are also instances of Po rise (AP, PN, PZ) during the word-final nasal. However, unlike the Po rise during oral consonants, the rise is more gradual during nasal consonants, a likely consequence of the reduced glottal flow and nasal leakage. An example of AP is provided in *Figure 15*. Notice that the peak in the Po trace is only reached in the latter part of the cluster duration, upon the offset of (nasal) voicing and the onset of the voiceless stop (cf., *Figure 7*: peak Po reached during the first half of K.p).

Figure 15: AP (All-Positive)
/iŋ.pu/. The example is taken from Speaker m1.

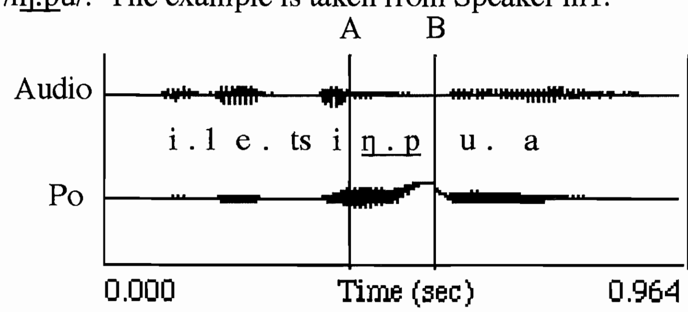


Table 5 summarizes the number of times (out of 36 repetitions) each pattern was attested during the consonant sequences (flanked by the vowels i-u) listed in the far left column. The patterns are indicated on the first row, not in any significant order. To facilitate the reading of this table, I have shaded the boxes for which zero results were obtained. Thus, the remaining unshaded boxes report only positive (non-zero) results.

Table 5. Summary of Results by Po Patterns

	AP	PN	NP	PZ	ZP	ZN	NC
im.ku		26		2		4	4
im.tu		16		10			10
iŋ.pu	30		5		1		
in.pu	31				5		

Appendix B presents the (same) results by speaker.

Interpretation of the Po data

The results in Table 5 were interpreted based on the following assumptions:

i. As discussed in Silverman and Jun (1994), a NP pattern indicates simultaneous closure by a non-labial C1 and a labial C2, i.e., there is gestural overlap and no reduction.

ii. A ZP pattern may indicate either labial closure during the second part of CC only, plus no significant gestural overlap, or labial closure during the entire duration of CC plus reduction of the non-labial (C1). Recall that we have concluded in Part I that a labial closure during nasal voicing will not necessarily result in a Po rise.

iii. A ZN pattern indicates simultaneous closure by a labial C1 and a non-labial C2, i.e., there is articulatory overlap plus no reduction; I consider this to be a subcase of PN. The ZN pattern further validates my conclusion from Part I that a zero change in Po during a nasal segment is *not* a reliable indication that the labial gesture is reduced, since the negative Po indicative of pressure rarefaction can only obtain in a sealed cavity.

iv. The patterns AP, PN, PZ, and AZ are interpreted in the same way as in Section 4.5.1.

To summarize, the results in Table 5 are interpreted based on the following criteria:

i. C1 is interpreted as unreduced in m.C2 if either positive-only (PZ: no overlap of mk) or positive-then-negative (PN: overlap of mC) Po were detected during the CC duration; the ZN cases are treated as an extreme subcase of PN. No conclusion is drawn regarding the status of labial reduction or gestural overlap from a zero change (AZ) in Po.

ii. For mt sequences, no conclusion is drawn regarding the degree of gestural overlap from an absence of negative pressure.

iv. C1 reduction is interpretable in C1.p only when C1.p was highly overlapped, and a non-zero Po was detected throughout the duration of C1.p. In such case, a positive-only (AP) Po pattern is interpreted as indicating gestural reduction in C1, while a negative-then-positive (NP) Po is interpreted as no reduction in C1.

v. C1 reduction is interpretable in Np only when Np was highly overlapped. In such case, a positive-only (AP) Po during CC is interpreted to mean gestural reduction in C1, while a negative-then-positive Po (NP) is interpreted to mean no reduction in C1. For Np sequences, initial zero change in Po (e.g., ZP) is considered an inconclusive indication of reduced C1 coupled by overlapping /p/, since this scenario cannot be distinguished from the non-overlapping CC scenario.

Summary of reduction in C1 and gestural overlap in CC

The numbers indicated in Tables 6a and 6b are derived from the results summarized in Table 5. Again, the total number of repetitions of each token is 36 (6 speakers x 6 repetitions per token); the denominators indicate the number of repetitions showing conclusive evidence of (non-)reduction/(non-)overlap. I have shaded the boxes for which no unambiguous data may be obtained. The reasons for the choice of the shaded boxes are as follows:

i. im.ku, im.tu, no reduction: The expected Po for reduced /m/ would be one in which there is no overall change in Po (AZ). However, we have concluded from Part I that such a Po trace is also obtainable from an unreduced [m].

ii. im.tu, no overlap: Reliable evidence for the non-overlap of labial-C is obtainable only when the labial is unreduced. Assuming this to be the case, non-overlapped labial-t should exhibit a positive-then-zero (PZ) Po trace. However, I have concluded in Section 4.4.1 that the same Po trace may result from an overlapped labial-t in the i-u environment.

iii. iŋ.pu, in.pu, no overlap: The expected Po trace for a non-overlapped nasal-p is zero-then-positive (ZP). However, the same trace may result from a highly overlapped Np with a reduced C1. Since the first portion of this sequence is produced with velic opening, and probably also voicing, a positive Po will not necessarily be detected.

Table 6a: Word-final Reduction in CC

	im.ku	im.tu	iŋ.pu	in.pu
reduction			30/35	31/31
no reduction	32/32	26/26	5/35	0/31
inconclusive	4	10	1	5

I infer from Table 6a that word-final labial nasals are less likely to reduce than non-labial nasals. Furthermore, non-labial nasals frequently reduce before [p].

Table 6b: Gestural Overlap in CC

	imku	imtu	iŋpu	inpu
overlap	30/32	16/16	35/35	31/31
no overlap	2/32			
inconclusive	4	20	1	5

I infer from Table 6b that word-final nasals frequently overlap with a following consonant. Furthermore, it is more likely for a non-labial C1 and a labial C2 to display gestural overlap than for a labial C1 and a non-labial C2 to show overlap.

Conclusion

This portion of the experiment supports the hypothesis that word-final nasals as well as oral stops may undergo reduction in the pre-consonantal position[24]. Furthermore, the observation from Section 4.5.1 that labial reduction is less frequent than non-labial reduction is corroborated by the NC sequences.

In addition, we have shown that the generalization that gestural overlap obtains in non-homorganic clusters, and that the overlap is more common in labial-C2 clusters than in labial-C1 clusters, also applies to NC sequences.

4.6 Conclusion

This experiment supports the hypothesis that Taiwanese pre-consonantal codas may be lenited in casual speech. Moreover, we have found that word-final reduction is optional before a consonant, and that pre-consonantal reduction is less frequent than pre-vocalic reduction.

Furthermore, results of this experiment suggest that (continuant-yielding) non-labial reduction is more common than labial reduction, and that overlap by a labial C2 is more common than overlap by a non-labial C2[25]. These generalizations have been shown to apply to both oral and nasal consonants occurring in the word-final position[26].

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[24] We might suspect that nasals lenite intervocalically as well, but that has no (significant) auditory or Po effect. One possible source of evidence may come from oral flow data, which this experiment did not collect.

[25] Although gestural overlap is not the focus of this investigation, we suspect that overlap by a labial C2 is more common than overlap by a non-labial C2 because labials are intrinsically longer than non-labials. Thus, the longer labial C2 is more likely to significantly overlap with C1 than a non-labial C2 would; similarly, the longer labial C1 is less likely to be completely overlapped by C2 than a non-labial C1 would.

[26] We suggest that the results of this experiment (that K, T reduction is more common than P reduction) are unlikely to be a word-frequency effect, i.e., the consonants found to reduce more readily are not necessarily the most frequently-used lexical items. Specifically, it is my impression that k^hiK 'carve' is *not* a frequent lexical item; nevertheless, reduction of its final K was always detected during the experiment.

Although the present experiment only provided data for labial + non-labial clusters, Electropalatography (EPG) studies on Taiwanese consonant clusters currently in progress by Shu-hui Peng indicate that word-final reduction also occurs in T.k and K.t clusters as well as in intervocalic T and K (Shu-hui Peng, p.c.).

Having established the occurrence of pre-consonantal reduction, we now return to the analysis of word-final lenition in Taiwanese.

5. Analysis of Consonant Reduction in Taiwanese

5.1 Observations

To recapitulate, this paper proposes to provide a unified account of the following observations about Taiwanese, within the framework of Optimality Theory (OT):

18 a. Word-final stops never have audible bursts, a fact which can be attributed to either overlap by a following consonant or to glottalization in the pre-pausal position.
b. Word-final stops at all places of articulation reduce intervocalically.
c. Word-final stops at all places of articulation may reduce pre-consonantally.
d. Word-initial stops never undergo lenition.
e. Lenition is detected more consistently in the intervocalic position than in the pre-consonantal position.
f. Lenition is not perceived pre-pausally.
g. Labial stops are less likely to reduce than non-labials.

In addition, there are two crucial differences between Korean (as discussed by Jun 1995) and Taiwanese we must explain in a unified account of reduction:

19 a. Taiwanese lenition occurs both intervocalically and pre-consonantally; Korean coda reduction is limited to the pre-consonantal position.
b. In Korean, labials and coronals reduce to the exclusion of velars. In Taiwanese, velars and coronals are more likely to reduce than labials.

5.2 Analysis

First, adopting Jun's (OT) reduction and preservation constraints introduced in Section 3.3, the Taiwanese facts in (18a-c) can be accounted for straightforwardly by the constraint ranking in (20):

20. **RED** >> Pres(pl(dor˺)) >> Pres(pl(lab˺)) >> Pres(pl(cor˺))

The constraint ranking in (20) indicates that unreleased stops (18a) at the velar, labial, and coronal places of articulation may undergo reduction (18b,c) since the preservation constraints for all three places are outranked by the reduction constraint RED. Moreover, since the constraint hierarchy does not restrict the environments where reduction may occur, we expect to find across-the-board reduction. This is indeed attested for word-final consonants in all phrase-/utterance-medial positions, both intervocalically and pre-consonantally. See the discussion of language L1 in Section 3.3.1.

Next, assuming a least-effort principle of speech production, languages will try to satisfy the reduction constraint RED whenever possible, that is, when there is no higher-ranked constraints which conflict with the output of RED. In Taiwanese, the presence of one such constraint is suggested by the failure of word-initial stops to undergo spirantization (18d):

21. Pres(F(w.i.)):
    All features associated to the word-initial position must be preserved, where <u>word</u> refers to monosyllabic free morphemes[27].

In addition to ensuring a faithful realization of the stricture features of word-initial consonants (stops and continuants alike), Pres(F(w.i.)) requires that place features and other manner features (e.g., [voice], [aspiration], [sibilant]) be preserved as well. Ranking Pres(F(w.i.)) above RED for Taiwanese will capture the observation that word-initial stops do not lenite:

22. <u>Pres(F(w.i.)) >> **RED**</u> >> Pres(pl(dor˺)) >> Pres(pl(lab˺)) >> Pres(pl(cor˺))

Focusing on the partial constraint hierarchy underscored in (22), the tableaux in (23a) and (23b) evaluate the relevant candidates illustrating the eventual outcome of word-initial /p/ versus non-word-initial /P/ in the intervocalic position; similar outcomes (word-

[27] Recall our assumption in Section 2.1 that all morphemes are monosyllabic in Taiwanese. Furthermore, only suffixes are bound morphemes. Thus, the current definition of <u>word</u> includes all monosyllabic morphemes except for affixes.

final lenition, word-initial preservation) are predicted for consonant clusters. In (23a,b), reduction is indicated by the lowering diacritic [˕]. We will assume that other constraints which prevent further reduction of the word-final consonant (or segmental deletion in general) are also active. For example, a general preservation constraint will ensure that some degree of labial constriction will be realized, thereby preventing deletion of the labial gesture[28] (i.e., VC.V -> *VØV).

23 a. Word-Initial /p/: No lenition.

/a.paʔ/ 'Dad'	Pres(F(w.i.))	RED
→ apaʔ		*
ap̞aʔ	!*	

b. Word-Final /P/: Lenition.

/aP.a/ 'box'	Pres(F(w.i.))	RED
aPa		!*
→ aP̞a		

In the tableaux in (23), the input is indicated in the top left cell, and the word-boundary is marked by a period. The relevant candidates are listed in the leftmost column, while the constraints are listed on the top row according to the hierarchical order in (22). Each asterisk "*" records one violation of the given constraint, and an exclamation point "!" precedes the asterisk which encodes the fatal violation. The arrow "→" has been placed next to the winning candidate form.

Returning our attention to the intervocalic labials in (23), consider first the word-initial /p/ in (23a): The second candidate satisfies RED, but commits one violation of Pres(F(w.i.)) in doing so, by failing to preserve the closure feature. In contrast, the winning candidate in (23a) with respect to the medial /p/ is the unreduced [p] in [a paʔ]. Although it commits one violation of RED by failing to spirantize, it does not commit the higher-ranked Pres(F(w.i.)), which its competing candidate violates.

[28] In Jun (1995), gestural deletion results from a different reduction constraint DELete.

(23b) evaluates the relevant candidates for word-final /P/. The first candidate in (23b) retains full closure, and violates the reduction constraint. The second candidate satisfies the reduction constraint by spirantization, and emerges as the winning candidate. The constraint Pres(F(w.i.)) is irrelevant here since /P/ is not word-initial.

Before continuing our discussion of the remaining observations in (18) and (19), we must address the issue of whether the descriptive statements about Taiwanese in (18b,c,d) are best analyzed as initial preservation plus final lenition (as suggested by (22)), or as initial fortition plus final non-fortition. The simplest kind of initial fortition analysis can be ruled out immediately: Fortition, if it applies generally to the word-initial position, would generate a word-initial consonant inventory consisting entirely of stops. However, as the Taiwanese consonant inventory in (2a) indicates, both stops and continuants (s, h) occur contrastively in the word-initial position. The variable contrastive continuancy in the word-initial position thus points against an analysis of initial fortition.

A more subtle argument in favor of word-initial preservation and final lenition is that such an analysis would predict more invariant articulations in the word-initial position, where an invariant output must be preserved, but more variable[29] articulation in the non-word-initial position, where the output is dependent on the extent of lenition. This is indeed attested: Word-initial stops (and s, h) are realized as such, while non-initial consonants have variable, non-contrastive realizations in terms of the stricture degree, ranging from non-continuants to continuants. The alternative analysis of word-initial fortition would predict more variable stricture realizations initially, depending on the extent of fortition; this is not attested. For example, word-initial /p/ is always realized as the stop

[29] By "variable articulation," I mean variations in the articulation which may lead to *potentially contrastive* percept. For example, the velar stop [k] and the velar fricative [x] are "variable articulations" in the present sense, since the difference in their stricture degree are sufficiently different in their acoustic consequences to be contrastive in some languages, e.g., Mandarin Chinese.

[p], and never as the fricative [ɸ]. Thus, we may conclude that the preservation hypothesis encoded in the constraint Pres(F(w.i.)) correctly predicts the non-spirantization of word-initial stops (as well as the continuancy preservation in /s/ and /h/). However, this is not to say that word-initial fortition may never occur. For example, it is plausible that word-initial stops are "strengthened" utterance-initially either by increasing the contact (closure) area between the articulators or by prolonging the closure duration, or both[30].

Having settled the appropriateness of the constraint Pres(F(w.i.)), we now return to the observations in (18) and (19). First, consider the Taiwanese-Korean asymmetry stated in (19a): While Taiwanese lenition occurs both intervocalically and pre-consonantally, Korean reduction is limited to pre-consonantal codas. (24) provides examples of Korean reduction (transcribed as place assimilation pre-consonantally) and non-reduction for word-final /p^h/ and /p/[31] (Sun-Ah Jun, p.c.):

24 a. Pre-consonantal stop: optional lenition

/ip^h	+ kwa/	->	[ipk'wa] ~ [ikk'wa]
'leaf'	*and'*		
/ip	+ kwa/	->	[ipk'wa] ~ [ikk'wa]
'mouth '	*and'*		

b. Pre-vocalic stop: no lenition

/ip^h	+ i/	->	[ip^hi]
'leaf'	*NOM*		
/ip	+ i/	->	[ibi]
'mouth '	*NOM*		

Preservation of pre-vocalic stops in Korean is predicted by the constraint in (25), ranked above RED by J. Jun, as shown in (26):

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[30] This has been shown for English by Fougeron and Keating (1995).

[31] In (24a), the aspirated /p^h/ is realized as an unreleased lenis stop due to a regular process of coda neutralization in Korean. In addition, the superscript ['] marks the preceding stop as fortis; this is the output of a regular process of post-obstruent fortition in Korean. In (24b), the gloss *NOM* stands for the Nominative Case marker.

25. Pres(mnr(-cont)): Preserve perceptual cues for noncontinuancy (p.158).

26. Partial ranking for Korean (Jun 1995: 173, adapted from his Ch. 4, (32)):
Pres(mnr(-cont)) >> RED

As stated, the constraint Pres(mnr(-cont)) requires preservation of the percept of stophood. Pre-consonantally, this constraint is satisfied in Korean during coda reduction by compensatory lengthening of the following stop closure. Although Jun (1995) did not discuss the consequence of the ranking in (26) for intervocalic stops, the hierarchy correctly predicts the non-occurrence of intervocalic lenition: Since there are no neighboring stops which may compensatorily lengthen in the intervocalic position, Pres(mnr(-cont)) would prevent reduction in this environment[32]. Consequently, the lower-ranked constraint RED is violated[33].

In contrast, Taiwanese appears to obey the reduction constraint both intervocalically and pre-consonantally[34], since non-word-initial stops may lenite in both environments. This suggests that the relative ranking of Pres(mnr(-cont)) and RED is reversed for Taiwanese, as shown in (27). The relative ranking between Pres(mnr(-cont)) and the Pres(pl) constraints is left undetermined for Taiwanese.

27. Pres(F(w.i.)) >> **<u>RED</u>** <u>>> Pres(mnr(-cont))</u>,
{Pres(pl(dor˺)) >> Pres(pl(lab˺)) >> Pres(pl(cor˺))}

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32 Another way of preserving the percept of stophood is by glottalization, in which case the question of whether the supralaryngeal closure is preserved is irrelevant. However, glottalization seems not to be an option in Korean in the implementation of Pres(mnr(-cont)).

33 In a way, both constraints RED and Pres(mnr(-cont)) are satisfied in the intervocalic position, since, both the intervocalic /pʰ/ and /p/ are shorter in duration compared to their non-intervocalic counterparts. It is this shortened duration that results in the voicing of the lenis /p/ in /ip̠ i/ 'mouth-NOM' in (24b) (Sun-Ah Jun, p.c.). However, Korean intervocalic reduction differs from Taiwanese intervocalic reduction in that only in the latter case does spirantization result.

34 In a cluster <u>C1C2</u>, where <u>C1</u> may be reduced, the preceding word is identified as a closed syllable by Taiwanese speakers; this might be interpreted as indication of compensatory lengthening. However, non-Taiwanese speakers tend to identify the "assimilated clusters" as singleton consonants, suggesting that the native Taiwanese speakers' intuitions of consonant clusters are based on cues other than the "cluster" duration. A likely candidate is tone, since closed syllables carry different tones from open syllables, and this difference is maintained irrespective of the occurrence of place assimilation, or more precisely, coda reduction.

(28) evaluates two hypothetical concatenated strings in Taiwanese and Korean. The lowering diacritic [̞] indicates reduction. As the tableaux in (28) illustrate, for both Taiwanese and Korean, intervocalic reduction satisfies RED but violates Pres(mnr(-cont)), while intervocalic stop preservation satisfies Pres(mnr(-cont)) but violates RED. The language-specific relative ranking of the two constraints yields intervocalic lenition in Taiwanese, but not in Korean.

28 a. Taiwanese intervocalic (word-final) stops: reduction possible

aP.a	RED	Pres(mnr(-cont))
aPa	!*	
→ aP̞a		*

b. Korean intervocalic stops: reduction impossible

/ap.a/	Pres(mnr(-cont))	RED
→ apa		*
ap̞a	!*	

An additional prediction of the partial Taiwanese ranking RED >> Pres(mnr(-cont)) is that in Taiwanese, place assimilation is not obligatory, i.e., in the cluster C1C2, C2 will not necessarily lengthen as C1 reduces. This is indeed attested: To the phonetically trained ear, repetitions of the string /tsaP k^{h}ɔ/ 'ten dollars' range from the unreduced [tsa^{ʔ}pk^{h}ɔ], to the reduced and assimilated [tsakk^{h}ɔ], to the reduced but unassimilated (and non-overlapping) [tsaβk^{h}ɔ], to the reduced and overlapping [tsak^{h}ɔ].

Next, consider the observation about Taiwanese in (18e): Why is lenition detected more consistently intervocalically than pre-consonantally? Before answering this question, note first that consonantal reduction has different perceptual consequences depending on the environment: Intervocalic reduction is perceived as lenition, but pre-consonantal reduction is often heard as place assimilation. Put another way, while reduction in the pre-consonantal position may result in the perceptual deletion of place cues, the place of articulation information is more easily salvageable intervocalically, even after reduction, because of the C-to-V transition and the absence of a dominant[35], overlapping C2 (to mask the word-final consonant's place cues). Thus, the perceptual cost (i.e., information loss) of reduction is greater pre-consonantally than intervocalically. Accordingly, reduction is less frequently observed in the former environment[36]. We might ask, then, that given the presence of the C-to-V transition, why does the intervocalic, word-final consonant not preserve the stophood, which will contribute an even more salient cue in the C-to-V transition, i.e., the stop burst? Recall, however, the dominating constraint RED requires the minimization of effort, and reduction must therefore apply.

In addition to perceptual considerations, the higher frequency of lenition in V-V when compared with lenition in V-CV may be due to increased vowel-consonant-vowel co-articulatory pressure in the former environment, which would predict more target undershoot for the word-final consonant in the intervocalic position.

Let us turn now to (18f): Lenition is not perceived pre-pausally in Taiwanese. There are two potential articulatory contributors to the percept of stophood: pre-pausal glottalization and supralaryngeal stop closure. While glottalization is consistently perceived, supralaryngeal reduction is harder to detect in the presence of glottalization. Nevertheless, differences in lenition has been observed across different environments, at least for word-final labials, in an examination of the author's videotaped speech, which showed labial reduction pre-vocalically and pre-consonantally, but not utterance-finally. Therefore, one reason lenition is not perceived pre-pausally is that the oral articulation is not reduced.

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35 By a dominant C2, I mean one that influences the (acoustic) place cues present in the V-to-C1 transition.

36 This need not be a counterexample to the Production Hypothesis, even though more effort seems to be incurred in the less salient environment: Since the crucial cues carried by the final consonants are place and nasality, and since both types of information will still be present intervocalically even with reduction, in all speech rates and styles, the effort-conserving option of intervocalic lenition is always preferred. In contrast, pre-consonantal reduction is more variable, depending on speech rate and style.

With respect to final glottalization, I assume a pre-pausal glottal fortition analysis: The word-final stops are strengthened (perceptually) by glottalization, which enhances the percept of stophood at a phrasal/utterance boundary. The constraint in (29) is proposed to account for pre-pausal glottalization:

29. Glott(C#): The pre-pausal consonant must be glottalized.

We suggest that Glott(C#) may be a way of marking the end of utterances, and word-boundaries in careful speech; it may thus be considered phrasal-edge strengthening. In addition, glottalization may serve to enhance the contrast between open (CV) and closed (CVC) syllables, since the constraint in (29) will only force glottalization in pre-pausal closed syllables, and not in open syllables. (Additional cues to the syllable types include tones and vowel length.)

I propose that the constraint Glott(C#) be ranked above RED, since the reduction constraint aims to conserve articulatory effort not only by reducing supralaryngeal constrictions, but by reducing the magnitude of all articulatory gestures, including the glottal adduction gesture. The proposed ranking is shown in (30):

30. Pres(F(w.i.)), Glott(C#) >> **RED** >>
Pres(mnr(-cont)), {Pres(pl(dor˺)) >> Pres(pl(lab˺)) >> Pres(pl(cor˺))}

In (30), the relative ranking between Pres(F(w.i.)) and Glott(C#) is left undetermined, since these two constraints will never interact, and will therefore never provide evidence showing their relative ranking.

Returning to the supralaryngeal gesture of pre-pausal stops, I suggest that the demand for effort conservation is not less in the pre-pausal position. In fact, EPG studies of Taiwanese consonants currently in progress by Shu-hui Peng reveal that utterance-final /T/ and /K/ are frequently reduced in fast speech[37] (Shu-hui Peng, p.c.). The constraint

[37] Although my videotaped speech showed non-lenition of utterance-final labials, the observation is based only on six repetitions of /liP/ 'to enter' and /laP/ 'to pay' of one speaker under experimental condition, which should hardly be claimed as a counterexample to utterance-final lenition. Moreover, I have already

ranking proposed thusfar would predict this behavior, since the constraint **RED** is not outranked by a constraint such as Pres(F(u.f.)) which demands the preservation of all features associated to the utterance-final, or pre-pausal position, including the stophood of the final consonant.

Finally, turning our attention to the observation that labial stops are less likely to reduce than non-labials in Taiwanese (18g), I would like to point out the Taiwanese-Korean asymmetry stated in (19b), repeated below:

> 19b. In Korean, labials and alveolars reduce to the exclusion of velars. In Taiwanese, velars and coronals are more likely to reduce than labials.

As discussed in Section 3.3, the pattern of reduction in Korean place assimilation (i.e., coronal and labial stops may reduce to the exclusion of velar stops) is one of the possible patterns of reduction predicted by Jun's acoustically-motivated universal preservation hierarchy in (17):

> 17. Pres(pl(dor˺)) >> Pres(pl(lab˺)) >> Pres(pl(cor˺))

Depending on the ranking of the reduction constraint RED, a language may reduce all unreleased gestures, only unreleased labials and coronals, only unreleased coronals, or nothing. All four patterns of reduction have been attested (See Section 3.3), and Korean is an instantiation of the second possibility. Thus, (17) would suggest that, based on acoustic considerations, coronals are more likely to reduce than labials, which are in turn more likely to reduce than velars. What (17) does *not* predict is that velars would be more likely to reduce than labials, as has been observed in Taiwanese.

Is the Taiwanese reduction pattern evidence against the claim that the acoustically-motivated ranking in (17) is universal? That is, would it be appropriate to account for Taiwanese simply by reranking the constraints in (17), such that Pres(pl(lab˺)) outranks

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suggested that word-final labials are the least likely candidates to undergo reduction, of the three places of articulation; this is a further caution in basing a non-lenition generalization on the behavior of labials.

Pres(pl(dor˺)) in Taiwanese? The proposed answer here is no, since the acoustic factors encoded in (17) are based on physical constraints of the human auditory system; we do not expect these constraints to vary (in a relevant way) from speaker to speaker, nor from language to language, unless the articulations are quite different across different languages. The Taiwanese reduction pattern (velars reduce more readily than labials) should therefore not be analyzed as a counterexample to the acoustically-motivated universal preservation hierarchy in (17).

If the universal status of the preservation hierarchy in (17) is valid, how then do we account for the seemingly contradictory velar-labial reduction frequency in Taiwanese? Recall the suggested ranking in (20) for Taiwanese:

20. **RED** >> Pres(pl(dor˺)) >> Pres(pl(lab˺)) >> Pres(pl(cor˺))

Ranking RED above the entire place preservation hierarchy correctly predicts that (non-initial) stops at all places of articulation may be reduced. The relative frequency of observed reduction in Taiwanese, then, must find explanation within the nature of the constraint RED. That is, why are some places more vulnerable to reduction than others?

Recall that the constraint RED is defined by Jun (1995) as a requirement for conservation of articulatory effort. In an unreduced VCV sequence, where C is a stop consonant, the vocal tract must alternate between an open configuration for the vowels and a closed configuration for the stop. One way of conserving articulatory effort is to reduce the open-closed-open trajectory by gestural reduction in the stop consonant. The result is that the consonant is now a continuant, and is produced with relatively more open vocal tract configurations. This is the case of word-final intervocalic reduction in Taiwanese.

There are three articulatory factors we will consider here in relation to reduction. First, regarding the stop-vowel asymmetry in the openness of the vocal tract, one major contributor is the jaw. It is clear from Keating, et al's (1994) cross-language study of jaw height that stops are articulated with a higher jaw position than vowels (p. 412, inferred from Table I). One might then hypothesize that a reduced stop will be articulated with a lower jaw position (more "vowel-like") than an unreduced stop; this is the hypothesis of Beckman et al. (1992). Interpreting phonemic approximants and stops as articulatory counterparts of (non-contrastive) reduced and unreduced stops in a leniting language, Keating, et al's data seem to support this hypothesis: They found that English coronal stops [t,d] are articulated with a higher jaw position than the coronal approximant [ɹ].[38] Moreover, the jaw position is the highest for coronal stops (t), the next highest for labial stops (p), and the lowest for velar stops (k). This means that in the absence of reduction, jaw displacement during VCV is the greatest in VtV, and the least in VkV.

During reduction, one way of conserving effort is to restrict the extent of jaw displacement during VCV; the constraint *RaiseJaw embodies this restriction:

31. *RaiseJaw: Do not exceed Xmm of intersegmental jaw displacement.

(31) says that for any two adjacent segments S1 and S2, the distance traveled by the jaw from S1 to S2 must not exceed a certain distance X. Depending on the degree of reduction, X may be smaller for more reduction or greater for less reduction. Generalizing across different vowel environments, implementation of *RaiseJaw is most likely to affect VtV, and the least likely to affect VkV, since an unreduced VtV sequence is more likely to violate the maximum displacement threshold X than an unreduced, intervocalic labial or velar stop. A *RaiseJaw-driven reduction (abbreviated as "red*$_{RJ}$")would then result in the reduction pattern in (32), where the symbol ">" denotes "is more likely than":

32. red*$_{RJ}$(cor) > red*$_{RJ}$(lab) > red*$_{RJ}$(dor)

Note that (32) is *not* a constraint hierarchy, but simply a descriptive statement predicted by the constraint *RaiseJaw. (32) indicates that *RaiseJaw is most likely to result in reduction in coronals, then in labials, and finally in velars. The coronal-non-coronal asymmetry in

[38] Similarly, Swedish coronal stops [t,d] have higher jaw positions than the apical trill [r].

(32) is attested in English, in which coronal stops in weak positions undergo flapping[39], but non-coronals never do. However, (32) does not make the correct predictions for Taiwanese: It is true that word-final coronals are more likely to undergo lenition than labials. However, the extent of perceived reduction is less in coronals than in velars, since intervocalic coronal finals are perceived as flaps while velars in the same environment are perceived as approximants. Moreover, (32) predicts that labials should reduce more readily than velars; the opposite is observed for Taiwanese. We conclude, then, that while the constraint *RaiseJaw and the resulting reduction hierarchy in (32) may be active in Taiwanese, it is not the only active constraint underlying Taiwanese reduction. We now turn to a second articulatory component in reduction.

First, we assume that for every speech rate and style, there is an articulator-specific "comfortable" velocity X during articulator displacement, and that acceleration beyond this velocity X is disfavored[40]. This proposal is captured by the *Accel constraint in (33):

33. *Accel: Do not increase gestural stiffness beyond some articulator-specific peak velocity X for the given speech style.

In (33), stiffness refers to the ratio of the articulator's peak velocity to its peak displacement; "less stiffness results in slower movement towards the target" (Hawkins, 1992: 16).

Next, we assume that during vowel-consonant-vowel co-articulation, the demand for articulator acceleration is increased, since lack of acceleration may result in target undershoot. We propose that in Taiwanese, *Accel outranks the entire Pres(pl) hierarchy

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[39] I speculate that flaps are produced with a lower jaw position than alveolar stops. Furthermore, the low position of the jaw is one contributing factor to the flap's short duration, since, more effort would be required in tongue tip raising (from a low jaw position) to maintain "long" closure during a flap.

[40] Implicit in the *RaiseJaw constraint is also the avoidance of jaw movement acceleration. *RaiseJaw is thus a particular instantiation of *Accel.

in word-final positions, where lenition is attested, and that the ranking is reversed[41] in word-initial positions, where stop preservation is attested.

What is the pattern of propensity to stop reduction predicted by *Accel? Recall our assumption that acceleration may be needed to avoid target undershoot to the extent that the neighboring gestures involve the same articulators (but potentially spatially-opposing targets). Therefore, the articulator that is shared in both vowel and stop formation, e.g., the tongue dorsum, will be the most likely to result in target undershoot due to *Accel, since the required configurations for the neighboring vowels prevent a possible (temporally-)lengthened, but unaccelerated trajectory of the shared articulator for the consonant. In this view, then, the reduction pattern in (34) is predicted by *Accel:

34. $\text{red}_{*\text{Accel}}(\text{dor}) > \text{red}_{*\text{Accel}}(\text{cor}) > \text{red}_{*\text{Accel}}(\text{lab})$

As is the case in (32), (34) is *not* a constraint hierarchy. (34) indicates that *Accel-driven reduction is the most likely to result in velar lenition. This is so since the tongue dorsum is the primary active articulator in vowel production. The next likely candidate of reduction is the tongue tip, since the tongue tip is still somewhat dependent on the tongue body (crucial for vowels) in articulation. (Recall our observation during the Po experiment that front-back vowel co-articulation may result in retraction of the medial [t], a testimony to the dependence between coronal consonantal articulation and dorsal vowel articulation.) Finally, the lips are the most independent from the primary "vowel articulator," since they are not connected in any direct sense. We would then predict least *Accel-driven reduction in the labial consonants. (34) nicely captures the labial-non-labial asymmetry in Taiwanese (18g). Furthermore, it predicts more velar reduction than coronal reduction, also assumed to be the case for Taiwanese. The constraint *Accel may thus be considered an active, if not dominating, reduction constraint for Taiwanese.

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[41] The "reversal" of the relative ranking between *Accel and Pres in the word-initial position is encoded in the ranking Pres(F(w.i.)) >> *Accel. Note that the relative ranking between *Accel and Pres(pl) actually remains the same in both word-initial and word-final positions.

Finally, an additional, perhaps language-specific, factor which may contribute to the less likely reduction of Taiwanese labials is the extent of upper lip involvement in my production of Taiwanese and English /p/[42]. During a videotaped segment of my own speech, variable upper-lip lowering has been observed during Taiwanese /p/. The upper-lip lowering seems to be optional, since its occurrence cannot be generalized to, nor predicted by, the prosodic environment. In contrast, no upper lip lowering was observed during my production of the English [p]. This suggests that in Taiwanese, there is an additional potential active articulator in the production of labials. Both velars and coronals involve the raising of two active articulators (jaw plus tongue dorsum or tongue tip) toward a passive articulator, the roof of the mouth. In contrast, labials may behave either as having two active articulators (jaw plus lower lip) in the absence of upper lip lowering, or as having three compensating active articulators (jaw, lower lip, plus upper lip) when upper lip lowering occurs. Given the same amount of raising activity, the gesture which consists of an additional compensating, lowering activity by the target will be most likely to achieve closure, since less raising will be required by the other active articulators. Thus, we have observed during the oral pressure experiment that pre-consonantal labials alternate between reduced and unreduced articulations while pre-consonantal non-labials almost always reduce.

In sum, we have considered three possible articulatory factors in (effort-conserving) reduction for Taiwanese. These factors no doubt interact with each other. For instance, less jaw raising in the coronals would require more (compensation in the form of "extra") tongue tip raising if stop closure is to be achieved. Since we do not have experimental data to assess the relative significance of the proposed articulatory constraints, we will simply hypothesize a *descriptive* constraint hierarchy based on the observation in Taiwanese, i.e., the constraint hierarchy in (35):

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42 The author is a native speaker of Taiwanese, and a near-native speaker of American English.

35. RED(dor) >> RED(cor) >> RED(lab)

The ranking in (35) is tentatively assumed to be the result of language-specific articulatory interactions in Taiwanese (i.e., the net effect of *RaiseJaw, *Accel, and possibly a constraint which requires upper lip compensation during the articulation of labial consonants). (35) predicts that velars will be the most likely candidate of reduction, followed by coronals, followed by labials.

The entire range of the reduction hierarchy in (35) is ranked above the Pres(pl) hierarchy for Taiwanese, as shown in (36)[43]:

36. Glott(C#), Pres(F(w.i.)) >>
RED(dor) >> RED(cor) >> RED(lab) >>
{Pres(pl(dor˺)) >> Pres(pl(lab˺)) >> Pres(pl(cor˺))}, Pres(mnr(-cont))

Since the reduction hierarchy outranks the entire preservation hierarchy, the propensity to reduction will be determined by the reduction hierarchy, crucially, when the reduction pattern predicted by the two hierarchies are in conflict. A possibly language-specific reduction hierarchy can also be assumed for Korean. However, the outranking Pres(pl(dor˺)) constraint may conflict with, and thus, dominate the determination of the reduction pattern.

Thus, two major types of reduction are exemplified by Taiwanese and Korean. In Korean-type reduction, the reduction pattern is restricted to a proper subset of the places of articulation, since only for a subset of places is the relevant preservation constraint outranked by the reduction constraint. In contrast, in Taiwanese-type reduction, lenition is not restricted to particular places of articulation, since for every place of articulation, the reduction constraint outranks the corresponding preservation constraint. Of course, both types of reduction are the consequence of a compromise between articulatory and perceptual demands. They differ simply in the ways the compromises are reached.

[43] A more explanatory, but less descriptively explicit, account would substitute the reduction hierarchy in (36) by the (unranked?) constraints *RaiseJaw and *Accel.

5.3 Summary

The constraint hierarchy in (36) has been proposed to account for the observations about Taiwanese summarized in Section 5.1, restated below:

36. Glott(C#), Pres(F(w.i.)) >>
    RED(dor) >> RED(cor) >> RED(lab) >>
    {Pres(pl(dor˺)) >> Pres(pl(lab˺)) >> Pres(pl(cor˺))}, Pres(mnr(-cont))

18 a. Word-final stops never have audible bursts, a fact which can be attributed to either overlap by a following consonant or to glottalization in the pre-pausal position.
b. Word-final stops at all places of articulation reduce intervocalically.
c. Word-final stops at all places of articulation may reduce pre-consonantally.
d. Word-initial stops never undergo lenition.
e. Lenition is detected more consistently in the intervocalic position than in the pre-consonantal position.
f. Lenition is not perceived pre-pausally.
g. Labial stops are less likely to reduce than non-labials.

To recapitulate, (non-utterance-final) reduction of word final (unreleased) stops (18a,b,c) is accounted for by the partial ranking RED(dor) >> RED(cor) >> RED(lab) >> Pres(pl(dor˺)) >> Pres(pl(lab˺)) >> Pres(pl(cor˺)). The non-lenition of word-initial stops (18d) is predicted by the ranking Pres(F(w.i.)) >> RED(dor) >> RED(cor) >> RED(lab). The observation that lenition is more prevalent intervocalically than pre-consonantally (18e) is argued to be due to the relative ease of contrast preservation in the two environments when gestural reduction occurs; the presence of the C-to-V transition in V-V, and its absence in V-CV, translate into a "smaller cost," in terms of place-of-articulation information loss, of reduction in the former. Next, the "non-lenition" of pre-pausal stops (18f) is the consequence of the partial hierarchy Glott(C#) >> RED(dor) >> RED(cor) >> RED(lab); glottalization ensures the percept of stophood even in the presence of supralaryngeal reduction (predicted by the partial hierarchy RED(dor) >> RED(cor) >> RED(lab) >> Pres(pl(dor˺)) >> Pres(pl(lab˺)) >> Pres(pl(cor˺)).). The higher tendency of non-labial reduction (18g) is captured by the descriptive hierarchy RED(dor) >> RED(cor)

>> RED(lab), posited based on the observations about Taiwanese, and hypothesized to be the net effect of *RaiseJaw and *Accel.

5.4 Conclusion

In this section, we have provided a phonetically-based analysis of reduction in Taiwanese. Adopting the framework of the Optimality Theory, the reduction and non-reduction patterns in Taiwanese are shown to be the result of a particular reconciliation of the potentially conflicting goals of ease of articulation and ease of perception, embodied in the constraints proposed here. More specifically, we have argued that consonant reduction is a general effort-conserving phenomenon in Taiwanese, prohibited only in the word-initial position where preservation of informative acoustic cues via the medium of unreduced gestures is crucial to lexical access. After all, we speak to be heard to be understood, but efficiently so!

Appendix A: List of Taiwanese Phrases for the Oral Pressure Experiment (Section 4)

In the English glosses below, '*POSS*' stands for a Possesive marker, '*Cl.*' stands for Classifier, '*REL*' stands for Relativizer, '*DIM*' stands for Diminutive suffix and '*FAM*' stands for Familiar suffix.

1. li e papa — 'your dad'
   you POSS dad
2. li e mama — 'your mom'
   you POSS mom
3. gɔ tsaP e laŋ — 'fifty people'
   five ten Cl. people
4. li lam e laŋ — 'the people you are embracing'
   you hug REL people
5. i le tɕiP ku a — 'he is collecting beetles'
   he at collect beetle DIM
6. i e kim ku a — 'his beetles'
   he POSS gold beetle DIM
7. i le tɕiP tu a — 'he is collecting cabinets'
   he at collect cabinet FAM
8. i e kim tu a — 'his golden cabinet'
   he POSS gold cabinet FAM
9. i le kʰiK pu a — 'he is sculpting gourds'
   he at carve gourd DIM
10. i le tɕiŋ pu a — 'he is growing gourds'
    he at grow gourd DIM
11. i le tɕʰiT pu a — 'he is wiping the gourd'
    he at wipe gourd DIM
12. i ɕiaŋɕin puttsɔ[44] — 'he believes in Buddha'
    he believe Buddha

[44] In the dialects of Speakers f2, m3, and m4, the word for 'Buddha' is pronounced [huttsɔ], with an initial [h] rather than [p]. These speakers produced the initial [p] as shown in (12) only upon my request.

Appendix B: Summary of Po Results by Speaker

Each table below shows the resulting Po trace for CC for one speaker using the notations described in Section 4.4. The sequences analyzed are shown in the left-most column; the top row indicates the repetition (or the medial six) under consideration. The speaker identity is listed on the top left corner: m1 for Male Speaker 1, f1 for Female Speaker 1, etc.

m1	R1	R2	R3	R4	R5	R6
iPku	PN	PN	PN	PN	PN	PN
imku	PN	PN	PN	PZ	PN	PN
iPtu	PZ	PZ	PZ	PZ	PZ	PN
imtu	PZ	PN	PN	PZ	PZ	PZ
iKpu	AP	AP	AP	AP	AP	AP
iŋpu	AP	AP	AP	AP	AP	AP
iTpu	AP	AP	AP	AP	AP	AP
inpu	AP	AP	AP	AP	AP	AP

m2	R1	R2	R3	R4	R5	R6
iPku	PZ	PZ	PZ	PZ	PN	PZ
imku	PN	PN	PN	PN	PN	AZ
iPtu	PZ	PZ	PZ	PZ	PZ	PZ
imtu	AZ	AZ	AZ	AZ	AZ	AZ
iKpu	AP*	AP	AP*	AP	AP	AP
iŋpu	AP	AP	AP	AP	AP	AP
iTpu	AP	AP	AP	AP	AP	AP
inpu	AP	ZP	ZP	ZP	ZP	ZP

* Two tokens of iKpu showed positive Po throughout the Kp duration, with a brief return to zero Po during the middle of Kp. I have analyzed these two tokens as instantiations of AP, interpreting the medial zero *not* to be an interruption during two distinct, sequenced [p]s, but as the result of the pressure tube opening coming in contact with, and thus blocked by the teeth, resulting in zero pressure. This interpretation is plausible because Speaker m2 expressed concern earlier during the recording session about the tube coming into contact with his teeth. Furthermore, similar pressure traces during an intervocalic [p] resulted for the same speaker from an independent token not recorded for the purpose of this experiment, where we have no reason to posit two distinct [p] gestures. (See Appendix C)

m3	R1	R2	R3	R4	R5	R6
iPku	PN	PZ	PZ	PN	AZ	PN
imku	PN	PN	PN	PN	PN	PN
iPtu	AZ	PZ	PZ	PZ	PZ	PZ
imtu	PN	PN	PN	PN	PN	PN
iKpu	AP	AP	AP	AP	AP	AP
iŋpu	AP	AP	AP	AP	AP	AP
iTpu	AP	AP	AP	AP	AP	AP
inpu	AP	AP	AP	AP	AP	AP

m4	R1	R2	R3	R4	R5	R6
iPku	PZ	PZ	PZ	PZ	PZ	AZ
imku	PZ	PN	PN	PN	AZ	AZ
iPtu	PN	PZ	PZ	PZ	PZ	PZ
imtu	PN	PN	PN	PZ	AZ	PZ
iKpu	AP	AP	AP	AP	AP	AP
iŋpu	AP	AP	ZP	AP	AP	AP
iTpu	AP	AP	AP	AP	AP	AP
inpu	AP	AP	AP	AP	AP	AP

f1	R1	R2	R3	R4	R5	R6
iPku	PN	PN	PN	PN	PN	AZ
imku	PN	PN	PN	PN	PN	PN
iPtu	PN	PN	PZ	PN	PZ	AZ
imtu	PN	PZ	PN	PN	PN	PN
iKpu	AP	AP	AP	AP	AP	AP
iŋpu	NP	AP	NP	NP	NP	NP
iTpu	AP	AP	AP	AP	AP	AP
inpu	AP	AP	AP	AP	AP	AP

f2	R1	R2	R3	R4	R5	R6
iPku	AZ	AZ	AZ	AZ	AZ	AZ
imku	ZN	AZ	ZN	PN	ZN	ZN
iPtu	AZ	AZ	AZ	AZ	AZ	AZ
imtu	PZ	PZ	PZ	AZ	AZ	AZ
iKpu	AP	AP	AP	AP	AP	AP
iŋpu	AP	AP	AP	AP	AP	AP
iTpu	AP	AP	AP	AP	AP	AP
inpu	AP	AP	AP	AP	AP	AP

Appendix C: Examples of the Medial-Zero Po Pattern by Speaker m2

Figure C1: Example of Speaker m2's production of <u>iKpu</u> showing a medial zero in Po during the /Kp/ duration. The top waveform is the audio; the bottom is the Po trace. The vertical axis measures pressure while the horizontal axis measures the time. I have categorized the Po pattern between points A and B as an instantiation of AP, interpreting the medial zero to be the result of pressure tube blockage by the teeth.

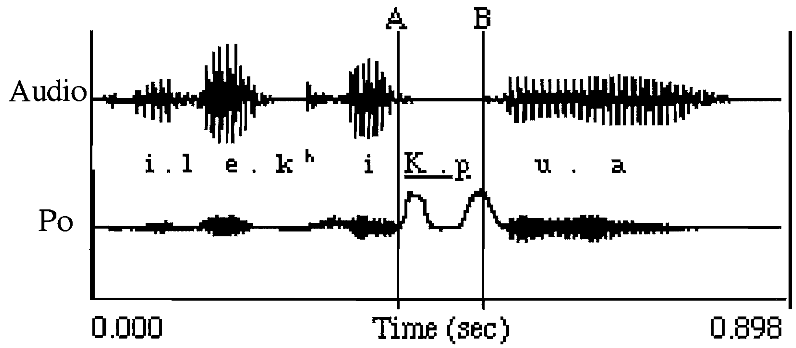
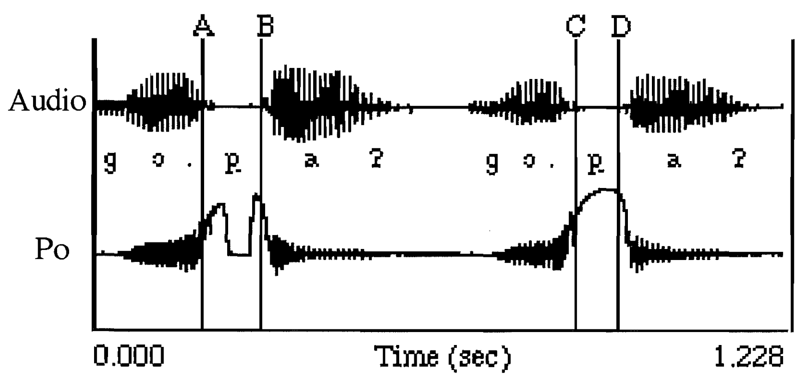


Figure C2: Two examples of intervocalic, initial [p] by the same speaker for the utterance [gɔ paʔ] 'five hundred'. The example on the left shows the same pattern as in *Figure C1*: positive pressure during the C(C) duration with a medial zero (the interval between A and B). The example on the right shows no medial zero (the interval between C and D): There was no pressure tube blockage during the production of this token.



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