THE PERCEPTUAL BASIS OF LONG-DISTANCE LARYNGEAL RESTRICTIONS

by

Gillian Elizabeth Scott Gallagher

B.A., Linguistics, University of Massachusetts, Amherst 2005

Submitted to the Department of Linguistics and Philosophy
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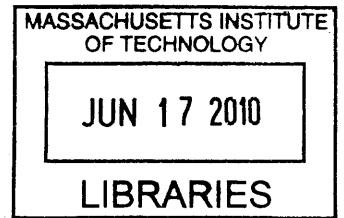**Doctor of Philosophy in Linguistics**

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ABSTRACT

The two main arguments in this dissertation are 1. That laryngeal cooccurrence restrictions are restrictions on the perceptual strength of contrasts *between* roots, as opposed to restrictions on laryngeal configurations in isolated roots, and 2. That laryngeal cooccurrence restrictions are restrictions on auditory, as opposed to articulatory, features.

Both long-distance laryngeal dissimilation, where roots may have one but not two laryngeally marked stops (MacEachern 1999), and assimilation, where stops in a root must agree in laryngeal features (Hansson 2001; Rose and Walker 2004) are given a unified account based on a grammatical pressure to neutralize indistinct contrasts. This analysis is supported by the finding that certain non-adjacent sounds interact in perception. Specifically, the perception of a contrast in ejection or aspiration is degraded in roots with another ejective or aspirate as compared to another plain stop (e.g. the pair *k'ap'i-kap'i* is more confusable than the pair *k'api-kapi*). Roots that are minimally distinguished by having one vs. two laryngeally marked stops are confusable (e.g. *k'ap'i* is confusable with *kap'i*), and thus languages may avoid having both types of roots. The analysis integrates long-distance neutralizations with analyses of local neutralizations based on phonetic cues and contrast strength (Flemming 1995, 2004; Steriade 1997), showing that both local and non-local phenomena are driven by constraints against perceptually indistinct contrasts.

The interaction between ejectives and aspirates in Quechua provides evidence for auditory features. These two articulatorily disparate sounds pattern together in the cooccurrence restrictions of Quechua, showing that some feature must pick them out as a class. It is argued that ejectives and aspirates may pattern together because they share long voice onset time. It is shown that defining laryngeally marked stops based on their language specific auditory properties correctly accounts both for ejective-aspirate interactions in Quechua and also for the interaction between ejectives and implosives in Hausa and Tz'utujil.

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The perceptual basis of long-distance laryngeal restrictions

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Gillian Gallagher

For Eleanor.

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CONTENTS

Chapter 1   Introduction

This dissertation pursues a novel approach to the analysis of long-distance phonological interactions, based on the empirical finding that certain non-adjacent sounds interact with one another in perception. The analysis integrates non-local phonological neutralizations with analyses of local neutralizations based on phonetic cues and contrast strength (Flemming 1995, 2004, 2006; Steriade 1997). The central idea is that both local and non-local phonological phenomena are driven by grammatical constraints against perceptually indistinct contrasts. In local contexts, a certain contrast may be absent when the phonetic cues to that contrast are unavailable, e.g. place contrasts in stops may be neutralized in environments where stops are unreleased (Jun 1995, 2004). I show that long-distance restrictions on laryngeal features have a similar explanation. The perceptual strength of a laryngeal contrast is sensitive to the non-local context, and laryngeal contrasts are neutralized where they are weakened by the non-local environment.

1.1   Overview of the analysis

The very basic outline of the phenomenon and analysis is as follows. Long-distance laryngeal restrictions can be seen as contextual contrast neutralization. Consider the data in (1) from Chol (Mayan) (Aulie and Aulie 1978). In this language, an ejective may appear in either initial or final position of a CVC root with another non-ejective consonant, but roots with pairs of distinct ejectives are unattested.

(1) Chol – cooccurrence restriction on ejectives
    a. **p'it^j**   'to tie a load'   b. **kats'**   'smooth'   c. ***k'ats'**
       k'ah   'gadfly'   **mop'**   'to grab'   ***p'it^j'**

The pattern shown by the data in (1) is neutralization of the contrast between an ejective and a voiceless unaspirated stop in the context of another, non-adjacent ejective stop in the root. The restriction is stated in these terms in (2). A contrast between two sounds is represented as an unordered set {X, Y}; K' stands for any ejective and K for any voiceless unaspirated stop or affricate. The notation [...K...]$_{RT}$ represents a position anywhere in a root with another ejective.

(2) *{K', K} / [...K'...]$_{RT}$

Given the conceptualization of the restriction in (2), a contrast between an ejective and a plain stop is grammatical in a root with another non-ejective consonant, but not in a root with another ejective. Roots with two ejectives, like hypothetical [k'ap'], are unattested in Chol because they may not contrast with roots like [k'ap] or [kap']. Contrasts involving roots with one ejective, like [k'ap], however, are attested because they may contrast with a root like [kap]. A language like Chol allows a contrast between roots with one ejective and roots with zero ejectives, as schematized in (3a), but does not allow a contrast between roots with two ejectives and roots with one ejective, as in (3b). The notation K-T stands for any pair of stops and/or affricates.

(3) a. ✓ {K'-T, K-T}   e.g. [k'at] may contrast with [kat]
     b. *{K'-T', K'-T}   e.g. [k'at'] may not contrast with [k'at]

In these terms, a cooccurrence restriction against roots with two ejectives is seen as positional neutralization of a laryngeal contrast in a particular non-local environment. Crucially, laryngeal contrasts are more difficult to perceive in the environment of neutralization. A series of perception experiments finds that English speaking subjects have more difficulty distinguishing roots that contrast one and two (1 vs. 2) laryngeally marked stops (e.g. *k'ap'i-k'api*) than roots that contrast one and zero (1 vs. 0) laryngeally marked stops (e.g. *kap'i-kapi*). The restriction in Chol thus reflects a prohibition against a perceptually difficult contrast. Forms like [k'ap'] may not contrast with forms like [k'ap] and [kap'] because these two types of forms are too similar perceptually. This is the main claim of the analysis. Restrictions like that in Chol are driven by a grammatical constraint against the contrast between one and two laryngeally marked stops, a contrast that is penalized because it is perceptually weaker than the contrast between one and zero laryngeally marked stops. The hierarchy of perceptual strength in (4a), where "<" means "less distinct than", projects a fixed hierarchy of constraints as in (4b).

(4) a. Perceptual strength hierarchy
　　　　{K'-T', K'-T}　　<　　{K-T', K-T}

　　b. Constraint hierarchy
　　　　*{K'-T', K'-T}　>>　*{K-T', K-T}

Long-distance laryngeal restrictions like that in Chol are analyzed as the effect of contrast markedness constraints that favor neutralization of perceptually indistinct contrasts. The analysis is cast in the Dispersion Theory of Contrast (henceforth DT) (Flemming 1995, 2004, 2006), and follows much previous work integrating the systemic evaluation of contrasts into phonological theory including Contrast Preservation Theory (Lubowicz 2003) and other work in DT (Padgett 2003; Sanders 2003; Ni Chiosain and Padgett 2007).

1.2　Connections to previous work

Under the proposed account, long-distance restrictions are phonetically grounded in perceptual asymmetries, as has been proposed for many local phonological neutralizations (Steriade 1997; Flemming 2004). While local neutralizations are often shown to correlate with the availability of acoustic cues, the experimental findings in this dissertation show that perceptual asymmetries may also arise in the absence of acoustic ambiguity (ie. when all the cues to a contrast are available). Both local and long-distance phonological restrictions reflect conditions on contrast strength, though perceptual asymmetries in contrast strength cannot always be reduced to the availability of locally identifiable cues.

　　The correlation between cue availability and contrast strength has been an integral part of phonological analyses based on contrast markedness. Consider local laryngeal neutralization as an example. In Ancient Greek, voiceless aspirated and unaspirated stops contrast in pre-sonorant position (5a), but only voiceless unaspirated stops are found in pre-obstruent position (5b) (Steriade 1997).

(5) a. deik-nu:-mi　'I show'　　　　　b. deik-teos　'to be shown'
　　　　ek^h-o　　　'I have'　　　　　　　hek-teos　'to be had'

In (5), the root *deik* is invariant, while the laryngeal features of the final stop in *ek^h* vary depending on context. This root appears with an aspirated stop when followed by a vowel in (5a), but as a voiceless unaspirated stop when followed by an obstruent (5b).

The insight of Steriade's analysis of Ancient Greek (and many other languages that show similar patterns) is that the environment for aspiration neutralization correlates with the availability of acoustic cues to aspiration. The difference between voiceless aspirated and unaspirated consonants is primarily one of Voice Onset Time (VOT); the time between the release of the closure and the onset of voicing is long in an aspirated stop and short in an unaspirated stop. This cue is available only in pre-sonorant position. Before an obstruent or in final position, there is no onset of voicing following the stop and thus no VOT. The neutralization pattern for aspiration contrasts mirrors the distribution of phonetic cues to this contrast. Aspiration contrasts are more perceptible in pre-sonorant position than in pre-obstruent of final position, as shown schematically in (6a). This hierarchy projects a fixed ranking of context sensitive markedness constraints in (6b), which favor neutralization of the aspiration contrast where it is less perceptible.

(6)   a. Perceptual strength hierarchy
        $\{K^h, K\}$ / ___$\{[\text{-son}], \#\}$ < $\{K^h, K\}$ / ___ $[\text{+son}]$

        b. Constraint hierarchy
        *$\{K^h, K\}$ / ___$\{[\text{-son}], \#\}$ >>   *$\{K^h, K\}$ / ___ $[\text{+son}]$

The analysis of local laryngeal neutralization outlined above makes crucial reference to phonetic cues. Contrasts in aspiration are dependent on VOT cues, and are prone to neutralization when these cues are absent. In long-distance laryngeal restrictions, however, local acoustic cues are not at issue. In Chol, for example, both ejectives and plain stop appear in pre-sonorant, pre-obstruent and final position. The inability of two ejectives to cooccur in a root cannot be reduced to their local context, as the presence of one ejective in a root does not alter the acoustic cues to another ejective elsewhere in the root, a point that will be shown in more detail in Chapters 3 and 4.

Long-distance laryngeal neutralization initially seems like a very different phenomenon from local neutralization, since the cues to a laryngeal contrast are unaffected by the non-local environment. The series of perception experiments in Chapter 4 show that perceptual asymmetries exist independent of acoustic ambiguity and the presence of cues. The 1 vs. 2 contrast in laryngeal features is more difficult than the 1 vs. 0 contrast, despite the fact that the difference between forms in these two contrast pairs is identical. A pair of roots like {k'ap'i, k'api} is more difficult to distinguish than a pair like {kap'i, kapi}, even though the acoustic difference between [p'] and [p] is identical in the two pairs. These experiments thus document an effect of higher level, long-distance perceptual interference, independent of ambiguity in the acoustic signal.

A main result of this dissertation is to show that long-distance and local laryngeal neutralization both correlate with perceptual asymmetries, though they differ as to whether these perceptual asymmetries can be reduced to the availability of acoustic cues. Long-distance restrictions do not contradict the hypothesis that phonological neutralizations occur to optimize the perceptual distance between contrasting forms. Rather, both local and non-local phenomena

show a preference for more perceptible contrasts, reflecting a fixed ranking of systemic markedness constraints against less perceptible contrasts.

1.3   Insights of the analysis

The contrast based analysis developed in this dissertation has two main typological advantages over previous accounts. First, it integrates dissimilation and assimilation, explaining both why two seemingly contradictory patterns occur in language and why no language penalizes *both* roots with stops that agree and disagree in laryngeal features. The schematic representations in (7) show that in a language with dissimilation, two instances of the same laryngeal feature are not allowed to cooccur in a root, while in a language with assimilation stops in a root must have the same laryngeal features. In both types of languages, pairs of unmarked stops may cooccur and laryngeally marked stops may cooccur with non-stops.

(7)   a. Dissimilation: *K'-T'   ✓K'-T   ✓K-T   ✓K'-N

       b. Assimilation: ✓K'-T'   *K'-T   ✓K-T   ✓K'-N

The existence of both dissimilation and assimilation in laryngeal features is puzzling because these two patterns are opposites. The configuration that is disallowed in dissimilation, roots with two laryngeally marked stops K'-T', is exactly the configuration that is required in assimilation. Similarly, the configuration of laryngeal features that is allowed in dissimilation, roots with one laryngeally marked and one plain stop K'-T, is disallowed in assimilation. In previous work, these two types of restrictions are given distinct accounts based on constraints that penalize either forms with two laryngeally marked stops, *K'-T', or stops that disagree in laryngeal features *K'-T. The problem with this type of account is that it predicts that both types of forms could be ungrammatical in the same language. If both constraints are high-ranked, a language is predicted that allows laryngeally marked stops only in roots with a single stop.

(8) unattested language: *K'-T'   *K'-T   ✓K-T   ✓K'-N

The analysis developed here avoids the prediction in (8) because markedness is a property of contrasts. A root with two laryngeally marked stops is marked if and only if it contrasts with a root with a single laryngeally marked stop and vice-versa. The operative constraint in cooccurrence restrictions in the contrast between roots with one and two laryngeally marked stops, *{K'-T', K'-T}, and thus there is only motivation for eliminating one of these two types of roots.

       The second advantage of the contrast based account is that it is perceptually grounded, and thus makes predictions about possible asymmetries in the typology of long-distance phonological restrictions. Under the proposed account, laryngeal features are subject to long-distance restrictions because they interact long-distance in perception. A contrast between one and two laryngeally marked stops is less perceptible than a contrast between one and zero larygneally marked stops.

(9)   K'-T' vs. K'-T   <   K-T' vs. K-T

If phonological restrictions are driven by constraints projected from perceptual asymmetries like that in (9), then only those features that show long-distance perceptual asymmetries are predicted to show long-distance phonological restrictions. A feature like continuancy, for example, which is not subject to non-local phonlogical restrictions, is not predicted to exhibit long-distance perceptual interactions. If phonological constraints are projected from perceptual asymmetries, than the specific perceptual properties of individual sounds are predicted to affect the phonological patterning of these sounds. This is an improvement over proposals that are not phonetically grounded, and thus predict that a given constraint can freely refer to any feature.

1.4   Organization of the dissertation

The dissertation is organized as follows. Chapter 2 lays out the preliminaries of the analysis, beginning with a typology of laryngeal cooccurrence restrictions and a schematic outline of the contrast based analysis developed formally in later chapters. Chapter 2 also presents detailed arguments for auditory featural representations for laryngeally marked segments and lays out the formal properties and assumptions of the DT framework. The auditory representations and groupings of larygneal features are supported by the survey of laryngeal acoustics in Chapter 3. Here, previous studies of the laryngeal systems of various languages are summarized, along with two new case studies of Bolivian Quechua and Chol. In Chapter 4, the perceptual properties of laryngeal features are documented. These chapter presents a series of three perception experiments documenting long-distance perceptual interference for ejectives, aspirates, and between ejectives and aspirates. The case studies of laryngeal cooccurrence restrictions are presented in Chapters 5-7. These chapters introduce and formally define systemic markedness and other constraints employed in the analyses as they are needed. Chapter 5 begins by analyzing dissimilation in Chol, Hausa and Tz'utujil. The comparison of Hausa and Tz'utujil shows two different patterns in languages with both implosives and ejectives. Chapter 6 addresses languages with both dissimilation and an ordering restriction, with case studies of Souletin Basque, Quechua and Bolivian Aymara. The comparison of Quechua and Bolivian Aymara show two different patterns in languages with both aspirates and ejectives. Assimilation is analyzed in Chapter 7, with case studies of Kalabari Ijo, Amharic and Zulu. Chapter 8 concludes.

17

Chapter 2   Preliminaries

2.1   Typology and conceptual analysis

This section presents an overview of laryngeal cooccurrence patterns in §2.1.1, summarizing the data presented in more detail and analyzed in each of the case studies in later chapters. The proposed analysis is discussed and argued for on a conceptual level in §2.1.2, and compared with previous approaches in §2.1.3. The goal of this section is to give a general outline of the data and the analysis, detailed descriptions of each language and the full formal analysis are found in Chapters 5 through 7.

2.1.1 The typology of laryngeal cooccurrence restrictions

Languages that exhibit long-distance restrictions on laryngeal features can be broadly divided into two types, those that show dissimilation in laryngeal features and those that show assimilation. These two basic patterns are schematized in (1). The notation "K-T" stands for any pair of stops; ejection is indicated with an apostrophe and stands for ejection, aspiration or implosion.

(1) a. dissimilation: ✓ K'-T   *K'-T'   ✓ K-T
     b. assimilation: *K'-T   ✓ K'-T'   ✓ K-T

In a language with dissimilation, as in (1a), a laryngeally marked consonant may cooccur with a plain stop, but two laryngeally marked stops may not cooccur. Languages with assimilation show the opposite pattern (1b); a laryngeally marked stop may not cooccur with a plain stop, but may cooccur with another stop with the same laryngeal specification. In both types of languages, pairs of plain stops are grammatical.

Dissimilatory restrictions are well documented by MacEachern (1999), while assimilatory restrictions are discussed in Hansson (2001) and Rose and Walker (2004). These surveys are the main sources for the data in this dissertation. Several of the case studies here are also discussed and analyzed in Mackenzie (2009). The majority of cooccurrence restrictions are static restrictions on the shape of roots in a language. The terms 'dissimilatory' and 'assimilatory' are not meant to imply that there is evidence for dissimilatory or assimilatory *alternations* in a given language, but rather that the shape of roots in the lexicon of that language shows disagreement or agreement in laryngeal features. Since long-distance laryngeal restrictions apply almost exclusively to roots, the unattested combinations of root consonants may surface at the word level, due to compounding or affixation.

Dissimilatory restrictions are attested for ejection, aspiration and implosion. Case studies of dissimilation in Chol (Mayan), Hausa (Afro-Asiatic), Tz'utujil (Mayan), Souletin Basque (isolate), Bolivian Quechua (Quechuan) and Bolivian Aymara (Aymaran) are presented in Chapters 5 and 6; the basic patterns are discussed here. In Chol (Gallagher and Coon 2009), ejectives may cooccur with voiceless unaspirated stops in a CVC root, but may not cooccur in pairs, as shown in (2).

(2) Chol – dissimilatory restriction on ejectives
    a. **p'it^j**   'to tie a load'   ✓ K'-T
    b. ***p'it^j'**   *K'-T'
    c. **pat^j**   'back'   ✓ K-T

Tz'utujil (Dayley 1985; MacEachern 1999) and Bolivian Aymara (de Lucca 1987; MacEachern 1999) have comparable restrictions on ejectives, as demonstrated by the data in (3) and (4).

(3) Tz'utujil – dissimilatory restriction on ejectives
    a. **pa:tʃ'**   'braid'   ✓ K'-T
    b. ***p'a:tʃ'**   *K'-T'
    c. **tik**   'sew'   ✓ K-T

(4) Bolivian Aymara – dissimilatory restriction on ejectives
    a. **k'astu**   'pole'   ✓ K'-T
    b. ***k'ast'u**   *K'-T'
    c. **kuʎta**   'button'   ✓ K-T

In addition to the three languages above, which are the subject of case studies, MacEachern reports dissimilation between ejectives in Sushwap (Salish) and Old Georgian (Caucasian). Souletin Basque exhibits dissimilation in aspiration (Hualde 1993; MacEachern 1999). The data in (5) show that aspirates may cooccur with voiceless unaspirated stops, but not in pairs.

(5) Souletin Basque – dissimilatory restriction on aspirates
    a. **t^{h}orpe**   'heavy'   ✓ K^h-T
    b. ***t^{h}orp^{h}e**   *K^h-T^h
    c. **pártü**   'to cross'   ✓ K-T

Bolivian Quechua shows a dissimilatory restriction on both ejectives and aspirates, as shown in (6). MacEachern discusses a similar pattern in Peruvian Aymara, a language which is not included in the case studies.

(6) Bolivian Quechua – dissimilatory restriction on ejectives and aspirates
    a. **k'inti**   'a pair'   ✓ K'-T
          k^{h}astuy 'to chew'   ✓ K^h-T
    b. ***k'int'i**   *K'-T'
          *k^{h}ast^{h}uy   *K^h-T^h
    c. **kintu**   'a bunch'   ✓ K-T

Languages with dissimilation between aspirates that are not analyzed here are Old Georgian, Ofo (Siouan) and Sanskrit (Indo-Aryan). Finally, both ejectives and implosives are subject to dissimilation in Hausa (Abraham 1962; MacEachern 1999). This is the only case of dissimilation between implosives that I know of.

(7) Hausa – dissimilatory restriction on ejectives and implosives

a. k'uta   'displeasure'[1]   ✓ K'-T

   ɗìge: 'filter'[2]   ✓ ɓ-D

b. *k'ut'a   *K'-T'

   *ɓaɗi   *ɓ-ɗ

c. ke:tʃè   'is split, torn'   ✓ K-T

   bùgu   'to be drunk'[3]   ✓ G-D

Languages with assimilatory restrictions show the reverse pattern from the dissimilatory languages in (2)-(7). The case studies of assimilation in Chapter 7 analyze restrictions in Kalabari Ijo (Ijoid), Amharic (Semitic) and Zulu (Bantu). Assimilatory restrictions on ejectives are found in Amharic (Rose and King 2007) and Chaha (Rose and Walker 2004; Rose and King 2007), as shown in (8) and (9). Additionally, a gradient assimilatory effect between ejective and plain stops is reported by Brown (2008) for Gitksan (Tsimshianic).

(8) Amharic – assimilatory restriction on ejectives

a. t'ik':a   'to beat, knock'   ✓ K'-T'

b. *t'ik:a   *T'-K

c. tik:a   'to replace'   ✓ K-T

(9) Chaha – assimilatory restriction on ejectives

a. ji-t'əβk'   'it is tight'   ✓ K'-T'

b. *t'əβk   *T'-K

c. ji-kəft   'he opens'   ✓ K-T

Kalabari Ijo shows assimilation in implosives (Jenewari 1989; Hansson 2001). Roots in this language may have two voiced plosives or two implosives, but plosive-implosive combinations are unattested.

(10)   Kalabari Ijo – assimilatory restriction on implosives

a. ɗábá   'lake'   ✓ ɓ-ɗ

b. *ɗábá   *ɓ-D

c. badara 'be(come) very wide'   ✓ B-D

A similar restriction to that in Kalabari Ijo is found in another Ijoid language, Bumo Izon (Efere 2001; Hansson 2001), which is not addressed in this dissertation. Zulu has an interesting pattern of assimilation between the three contrasting series of ejectives, aspirates and slack-voiced stops (Khumalo 1987; Hansson 2001), as shown in (11).[4] Similar restrictions are found in the other closely related languages of the Nguni sub-group, Xhosa, Swati and Ndebele (Hansson 2001).

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[1] Taken from an online Hausa-English dictionary: http://www.websters-online-dictionary.org/translation/Hausa/.

[2] Taken from an online Hausa-English dictionary: http://www.websters-online-dictionary.org/translation/Hausa/.

[3] Taken from an online Hausa-English dictionary: http://www.websters-online-dictionary.org/translation/Hausa/.

[4] The categorization of Zulu "b, d, g" as slack voiced follows several phonetic studies of these sounds, discussed in Chapter 3.

(11) Zulu – assimilatory restriction on ejectives, aspirates and slack-voiced stops
 a. **k'ap'** 'spit' ✓ K'-T'
 b. **kʰapʰ** 'push violently' ✓ Kʰ-Tʰ
 c. **gub** 'celebrate' ✓ G-D
 d. ***k'-pʰ*** *Kʰ-Tʰ
   k'-b *K'-D
   kʰ-b *Kʰ-D

The data above illustrate the basic dichotomy in laryngeal cooccurrence restrictions between dissimilatory and assimilatory restrictions. Within these two categories, however, there are further variations in the types of attested restrictions. The most major split is in the class of dissimilatory languages, which may show one of the two patterns schematized in (12). In one class of languages (12a), roots with a single laryngeally marked stop may have this stop in either initial or medial/final position. In another class of languages (12b), laryngeally marked stops may only appear in initial position if there is another stop in the word.

(12) a. *K'-T' ✓ K'-T | ✓ K-T' | ✓ K-T
   b. *K'-T' ✓ K'-T | *K-T' | ✓ K-T

The pattern in (12a) is simple dissimilation. In languages with the pattern in (12b), dissimilation is accompanied by an additional restriction on the ordering of laryngeally marked stops and plain stops. There are four languages in MacEachern's survey that exhibit ordering restrictions, Souletin Basque, Quechua, Bolivian Aymara and Peruvian Aymara, the first three of which are the topic of the case studies in Chapter 6. To see the difference between simple dissimilation and dissimilation with an ordering restriction, compare the patterning of ejectives in Chol and Quechua in (13) and (14); the same pattern holds for aspirates in Quechua, though these data are not shown here. "N" in the schematic representations stands for any non-stop (fricative or sonorant).

(13) Chol – simple dissimilation
 a. **k'atʃ** 'to twist' ✓ K'-T
 b. **kets'** 'obstructed' ✓ K-T'
 c. **k'uʃ** 'to hurt' ✓ K'-N
 d. **ʃak'** 'astride' ✓ N-K'

(14) Quechua – dissimilation and ordering restriction
 a. **k'apa** 'cartilage' ✓ K'-T
 b. ***kap'a** *K-T'
 c. **k'iri** 'injury' ✓ K'-N
 d. **ruk'iy** 'to pack tightly' ✓ N-K'

In Chol, ejectives may appear in either initial or final position in a CVC root, both in roots with another plain stop (12a,b) and in roots with another non-stop (12c,d). In Quechua, however, ejectives may only appear in either initial or medial position in words with another non-stop (13c,d). In words with one ejective and one plain stop, the ejective must precede the plain stop (13a,b).

Languages with assimilatory restrictions also show variation in the details of the restriction. The point of variation is in the degree of similarity between consonants that are required to assimilate. In some languages, assimilation is only required between a laryngeally marked consonant and its minimally contrastive counterpart, while in other languages assimilation holds between all stops. To give a schematic representation, consider a language with ejectives, voiceless unaspirated and voiced stops. In languages that require assimilation only between the most similar pairs of consonants, ejectives may not cooccur with voiceless unaspirated stops but may cooccur with voiced stops (14a). In languages with a more general assimilatory restriction, ejectives may not cooccur with either voiceless unaspirated or voiced stops (14b).

(14) a.   ✓ K'-T'   *K'-T | ✓ K'-D | ✓ K-T
      b.   ✓ K'-T'   *K'-T | *K'-D | ✓ K-T

Amharic and Kalabari Ijo exhibit the pattern in (14a), where assimilation only holds between the most similar consonants. In Amharic, ejectives and voiceless unaspirated stops may not cooccur, but ejectives and voiced stops may.

(15)   Amharic – assimilation between ejectives and voiceless unaspirated stops
      a. t'ik':a   'to beat, knock'   ✓ K'-T'
      b. *t'ik:a   *K'-T
      c. t'ig:a   'to approach'   ✓ K'-D

In Kalabari Ijo, implosives may not cooccur with voiced plosives, but may cooccur with voiceless unaspirated stops. While the original source for Kalabari Ijo does not give examples of roots with both implosives and voiceless stops, it is stated clearly that assimilation holds only between voiced plosives and implosives. The Kalabari Ijo pattern is shown in (16).

(16)   Kalabari Ijo – assimilation between implosives and voiced stops
      a. ɗáɓá   'lake'   ✓ ɓ-ɗ
      b. *ɗábá   *ɓ-D
      c. ɓ-t   ✓ ɓ-T

In Zulu, assimilation is not restricted to the most similar pairs of stops, but rather applies between all three laryngeal categories. Zulu contrasts ejectives, aspirates and slack voiced stops, no one series of which can occur with any other series. The generality of the pattern is shown for aspirates in (17).

(17)   Zulu – assimilation between aspirates and ejective or slack voiced stops
      a. k^hap^h 'push violently'   ✓ K^h-T^h
      c. *$k'-p^h$ *K'-T^h
      d. *k^h-b   *K^h-D

The data given above in this section instantiate four cooccurrence patterns. There are languages with simple dissimilation, and languages with both dissimilation and an ordering restriction. Assimilatory languages may require assimilation between only the most similar pairs of stops, or between all stops. These four patterns are summarized in (18).

22

(18) a. Dissimilation I – Hausa, Tzutujil, Shuswap (Chapter 5)
          *K'-T'   ✓ K'-T   ✓ K-T'   ✓ K-T

      b. Dissimilation II – Quechua, Bolivian Aymara, Souletin Basque (Chapter 6)
          *K'-T'   ✓ K'-T   *K-T'   ✓ K-T

      c. Assimilation I – Kalabari Ijo, Amharic (Chapter 7)
          ✓ K'-T'   *K'-T   *K-T'   ✓ K-T   ✓ K'-D   ✓ G-T'

      d. Assimilation II – Zulu (Chapter 7)
          ✓ K'-T'   *K'-T   *K-T'   ✓ K-T   *K'-D   *G-T'

The analysis of these patterns, which is outlined in the next section and developed formally in later chapters, accounts for the range of cooccurrence restrictions as conditions on the strength of allowable contrasts between roots in a language. While languages with all four of the patterns in (18) impose some minimal threshold on the perceptual distinctness of contrasting roots, they differ as to the degree of distinctness that is required. The next section sketches the conceptual side of the analysis, looking closely at the types of contrasts that are or are not allowed in each of the restrictions in (18).

2.1.1.1   A brief note on the identity effect

The typology of laryngeal cooccurrence restrictions includes one other dimension of variation that has not been discussed so far, and is not analyzed in any of the case studies in following chapters: the identity effect (MacEachern 1999). In some languages, pairs of heterorganic stops and pairs of homorganic stops are subject to different restrictions. In languages with dissimilation (with or without an ordering restriction), dissimilation may only apply to heterorganic consonants, while assimilation applies to homorganic consonants. In these languages, pairs of non-identical, heterorganic laryngeally marked stops are unattested, but pairs of identical laryngeally marked stops are attested. Relatedly, pairs of stops that minimally differ in a laryngeal feature may not cooccur in a root. The examples from Chol in (19) illustrate the pattern.

(19)   Dissimilation and the identity effect – Chol
      a. **k'atʃ**   'to twist'   ✓ K'-T
          kets'   'obstructed'

      b. ***k'atʃ'**   *K'-T'

      c. ***p'ap**   *K'-K
          ***pap'**

      d. **k'ok'**   'healthy'   ✓ K'-K'
          p'ip'   'wild'

23

In languages with the identity effect, the cooccurrence restrictions on laryngeal features are split based on place of articulation. A dissimilatory restriction holds between heterorganic segments, and assimilation between homorganic segments. Besides Chol, Bolivian Aymara, Peruvian Aymara, Hausa and Tz'utujil are characterized by the identity effect. While I do not provide a formal analysis of this type of pattern nor present the data for individual languages in the case studies, the identity effect does not pose any particular problem to the analysis presented here. The analysis accounts for the existence of dissimilation and assimilation as two different reflexes of the same general principle. In a language with the identity effect, dissimilatory and assimilatory patterns cooccur in the same language. Pairs of roots with heterorganic stops show dissimilation, while pairs of roots with homorganic stops show assimilation.

(20)   a.   heterorganic stops – dissimilation
            *K'-T'   ✓K'-T   ✓K-T'   ✓K-T

       b.   homorganic stops – assimilation
            ✓K'-K'   *K'-K   *K-K'   ✓K-K

A language with the identity effect has a place based split, and requires that the constraints determining whether a language has dissimilation or assimilation refer to place of articulation. How the analysis developed in this dissertation can be extended in this way is discussed briefly in the Conclusion in Chapter 8.

2.1.2 *Conceptual outline of the contrast based analysis*

The central argument in this dissertation is that laryngeal cooccurrence restrictions are driven by a grammatical pressure to maximize the perceptual distance between possible roots. From this view, the operative constraints in laryngeal cooccurrence restrictions are not standard Optimality Theory (henceforth OT) (Prince and Smolensky 1993, 2004) markedness constraints. Rather, they are systemic constraints that evaluate the markedness of the set of possible contrasts in a language. This section outlines the conceptual side of the contrast based analysis, which is supported by experimental evidence in Chapter 4 and developed formally in Chapters 5-7.

At first glance, the range of cooccurrence restrictions seems contradictory. Assimilatory and dissimilatory restrictions are opposites – what is prohibited in one type of language is precisely what is required in another. The contradictory nature of the requirements poses a problem for analyses based on standard notions of markedness, since it is not possible to claim that one laryngeal configuration is universally more marked than another. Dissimilatory restrictions, for example, suggest that a single occurrence of a laryngeal feature in a word is less marked than multiple occurrences of that feature (K'-T' is more marked than K'-T). Assimilatory restrictions lead to the opposite conclusion, that it is less marked to agree in laryngeal features than to disagree (K'-T is more marked than K'-T'). It is thus not possible to account for the range of restrictions with a single standard markedness constraint. Indeed, previous analyses of long-distance dissimilation and assimilation have treated these patterns as distinct phenomena. The benefits of a unified, contrast based approach are discussed in §2.1.3, where previous proposals are summarized and discussed.

The puzzling dichotomy in cooccurrence patterns is understandable if markedness constraints evaluate the contrasts between roots in a language. In a theory with systemic markedness

constraints, it is not necessary to claim that a root with one instance of a laryngeal feature is inherently more marked than a root with two instance of that feature, or vice-versa. Rather, what is marked is the *contrast* between these two types of forms, written {K'-T', K'-T}. Both dissimilatory and assimilatory cooccurrence restrictions disallow a contrast between one and two instances of a laryngeal feature in a root, *{K'-T', K'-T}. The claim is schematized in (20). A system that contrasts the number of laryngeally marked segments in a root (20a) is more marked than systems that contrast only the presence vs. absence of a laryngeal feature in a root (20b-d).

(20) a. * {T'-K', T'-K, T-K', T-K}   no restriction
      b. ✓ {T'-K, T-K', T-K}   dissimilation
      c. ✓ {T'-K, T-K}   dissimilation & ordering restriction
      d. ✓ {T'-K', T-K}   assimilation

The language represented in (20a) allows words that contrast in any number of laryngeal features; words in this language may have zero, one or two (and conceivably more than two) laryngeally marked consonants. This is a language without cooccurrence restrictions on laryngeal features. The languages in (20b-d) neutralize the contrast based on 1 vs. 2 laryngeally marked consonants ({K'-T', K'-T}). Only contrasts between the existence and absence of a laryngeal feature in the word are viable. Languages with cooccurrence restrictions are of the type represented by (20b-d). The contrast between one and two instances of a laryngeally marked segment is neutralized while the contrast between the existence and absence of a laryngeal feature in the word is maintained.

The unifying factor underlying dissimilatory and assimilatory restrictions is the neutralization of the 1 vs. 2 contrast in laryngeal features. The outcome of this neutralization, however, varies depending on the type of restriction. In languages with dissimilatory restrictions, the 1 vs. 2 contrast is neutralized to forms with one laryngeally marked stop, while in a language with an assimilatory restriction it is neutralized to forms with two laryngeally marked stops. Consider the input-output mappings for languages with basic dissimilation and assimilation in (21).

(21) a. Dissimilation   {/K'-T', K'-T, K-T', K-T/}   →   {[K'-T, K-T', K-T]}

      b. Assimilation   {/K'-T', K'-T, K-T', K-T/}   →   {[K'-T', K-T]}

Languages with dissimilation and those with assimilation differ in the outcome of neutralization of the 1 vs. 2 contrast in two ways. First, dissimilation allows three contrasting forms where assimilation only allows two contrasting forms. The dissimilatory mapping in (21a) is thus more faithful than the assimilatory mapping in (21b), as it eliminates one of the input forms while assimilation eliminates two of the input forms. Second, the resulting contrasts are different in the two types of languages. In dissimilation, output forms contrast one and zero (1 vs. 0) instances of a laryngeal feature (as well as the position of the laryngeally marked stop), while in assimilation output forms contrast two and zero instances of a laryngeal feature. The contrasting roots in an assimilatory language differ in (at least) two consonants, while in a dissimilatory language roots may differ in only one stop. This comparison of the input-output mappings allows for an understanding of why both the dissimilatory and assimilatory patterns are attested neutralizations of the 1 vs. 2 contrast. Dissimilation allows for more contrasting forms and thus greater faithfulness to the input set of potential forms. Assimilation, however, results in a stronger

contrast between the two possible types of forms. The tension between dissimilation and assimilation is thus a tension between more, less distinct contrast and fewer, more distinct contrasts. In dissimilatory languages, constraints favoring greater faithfulness and a larger number of contrasts outrank constraints favoring stronger contrasts, while in assimilatory languages the reverse is true.

The analysis outlined above rests on two systemic markedness constraints, one that penalizes a 1 vs. 2 contrast in laryngeal features, and another that penalizes a 1 vs. 0 contrast in laryngeal features. The hypothesis underlying these two constraints is that the perceptual strength of contrasts in laryngeal configurations between roots varies. Specifically, a contrast in a single larnyngeal feature is hypothesized to be weaker in a root with another segment marked for that laryngeal feature than in a root with no other laryngeally marked segment. This hierarchy is schematized in (22). The "<" sign stands for "is weaker than".

(22)   {K'-T', K'-T}   <   {K'-T, K-T}
          e.g. {k'ap'i, kap'i}   e.g. {k'api, kapi}

Additionally, a contrast in only one instance of a laryngeally feature is weaker than a contrast in two instances of that feature, as schematized in (23).

(23)   {K'-T, K-T}   <   {K'-T', K-T}
          e.g. {k'api, kapi}   e.g. {k'ap'i, kapi}

The two hypotheses in (22) and (23) combine to form the hierarchy of perceptual strength in (24), where "<" stands for "less perceptible than". This scale is supported by the series of perception experiments in Chapter 4. The proposed analysis view dissimilation and assimilation as two points along this continuum. In dissimilation, only the weakest 1 vs. 2 contrast is neutralized, while in assimilation both the 1 vs. 2 and 1 vs. 0 contrasts are neutralized.

(24)   {K'-T', K'-T}   <⟩   {K'-T, K-T}   <⟩   {K'-T', K-T}
                          dissimilation   assimilation

This approach views dissimilation and assimilation not as two contradictory requirements, but rather as two points along a single scale. Both types of restriction reflect a preference for more distinct contrasts over less distinct contrasts; they differ only in the degree of perceptual distinctness that is required. Dissimilatory restrictions impose a less stringent requirement on allowable contrasts than assimilatory restrictions.

The above discussion outlines the principles at play in simple dissimilation and assimilation. To account for ordering restrictions in some dissimilatory languages, further principles must be at play. The input-output mapping for a language with both dissimilation and an ordering restriction is given in (25).

(25)   Dissimilation & ordering restriction
        {/K'-T', K'-T, K-T', K-T/}   →   {[K'-T, K-T]}

Unlike in a language with simple dissimilation, in languages with an ordering restriction there is no contrast for the position of a laryngeal feature in a root. Languages with just dissimilation allow roots with either an initial or non-initial laryngeally marked consonant {K'-T, K-T'}, while languages with an ordering restriction allow only an initial laryngeally marked consonant in roots with two stops {K'-T}. I hypothesize that ordering restrictions are driven by a further systemic markedness constraint that penalizes a contrast in the position of a laryngeal feature, *{K'-T, K-T'}. The contrast in the position of a laryngeal feature is stronger than the 1 vs. 2 contrast, but weaker than a 1 vs. 0 contrast. The full hierarchy of systemic markedness constraints is given in (26). Given this hierarchy, the three cooccurrence patterns of dissimilation, dissimilation with an ordering restriction and assimilation stand in a clear relation to one another. An ordering restriction reflects a higher threshold for the distinctness of contrasting roots than simple dissimilation, but a lower threshold than assimilation.

(26) {K'-T', K'-T} < {K'-T, K-T'} < {K'-T, K-T} < {K'-T', K-T}

       dissimilation   dissimilation   assimilation
                             & ordering

The analysis of languages with both dissimilation and an ordering restriction requires two further constraints. First, the outcome of neutralization of the positional contrast to a form with an initial laryngeally marked stop must be accounted for {/K'-T, K-T'/} → {[K'-T]}. The idea here is that initial contrasts are generally more perceptible and thus preferable to non-initial contrasts. While a language with dissimilation and an ordering restriction generally allows non-initial contrasts (ie. in words with only a single stop), a low-ranking constraint against non-initial constraints may have an effect in the event of neutralization. The positional contrast {K'-T, K-T'} is neutralized to a form with an initial laryngeally marked consonant because this makes for a stronger contrast with roots with no laryngeally marked consonants, {K'-T, K-T} is preferred over {K-T', K-T}.

Second, the preference for dissimilation {K'-T, K-T} over assimilation {K'-T', K-T} must be accounted for. Above, the tension between dissimilation and assimilation was framed as one of faithfulness (dissimilation) competing with a preference for stronger contrasts (assimilation). In languages with both dissimilation and an ordering restriction, however, dissimilation is not more faithful to the input and does not allow more output contrasts than assimilation. Both dissimilation with an ordering restriction and assimilation result in a contrast between two laryngeal configurations. Therefore, some additional consideration must be at play in order to prefer the weaker 1 vs. 0 contrast in languages with both dissimilation and an ordering restriction over the stronger 2 vs. 0 contrast seen in assimilation. While assimilation allows for the strongest possible contrast, dissimilation may be preferred over assimilation on articulatory grounds. A form with only a single laryngeally marked segment requires simpler and fewer articulatory gestures than a form with two laryngeally marked segments.

The hierarchy of perceptual distinctness in (26) above underlies three systemic markedness constraints, which stand in a fixed hierarchy reflecting the relative perceptual distinctness of each contrast. The hierarchy of constraints is given in schematic form in (27). The constraints *{K'-T', K'-T} and ({K'-T, K-T} are formalized and defended in §5.1; *{K'-T, K-T'} is formalized and defended in §6.1.

(27) *{K'-T', K'-T}   >>   *{K'-T, K-T'}   >>   *{K'-T, K-T}

The range of cooccurrence restrictions is accounted for with the interleaving of faithfulness constraints and articulatory markedness constraints with the hierarchy of systemic markedness in (27). To summarize, the contrasts that are neutralized in each type of cooccurrence restriction are given schematically in (28).

(28)   a.   <u>Simple dissimilation</u> {K'-T, K-T', K-T}

        contrast neutralized: {K'-T', K'-T} (1 vs. 2)
        contrasts allowed: {K'-T, K-T'} (positional)
                               {K'-T, K-T} and {K-T', K-T} (1 vs. 0)

     b.   <u>Dissimilation & ordering restriction</u> {K'-T, K-T}

        contrasts neutralized: {K'-T', K'-T} (1 vs. 2)
                                {K'-T, K-T'} (positional)
        contrasts allowed: {K'-T, K-T} (1 vs. 0)

     c.   <u>Assimilation</u> {K'-T', K-T}

        contrasts neutralized: {K'-T', K'-T} (1 vs. 2)
                                {K'-T, K-T'} (positional)
                                {K-T', K-T} (1 vs. 0)
        contrasts allowed: {K'-T', K-T} (2 vs. 0)

The contrast based approach to laryngeal cooccurrence restrictions outlined here formalizes the idea that assimilation, dissimilation and ordering restrictions are a unified set of phenomena that all reflect a preference for more distinct contrasts. The difference between these three basic patterns is the degree of distinctness that is required of contrasting roots.

2.1.3 Comparison with previous analyses

The previous section outlined the contrast based analysis that is developed in this dissertation. This section compares the contrast based analysis to previous analyses of dissimilation, assimilation and ordering restrictions. There are two main issues with previous accounts of laryngeal cooccurrence phenomena, both of which are typological. First, the factorial typology of the standard syntagmatic markedness constraints that are needed to account for the range of cooccurrence phenomena overpredicts. Without systemic markedness constraints on contrast, disparate and contradictory constraints are necessary to derive the diverse range of patterns. These constraints are then predicted to interact in unattested ways. The second problem is that analyses of cooccurrence patterns that are not phonetically grounded overgenerate. Previous accounts propose markedness constraints that could in principle refer to any feature, predicting a many more long-distance phonological restrictions than are actually attested. Not all features show long-distance phonological restrictions, and not all segment types interact over long-distances. Similarly, the set of local phonological interactions is not the same as the set of

attested long-distance interactions. The contrast based analysis crucially derives long-distance restrictions on laryngeal features from independent perceptual facts; long-distance phonological restrictions are possible where long-distance perceptual interactions exist. This perceptual grounding provides a basis for predicting what types of long-distance patterns are and are not attested.

This section begins with a summary of previous approaches in §2.1.3.1 and then discusses the two typological problems summarized above in §2.1.3.2 and §2.1.3.3.

2.1.3.1   Summary of previous approaches

Dissimilation in laryngeal features is accounted for by MacEachern (1999) as an effect of the Obligatory Contour Principle (OCP) (Leben 1973; Goldsmith 1975; McCarthy 1986), which generally states that adjacent, identical features are disallowed. Following the formulation of Suzuki (1998), MacEachern adopts a set of OCP constraints that penalize multiple occurrences of the same laryngeal feature in a root. The Generalized OCP (GOCP), as this family of constraints is called, eschews the strict adjacency requirement of the classic OCP and instead forbids multiple occurrences of a given feature in some domain, regardless of locality. In the case of laryngeal dissimilation, the domain is the root. The GOCP constraint proposed by MacEachern to account for dissimilation between ejectives is given in (29).

(29)   GOCP:[constricted glottis]   The occurrence of two [cg] specifications is prohibited.

When this constraint outranks faithfulness to input laryngeal specifications, dissimilation results. The tableau in (30) shows dissimilation in a hypothetical input with two ejectives.

(30)   Dissimilation with the GOCP

/k'at'i/	GOCP:[cg]	IO-IDENT[cg]
a. k'ati		*
b. → k'at'i	* !	

In (30), the high ranked GOCP rules out candidate a which has multiple ejectives, the desired result for a language with dissimilation. The GOCP can thus account for laryngeal dissimilation.

Assimilatory restrictions on laryngeal features have been analyzed in the broader context of long-distance consonant assimilation by Hansson (2001) and Rose and Walker (2004). In their general framework, similar non-adjacent consonants interact via a correspondence relation. Consonants that stand in this output correspondence relation are then subject to a family of correspondence constriants, requiring identity in certain features between corresponding segments. Both output correspondence and identity between corresponding output consonants are governed by ranked and violable constraints. Laryngeal assimilation, for example, requires a constraint placing stop consonants in correspondence and a constraint requiring identity in laryngeal features between corresponding consonants. These constraints are defined loosely in (31); for formal definitions and detailed discussion, see Hansson (2001) and Rose and Walker (2004).

(31)   CORR-T↔K   Stops in the output stand in correspondence.
       CC-IDENT[lar]   Corresponding segments agree in laryngeal features.

Assimilatory restrictions, where stops are required to agree in laryngeal features, result when CORR-T↔K and CC-IDENT outrank input-output faithfulness, as shown in (34). Correspondence is indicated with subscripts.

(32)   The correspondence based analysis of laryngeal assimilation

/k'ati/	CORR-T↔K	CC-IDENT[lar]	IO-IDENT[lar]
a. k'a$_x$t$_y$i	* !		
b. k'$_x$at$_x$i		* !	
c. → k'$_x$at'$_x$i			*

In (32), CORR-T↔K requires that stops stand in correspondence, eliminating candidate a. CC-IDENT[lar] requires corresponding segments to have the same laryngeal specification, in (32) either ejective or plain. This constraint penalizes candidate b, where [k'] and [t] correspond but do not agree, but does not penalize candidate a, where [k'] and [t] do not correspond. Candidate c, with laryngeal assimilation wins because it satisfies both high ranked constraints, the two stops stand in correspondence and share the same laryngeal specification.

Ordering restrictions have been subject to two lines of analysis in previous studies, developed by MacEachern (1999) and Mackenzie (2009) respectively. Recall that in a language with ordering restrictions, a laryngeally marked stop may not follow an unmarked stop in a root, but may follow a non-stop. The pattern is schematized in (33).

(33)   Ordering restriction: ✓ K'-T   *K-T'
                                ✓ K'-N   ✓ N-K'

The challenge for an analysis of the pattern in (33) is to account for the ungrammaticality of medial laryngeally marked stops only in roots with another minimally contrastive stop.

MacEachern (1999) approaches the problem with constraints requiring that [constricted glottis] and [spread glottis] specifications appear on the leftmost available host consonant. The constraint for [constricted glottis] is defined in (34), from MacEachern (1999:124).

(34)   LEFTMOST[constricted glottis]   [constricted glottis] features should occur early in the morpheme. One violation is assessed for every available host consonant intervening between the beginning of the morpheme and the location of the [constricted glottis] feature.

This constraint interacts with standard IDENT[F] constraints as well as MAX[F].

(35)   IDENT[cg]   Corresponding input and output segments have the same value for [cg]

        MAX[cg]   Every [cg] specification in the input has a corresondent in the output.

MAX[cg] penalizes the deletion of a [cg] feature from an input entirely, but not the movement of a feature from one segment to another. IDENT[cg], on the other hand, penalizes every mismatch in features between input and output *segments*. The analysis of an ordering restriction on ejection is shown in (36) and (37).

30

(36)

/kap'a/	LEFTMOST[cg]	MAX[+cg]	IDENT[cg]
a. [kap'a]	* !		
b. [kapa]		* !	*
c. → [k'apa]			**

(37)

/map'a/	LEFTMOST[cg]	MAX[+cg]	IDENT[cg]
a. → [map'a]			
b. [mapa]		* !	*
c. [m'apa]			*!*

In (37), the fully faithful candidate does not violate LEFTMOST[cg] because [m] is not considered a "potential host" for the [cg] feature.

The LEFTMOST[F] constraints proposed by MacEachern have the same formal properties as a gradient ALIGN constraint, and thus are undesirable for the reasons outlined in McCarthy (2003). An analysis based on non-gradient ALIGN constraints is also not tenable. In languages with ordering restrictions, the position of a laryngeal feature is restricted not with respect to the left edge of the root but rather with respect to other consonants in the root. Laryngeal features surface only on the leftmost stop even when the leftmost stop is not root initial. A non-gradient alignment constraint woud require that a given feature be aligned with the left edge of the root. This constraint correctly eliminates roots like [kap'a] in favor of a root like [k'apa], but is silent about the order of laryngeal features when the relevant stops are not root initial. In a vowel initial root ([akʰapa] vs. [akapʰa]) or a tri-syllabic root ([makap'a] vs. [mak'apa]), ejectives or aspirates and plain stops should occur in either order. Data from Quechua suggests that this is not in fact the case. While the number of vowel initial or tri-syllabic roots with two stops is small, in all of the available examples (from the Ajacopa et al. 2007 dictionary) a laryngeally marked stop precedes a plains stop.

(38) Ejectives and aspirates appear on the leftmost stop in tri-syllabic roots – Quechua
    a. matʃ'ika 'biceps'   b. lapʰapay 'to flutter'   c. *matʃik'a
        huk'utʃa 'mouse'   makʰurka 'muscle stiffness'   *makukʰa

The data in (38) show that a non-gradient ALIGN constraint cannot account for ordering restrictions. Mackenzie's account of ordering restrictions does not appeal to either gradient or non-gradient alignment constraints, and thus avoids these problems.

Mackenzie's account of ordering restrictions is couched in a theory of contrastive underspecification, which allows for an account of the dichotomy between stops and non-stops in ordering restrictions. In this framework, the crucial difference between a laryngeally unmarked stop and a non-stop is that the laryngeally unmarked stop is specified for a "-" value of the laryngeal feature while the non-stop is unspecified for this feature. A representative example is given below for the three sounds [p', p, m].

(39)

	[constricted glottis]
p'	+
p	-
m	

The markedness constraints responsible for ordering restrictions in Mackenzie's analysis are of the form *[αF][+F]. A constraint from this family is defined below for the feature [constricted glottis].

(40)   *[αcg][+cg]   A segment specified as [+constricted glottis] may not follow
                          a segment specified for any value of [constricted glottis].

Given the feature specifications in (39), a form like [pak'a] violates the constraint in (40) while a form like [mak'a] does not. The [+cg] specification of [k'] follows the [-cg] specification of [p] in [pak'a], while in [mak'a] there is no [-cg] specification, as [m] is unspecified for this feature. The use of contrastive specifications in Mackenzie's analysis thus allows for a principled definition of what MacEachern's "potential host"; a potential host for a feature [+F] is a segment specified as [-F]. The markedness constraint in (40) interacts with MAX[+F] and IDENT[F], as defined in (41).

(41)   MAX[+cg]   For any [+cg] feature in the input, there is a corresponding
                          [+cg] feature in the input.

       IDENT[cg]   Correspondent segments must have the same value of the
                          feature [cg] (either + or -).

The analysis of an ordering restriction on ejection is shown in the two tableaux below.

(42)

/kap'a/	*[αcg][+cg]	MAX[+cg]	IDENT[cg]
a. [kap'a]	* !		
b. [kapa]		* !	*
c. → [k'apa]			**

(43)

/map'a/	*[αcg][+cg]	MAX[+cg]	IDENT[cg]
a. → [map'a]			
b. [mapa]		* !	*
c. [m'apa]			*!*

The faithful candidate in (42a) loses on high-ranked markedness because of the sequence [k...p']. Candidate b eliminates the markedness violation by deleting ejection entirely, while candidate c moves ejection to the initial consonant. The ranking of MAX >> IDENT selects candidate c as the winner. In (43), we see how the same ranking of constraints allows medial ejectives in words without an initial stop. Here there are no violations of high-ranked markedness, and thus the fully faithful candidate is preferred.

2.1.3.2   Advantages of the contrast based account

The first problem with the accounts sketched above is that they rely on separate constraints to enforce laryngeal dissimilation and assimilation. These opposite patterns require somewhat contradictory constraints. To account for dissimilation, a constraint must penalize multiple

instances of the same feature in a given domain, as the GOCP does. To account for assimilation, a constraint must penalize different specifications for the same feature in a given domain, as CC-correspondence constraints do. If both types of constraints exist, they are predicted to interact in unattested ways. To see the problem, consider a somewhat simplified version of these two constraints where the GOCP is represented as *[+F][+F] and CC-correspondence constraints are represented as a single markedness constraint *[αF][-αF]. Given these two constraints, three types of languages are predicted as shown in (44).

(44) a. *[+F][+F] outranks IDENT – dissimilation
          *K'-T'   ✓ K'-T   ✓ K-T   ✓ K'-N

      b. *[αF][-αF] outranks IDENT – assimilation
          ✓ K'-T'   *K'-T   ✓ K-T   ✓ K'-N

      c. both *[+F][+F] and *[αF][-αF] outrank IDENT – unattested
          *K'-T'   *K'-T   ✓ K-T   ✓ K'-N

The language in (44c) satisfies both markedness constraints by neutralizing all laryngeal features in roots with two stops. This language has a laryngeal contrast, but only in roots with a single stop. The language in (44c) is predicted by any theory with independent markedness constraints driving dissimilation and assimilation. While both of these patterns are attested, they are never known to cooccur in a language. The range of cooccurrence restrictions shows that a language may disallow roots with two instances of the same laryngeal feature *or* roots with disagreeing laryngeal features, but never both. This scenario supports a contrast based analysis. The trading relation between the grammaticality of forms with one (K'-T) or two (K'-T') laryngeally marked stops shows that it is the contrast between these two types of forms that is marked. A constraint on this contrast, *{K'-T, K'-T'} is satisfied by eliminating either forms with one or forms with two laryngeally marked stops, but never favors elimination of both types of forms. The informal tableau in (45) shows that deleting both roots with one and two laryngeally marked stops incurs excessive violations of faithfulness, and is harmonically bounded by the candidates that delete only one of these types of roots.

(45)

{/K'-T', K'-T, K-T, K'-N/}	*{K'-T, K'-T'}	FAITH
a. {[K'-T', K'-T, K-T, K'-N]}	* !	
b. → {[K'-T, K-T, K'-N]}		*
c. → {[K'-T',K-T, K'-N]}		*
d. {[K-T, K'-N]}		** !

The unification of dissimilation and assimilation as the effect of a single family of constraints on the perceptual strength of contrasts explains why both of these seemingly contradictory patterns exist, and, moreover, such a theory lacks the typological overprediction problem of a theory with only syntagmatic constraints.

33

2.1.3.3   Advantages of perceptual grounding

The analyses summarized above do not make predictions about what features should and should not show long-distance interactions. Moreover, the GOCP analysis employed by MacEachern and the analysis of Mackenzie do not make explicit hypotheses about the role of locality in phonological restrictions. Some of the problematic predictions are laid out below.

The GOCP analysis does not distinguish between local and non-local dissimilation. The GOCP penalizes any combination of two occurrences of the same feature in a single domain, regardless of whether the two occurrences of a given feature are strictly adjacent, adjacent on their autosegmental tier, or non-adjacent, as shown in (46).

(46)   Structures that violate GOCP:[cg]

	a. strictly adjacent	b. tier adjacent	c. non-adjacent
	CC	CVC	CVCC
	/ \	/ \	/ | \
	[+cg][+cg]	[+cg][+cg]	[+cg] [-cg] [+cg]
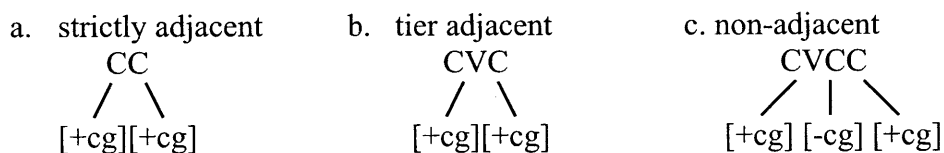
Equating strictly adjacent sequences as in (46a) with the long-distance sequences in (46b,c) is problematic because the same types of dissimilation are not attested for these two types of configurations. For example, long-distance dissimilation in place of articulation is well attested, most famously in Arabic (Greenberg 1960; McCarthy 1981, 1986; Pierrehumbert 1993; Frisch et al. 2004; Coetzee and Pater 2008), though also documented for English (Berkeley 1994), Javanese (Mester 1986), Muna (Coetzee and Pater 2008) and Tigrinya (Buckley 1997), among others. I do not know of any general case of dissimilation in major place in consonant clusters, however. Similarly, dissimilation in [anterior] is attested in local fricative-stop sequences in Chumash (isolate) (Applegate 1972; Poser 1993; McCarthy 2007), but I do not know of any language that has the long-distance counterpart of this pattern.

(47)   a.   Local dissimilation in [+anterior]: Chumash
         /s+nanʔ/   →   [ʃnanʔ]   'he goes'
         /s+tepuʔ/   →   [ʃtepuʔ]   'he gambles'
         /s+loxitʔ/ →   [ʃloxitʔ]   'he surpasses me'

         b.   Non-local dissimilation in [+anterior]?
         *[s…n]_{RT}   *[s…t]_{RT}   *[s…l]_{RT}

The GOCP was proposed to account for a broad range of dissimilatory phenomena that go beyond what falls under the scope of the traditional OCP. While the attested patterns of dissimilation are extremely varied, both with respect to the features that dissimilate and the locality conditions on dissimilation, there are also asymmetries between which features are subject to local dissimilations and which to non-local dissimilations. The GOCP does not have a metric for predicting the locality conditions on dissimilation in a given feature.

The correspondence based approach to laryngeal assimilation has a problem similar to that described for the GOCP above. This framework has two free parameters: the segments that stand in correspondence and the feature that corresponding segments are required to agree in. This

system fails to account for the fact that certain groups of segments only show agreement in certain features. For example, laryngeal agreement is attested between stops, but major place agreement is not.[5]

(48)   a. Long-distance agreement in laryngeal features between stops
         [k'...p']   [k...p]   *[k'...p]   cf. Chaha (Rose and Walker 2004)

       b. Long-distance agreement in place features between stops – unattested
         [k'...k]   *[k'...p]

The correspondence based approach to laryngeal assimilation does not account for the fact that non-adjacent stops crucially assimilate in laryngeal features and not other features. Another interesting example is sibilant harmony. It is relatively common for sibilants in a word to take on the same minor place features, but it is unknown for sibilants in a word to agree in voicing or continuancy.

(49)   a. Sibilants agree for minor place features
         [ts...s]   [tʃ...ʃ]   *[ts...ʃ]

       b. Sibilants agree for voicing – unattested?
         [ts...ʃ]   [dʒ...z]   *[ts...z]

       c. Sibilants agree for continuancy – unattested?
         [ts...tʃ]   [s...ʃ]   *[ts...s]

Mackenzie's analysis of ordering restrictions (and MacEachern's as well) also overpredicts. The schema for the markedness constraints that trigger an ordering restriction is too general. The schema *[αF][+F] predicts that ordering restrictions should exist for any and all features, when only four cases of laryngeal ordering restrictions are identified by MacEachern (two of which are analyzed by Mackenzie). While cases of ordering restrictions may be discovered beyond what is reported for ejectives and aspirates by MacEachern, the typology is most likely quite restricted.

    In the systemic markedness approach developed in this dissertation, long-distance phonological interactions result from perceptual confusibility. Thus, the attested range of interactions is predicted to mirror perceptual facts. Asymmetries like those schematized above are predicted to exist, since there is no reason to suppose that all features show the same long-distance perceptual interactions. Consider the asymmetry between laryngeal features, which commonly show long-distance interactions and continuancy, which does not. This asymmetry is predicted to correlate with asymmetries in the perceptual properties of laryngeal contrasts and continuancy contrasts. It will be shown in Chapter 4 that laryngeal contrasts are subject to long-distance interference. The hypothesis, which remains to be tested in future work, is that continuancy contrasts show no such interaction. Thus, while the perception of an ejection contrast is weaker in the presence of another ejective, a continuancy contrast should not be weaker in the presence of another continuant.

---

[5] There are no cases of major place assimilation in adult language, but this phenomenon is attested in child language (Smith 1973; Vihman 1978; Rose 2000; Pater and Werle 2001; Fikkert, Levelt and van den Weijer 2002).

(50) Hypothesis
   a. Laryngeal features interact long-distance
      k'ap'i-k'api   <   *kap'i-kapi*

   b. Continuancy does not
      faxi-faki   <   *paxi-paki*

The experimental results in this dissertation do not verify that the typology of long-distance phonological interactions correlates with long-distance perceptual interactions. Rather, the analysis lays out a research program and makes clear predictions about the possible explanations for featural asymmetries. The results in Chapter 4 show that the correlation between perception and phonology holds for laryngeal features. It is left to future work to show that other features that show long-distance phonological restrictions show long-distance perceptual interactions, and that those features that do not interact long-distance in phonology do not interact long-distance in perception. The insight of perceptual grounding as put forth in this dissertation is that all features are not equal, and that constraints should reflect the unique perceptual properties of individual features.

2.2   Auditory features in laryngeal cococurrence restrictions

The systemic markedness constraints projected from the hierarchy of perceptual distinctness refer to auditory features. This section presents the arguments for auditory representations from the typology of laryngeal cooccurrence restrictions. The problems raised for more standard, articulatory based features are a problem with the feature set itself, and do not directly pertain to the question of whether markedness constraints are systemic or not. The auditory feature set proposed in this section could, in principle, be integrated into any of the previous analyses of cooccurrence restrictions summarized in the previous section.

   The first sub-section summarizes the proposed auditory feature set and compares auditory and articulatory representations of laryngeal contrasts. The cooccurrence patterns in Quechua are argued in §2.2.2 to require auditory features. Supporting data from Hausa and Tz'utujil are presented in §2.2.3, though these languages are also analyzable with an articulatory feature set.

2.2.1   Auditory dimensions of contrast

This section develops a theory of auditory features for the laryngeal categories that are targeted for cooccurrence restrictions; that is, those auditory features that define ejectives, aspirates and implosives cross-linguistically. Auditory representations follow naturally from the claim that grammatical constraints are projected from the perceptual properties of speech sounds. Constraints on perceptual dispersion necessarily look at auditory representations, as these are the only representations over which perceptual distance can be evaluated (Flemming 1995). In principle, constraints on contrast could look at representations of any type; it is constraints on *perceptual* contrast that require an auditory feature system.

   Standard SPE features are based in articulation, and gloss over auditory differences that are relevant to phonology. The articulator based feature geometry based on the laryngeal node hypothesis (Mohanan 1983; Clements 1985) gives the following representation of laryngeal features.

(51)   laryngeal node

[voice]   [spread glottis]   [constricted glottis]
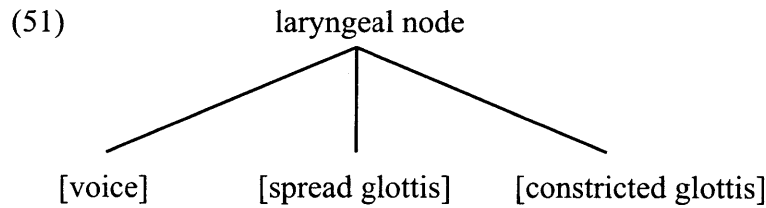
In the feature geometry in (51), aspirates are defined by the feature [spread glottis], and ejectives and implosives together are specified as [constricted glottis]; both of these features are dominated by the laryngeal node, which also dominates [voice]. Clements and Osu (2003) argue for the feature [implosive], also dominated by the laryngeal node, to define modally voiced implosives that are produced with a lowering of the glottis but no constriction of the glottis (and thus are not [constricted glottis]). The cooccurrence phenomena of Tz'utujil, discussed in §2.2.3 below, show that a featural distinction between modally voiced implosives and ejectives is necessary.

The feature set in (51) is deficient for describing and analyzing the phonology of laryngeal features in a number of ways. First, consider the interaction of laryngeal features in cooccurrence restrictions. There exist languages where ejectives and implosives pattern as a uniform class (Hausa), as predicted by the standard feature system (both are [constricted glottis]), but there also exist languages where ejectives and aspirates pattern as a class (Quechua). Given the representation in (51), the interaction between ejectives and aspirates can only be accounted for with reference to the laryngeal node. Two problematic predictions arise if ejectives and aspirates interact with one another only because they are both specified for features dominated by the laryngeal node. First, aspirates should also pattern with implosives in some languages. Second, ejectives and aspirates are predicted to interact with voiced stops as well as with each other. I know of no language that treats aspirates and implosives as a class (though the number of languages with both classes of sounds is small), nor any language where voiced stops pattern with aspirates or ejectives.

Another problem with the laryngeal node hypothesis is that ejectives, aspirates and implosives are grouped with voiced stops. Voiced stops, however, do not show the same cooccurrence phenomena as other laryngeally marked segments. While voiced stops are involved in some long-distance laryngeal restrictions, namely those of the Nguni sub-group of the Bantu family (Zulu, Ndebele, Xhosa), voiced stops in these languages are not modally voiced, but rather involve "slack" voice upon release (see the summary of acoustic studies of Zulu and Xhosa stops in §3.1.2). Additionally, languages with voiced stops often exhibit restrictions on other laryngeal features to the exclusion of voiced stops, suggesting that there is some systematic distinction between voicing and other laryngeal features. For example, aspirates are restricted in Souletin Basque, ejectives are restricted in Chaha and Amharic, and ejectives and implosives are restricted in Hausa.

Defining laryngeal categories in auditory instead of articulatory terms makes the correct predictions about cooccurrence restrictions on laryngeally marked segments. From an auditory perspective, aspirates and ejectives may pattern together because they share long VOT. Ejectives and aspirates don't pattern with voiced stops because they don't share any relevant auditory

property.[6] Similarly, ejectives and implosives pattern together only when they both share creaky phonation, as in Hausa.

The auditory correlates of ejectives, aspirates and implosives vary from language to language, as emphasized in the survey of acoustic studies in Chapter 3. Consequently, the auditory features that define laryngeal classes will not be the same across languages. This phonetic variation has implications for the analysis of laryngeal restrictions. If a language shows a cooccurrence restriction on ejectives, for example, the auditory feature that is restricted depends on the realization of ejectives in that language. In some languages, like Hausa, a restriction on the auditory dimension of creaky phonation governs the cooccurrence patterns of ejectives, while in other languages, like Quechua, the relevant auditory features refer to long VOT and loud burst amplitude. The chart in (52) summarizes the four auditory features that are needed to analyze the range of cooccurrence restrictions represented by the case studies in Chapters 5-7. The restrictions analyzed in this dissertation require this feature set; further investigation into laryngeal cooccurrence restrictions may reveal that other auditory features are also involved.

(52)

dimension	feature name
long VOT	[long VOT]
loud burst	[loud burst]
creaky phonation	[creak]
voicing amplitude increase	[v-amp]

The feature [v-amp] refers to an increase in voicing amplitude throughout closure, which Lindau (1984) finds characterizes implosives, like those that are subject to laryngeal assimilation in Kalabari Ijo. The acoustic details for each of the auditory dimensions/features in (52) are given in the survey of the phonetics of laryngeally marked segments in Chapter 3.

While aspirates are uniformly specified as [long VOT], the realization, and thus the auditory representation, of ejectives and implosives varies across languages. The acoustic survey in Chapter 3 finds at least three types of ejectives, with the representations in (53). Some ejectives have a loud burst and long VOT but no creaky phonation (53a), while others are characterized by creaky phonation but not a loud burst or long VOT (53b). Other languages have ejectives with both creaky phonation as well as a loud burst amplitude and long VOT (53c).

(53)   Auditory featural representations for ejectives
    a. [loud burst, long VOT]   e.g. Quechua ejectives
    b. [creak]   e.g. Hausa ejectives
    c. [loud burst, long VOT, creak]   e.g. Chol ejectives

Implosives have at least the two representations in (54). Both modally and creaky voiced implosives have a rising voicing amplitude throughout closure duration, but differ as to the quality of phonation during the closure.

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[6] Ejectives and aspirates of course share with voiced stops whatever auditory properties characterize all stops (a silent or relatively quiet closure, a release burst and transitions, etc.).

38

(54) Auditory featural representations for implosives[7]
    a. [v-amp]   e.g. Ijoid implosives
    b. [v-amp, creak]   e.g. Hausa implosives

There are additional auditory properties that characterize the set of sounds subject to long-distance restrictions. In Quechua, for example, aspirates induce breathy phonation on the following vowel in addition to having a long voice onset time filled with noise. Closure duration may also be a cue to laryngeal categories in some languages. The claim is then not that the features in (53) and (54) are sufficient for complete auditory representations of the sounds in question; rather, these are the auditory properties that are relevant for laryngeal cooccurrence restrictions. The hypothesis is that these auditory properties and not others exhibit long-distance perceptual interactions.

The empirical motivation for auditory representations in the domain of cooccurrence restrictions comes from the restrictions in languages with more than one class of laryngeally marked segments. In languages with both ejectives and aspirates, ejectives and aspirates may pattern as a single class, or ejectives may pattern independently. Ejectives and aspirates do not form a natural class in articulatory terms, but share the auditory feature [long VOT]. The uniform patterning of ejectives and aspirates in a language like Quechua thus requires an auditory feature, [long VOT], to accurately characterize the laryngeal restrictions in this language. Similarly, in languages with both ejectives and implosives, these sounds either pattern together, or ejectives are independent. The discussion of Hausa and Tz'utujil in §2.2.2 shows that ejectives pattern with implosives when both types of segments are associated with creaky phonation. The following two sections look specifically at interactions between laryngeal classes and the benefits of auditory features for their analysis.

2.2.2 Ejective and aspirate interactions

The main argument for auditory features comes from the uniform patterning of ejectives and aspirates in Quechua and Peruvian Aymara. The discussion here will focus on Quechua, which is subject to a full case study in Chapter 6. The pattern of Peruvian Aymara is identical to that of Quechua in all relevant respects.

As mentioned above, ejectives and aspirates form a natural class in auditory terms (both are characterized by [long VOT]) but not articulatory terms (ejectives are [constricted glottis] and aspirates are [spread glottis]). The patterning of ejectives and aspirates as a class provides typological evidence for the auditory feature [long VOT]. Further evidence, discussed below, comes from the results of one of the perception experiments reported in Chapter 4.

The cooccurrence pattern of Quechua shows that a feature that groups ejectives and aspirates is necessary. In Quechua, ejectives and aspirates pattern as a single class, distinct from the voiceless unaspirated (or plain) stops. The inventory of Quechua consonants is given in (55), taken from MacEachern (1999).

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[7] In addition to modal and creaky phonation, implosives can also be produced with a voiceless closure (Pinkerton 1986; Ladefoged and Maddieson 1996). I do not know of any languages where voiceless implosives are subject to cooccurrence restrictions, and thus do not discuss this class of implosives or the auditory features that define it.

(55)   Quechua consonant inventory

	labial	alveolar	postalveolar	velar	uvular	glottal
plain	p	t	tʃ	k	q	ʔ
aspirate	pʰ	tʰ	tʃʰ	kʰ	qʰ	
ejective	p'	t'	tʃ'	k'	q'	
fricative		s	ʃ			h
nasal	m	n	ɲ			
liquid		l ɾ	ʎ			
glide	w		j			

The majority of Quechua roots are disyllabic with an optional coda (usually a non-stop) in the first syllable, CV(C)CV. Ejectives and aspirates are subject to both dissimilatory and ordering restrictions. Examples of dissimilation are given in (56), taken from Ajacopa et al.'s (2007) dictionary. Pairs of ejectives, pairs of aspirates, and pairs of one ejective and one aspirate are unattested (MacEachern 1999). Pairs of plain stops are unrestricted.

(56)   Dissimilation - Quechua
    a. **k'inti**   'a pair'   ✓ K'-T
        kʰastuy   'to chew'   ✓ Kʰ-T
        kintu   'a bunch'   ✓ K-T

    b. ***k'int'i**   *K'-T'
        ***kʰastʰuy**   *Kʰ-Tʰ
        ***k'intʰi** / ***kʰint'i**   *K'-Tʰ

The dissimilation pattern shows that ejectives and aspirates are not subject to independent restrictions in Quechua. While the absence of pairs of ejectives (*K'-T') and pairs of aspirates (*Kʰ-Tʰ) can be accounted for with restrictions on the individual features referring to these two classes of segments, the absence of pairs of ejectives and aspirates (*K'-Tʰ) cannot be accounted for in this way. A pair of one aspirate and one ejective does not violate any constraint referring just aspirates or just ejectives.

    Both ejectives and aspirates in Quechua are also subject to ordering restrictions, as shown by the data in (57). Ejectives and aspirates must be initial in roots with another plain stop, but may appear in either initial or medial position in roots with another non-stop consonant.

(57)   Ordering restriction – Quechua
    a. **kʰapa**   'step'   ✓ Kʰ-T
        k'apa   'cartilage'   ✓ K'-T
        ***kapʰa**   *K-Tʰ
        ***kap'a**   *K-T'

    b. **kʰuru**   'small animal'   ✓ Kʰ-M
        k'iri   'injury'   ✓ K'-M
        rukʰu   'decrepit'   ✓ M-Kʰ
        ruk'iy   'to pack tightly' ✓ M-K'

2.2.2.1   The auditory feature account of Quechua

To account for the Quechua pattern, some feature must refer to ejectives and aspirates as a class, distinguishing them from plain stops. The proposed auditory feature [long VOT] does just this. Ejectives and aspirates in Quechua form a class in auditory terms because they share long voice onset time. The acoustic study of Quechua to follow in §3.2 shows that the average VOT of ejectives and aspirates is comparable (126 ms and 120 ms, respectively), and contrasts starkly with the average VOT for plain stops (23 ms).

As shown in the auditory feature chart in (58), the shared property of long VOT thus distinguishes ejectives and aspirates from plain stops. Additional acoustic correlates of laryngeal contrasts in Quechua uniquely identify one series: ejectives alone have a loud burst amplitude, and aspirates alone involve aspiration noise during VOT and breathiness in the beginning of following vowel (referred to by the feature [aspiration]).

(58)

	[long VOT]	[loud burst]	[aspiration]
K'	+	+	
K^h	+		+
K			

The feature specifications in (58) allow for reference to ejectives and aspirates as a class. The features [loud burst] and [aspiration] distinguish ejectives and aspirates from one another. Only two of the three features in (58) play a role in the analysis of Quechua in Chapter 6, [long VOT] and [loud burst]. While there is no direct evidence *against* restrictions on the distribution of [aspiration], there is only direct evidence *for* restrictions on [long VOT] and [loud burst].

In addition to the typological evidence from Quechua, the status of [long VOT] as a perceptually relevant auditory dimension is supported by the experimental results in Chapter 4. The experiments in that chapter found the same perceptual interaction between pairs of one ejective and one aspirate as between pairs of ejective and pairs of aspirates. The crucial result is that a 1 vs. 2 contrast between [long VOT] segments, regardless of whether they are ejective or aspirate, is perceptually weaker than the 1 vs. 0 contrast in [long VOT] segments. The relevant results are given in (59), where '<' means 'less perceptible than'. The experiment is discussed in detail in Chapter 4.

(59)   {k'ap^{h}i, k'api}   <   {kap^{h}i, kapi}
         {k^{h}ap'i, k^{h}api}   <   {kap'i, kapi}

In (59), an ejective interferes with the processing of an aspirate contrast, and an aspirate interferes with the processing of an ejective contrast. The interaction of ejectives and aspirates in the phonology of Quechua thus has a perceptual parallel, which I attribute to the shared acoustic property of ejectives and aspirates: long VOT.

The patterning of ejectives and aspirates provides direct evidence for restrictions on [long VOT]. Evidence for restrictions on [loud burst] comes from Bolivian Aymara. In Bolivian Aymara, which has the same consonantal inventory as Quechua, only ejectives are subject to dissimilation. As in Quechua, roots in Bolivian Aymara may not contain two ejectives. Unlike in Quechua, however, Bolivian Aymara roots may have two aspirates or one aspirate and one ejective.

(60) Bolivian Aymara dissimilation

    a.   **k'astu**   'pole'   ✓ K'-T

         k^{h}iti   'who'   ✓ K^h-T

         kuʎta   'button'   ✓ K-T

    b.   **k'ast'u*   *K'-T'

         k^{h}it^{h}a 'messenger'   ✓ K^h-T^h

         t'ink^{h}a   'tip'   ✓ K'-T^h

The cooccurrence patterns of Quechua and Bolivian Aymara can be accounted for with systemic markedness constraints referring to the auditory features [long VOT] and [loud burst], as is done in the formal analysis of both languages in Chapter 7. While aspiration noise is also an auditory characteristic of aspirates in these language, there is as yet no unambiguous evidence that aspiration noise is subject to long-distance restrictions independent of [long VOT]. Specifically, there are no known languages where aspirates are restricted to the exclusion of ejectives, and thus there is no direct support for constraints on aspiration noise.

The next two sub-sections consider two alternative analyses of the ejective-aspirate interactions in Quechua that do not appeal to auditory features. The contrastive underspecification account of Mackenzie (2009) is summarized in §2.2.2.2, and §2.2.2.3 sketches an analysis based on the laryngeal node. It is shown that both have these analyses have trouble accounting for the Quechua data and make undesirable typological predictions.

2.2.2.2   Alternative account 1: Mackenzie (2009)

Mackenzie (2009) develops an account of Peruvian Aymara, a language that shows the same dissimilatory and ordering restrictions on ejectives and aspirates as Quechua. Her analysis employs contrastively underspecified representations and derives both dissimilation and ordering restrictions from markedness constraints of the form *[αF][+F]. The analysis is given in the four tableaux in (61).

(61)   Dissimilation and ordering restrictions – Mackenzie (2009)

a.   Ordering restriction on ejectives

/kap'i/	*[αcg][+cg]	MAX[+cg]	IDENT[cg]
i. kap'i	* !		
ii. → k'api			**
iii. kapi		* !	*

b.   Dissimilation in ejectives

/k'ap'i/	*[αcg][+cg]	MAX[+cg]	IDENT[cg]
i. k'ap'i	* !		
ii. → k'api		*	*
iii. kapi		**!	**

42

c. Ordering restriction on aspirates

/kap^{h}i/	*[αsg][+sg]	MAX[+sg]	IDENT[sg]
i. kap^{h}i	* !		
ii. → k^{h}api			**
iii. kapi		* !	*

d. Dissimilation in aspirates

/k^{h}ap^{h}i/	*[αsg][+sg]	MAX[+sg]	IDENT[sg]
i. k^{h}ap^{h}i	* !		
ii. → k^{h}api			**
iii. kapi		* !	*

Constraints of the form *[αF][+F] penalize both roots with two ejectives or aspirates, and roots with a plain stop followed by an ejective or an aspirate. Under Mackenzie's account, plain stops are specified as [-cg, -sg], while non-stops are underspecified for both [αcg] and [αsg]. Feature specifications are assigned as they are needed to distinguish contrasting segments. The contrastive hierarchy for the stop system of Peruvian Aymara and Quechua is given in (62).

(62)   T, T^h, T'
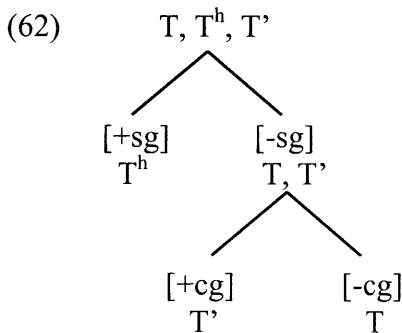
Plain stops and ejectives are specified for both [αcg] and [αsg], but aspirates are only specified as [+sg] and are underspecified for [αcg]. Given these representations, ejective-aspirate sequences violate *[αsg][+sg], but aspirate-ejective pairs do not violate either *[αsg][+sg] or *[αcg][+cg]. In order to account for the ungrammaticality of aspirate-ejective pairs, Mackenzie must propose an additional constraint, *[αcg][+sg]. While this constraint allows for an account of the ejective-aspirate interaction in Quechua, the analysis is stipulative. The ungrammaticality of ejective-aspirate pairs is not formally connected to the ungrammaticality of ejective pairs and aspirate pairs. Moreover, a constraint of the form *[αcg][+sg] raises the question of why it is sequences of just these two features that are disallowed; why are [+sg] segments disallowed following [αcg] segments as opposed to [αlabial] or [αnasal] segments? If in addition to *[αF][+F] constraints, we must admit *[αF][+G] constraints, we predict many phonological interactions between distinct features. As will be discussed more in the next sub-section, just the range of interactions between laryngeal features is quite restricted, let alone the range of interactions between more phonetically disparate features.

2.2.2.3 Alternative account 2: the laryngeal node

While there is no articulatory feature that groups ejectives and aspirates, standard feature geometry does allow for reference to these two types of stops via the laryngeal node. The laryngeal node hypothesis faces two difficulties. First, reference to the laryngeal node cannot actually account for cooccurrence restrictions in Quechua. Second, even if an analysis of Quechua based on the laryngeal node did work, it makes unattested predictions for the range of interactions between laryngeally marked segments.

An analysis of Quechua referring to the laryngeal node would look as follows. Assume that ejectives and aspirates are both specified for a feature dominated by the laryngeal node, and plain stops simply have no laryngeal node at all, as in (63). All stops are specified for place features etc., but only ejectives and aspirates have a laryngeal node.

(63) Representation of Quechua stops – laryngeal node analysis
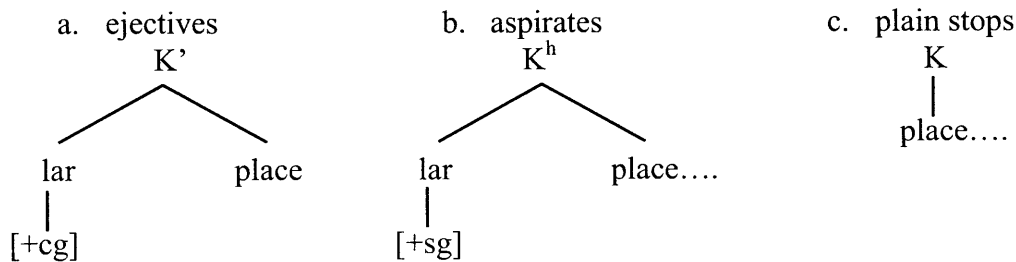
Given the representations in (63), the absence of roots with pairs of ejectives, pairs of aspirates, and ejective-aspirate pairs can be accounted for with a high ranked markedness constraint against root with two laryngeal nodes, *[lar][lar]. The tableaux in (64) shows how this constraint penalizes roots with two laryngeally marked consonants, but correctly allows pairs of plain stops, which lack a laryngeal node, to surface faithfully.

(64) Dissimilation – laryngeal node analysis

a. Dissimilation in pairs of ejectives

/k'ap'i/	*[lar][lar]	IDENT
i. k'ap'i	* !	
ii. → k'api		*

b. Dissimilation in pairs of aspirates

/kʰapʰi/	*[lar][lar]	IDENT
i. kʰapʰi	* !	
ii. → kʰapi		*

c. Dissimilation in ejective-aspirate pairs

/kʰap'i/	*[lar][lar]	IDENT
i. kʰap'i	* !	
ii. → kʰapi		*

d.   Pairs of plain stops surface faithfully

/kapi/	*[lar][lar]	IDENT
i. → kapi		
ii. kʰapi		* !

If plain stops are presumed to not have a laryngeal node at all, that is, to not be specified as [-cg] and [-sg], then dissimilation in Quechua can be analyzed as a prohibition against most than one laryngeal node in a root. The underspecification of plain stops, however, is not compatible with the ordering restriction in Quechua. Ejectives and aspirates may not follow plain stops in a root, but may follow other non-stops. If plain stops do not have a laryngeal node at all, then the analysis of ordering restrictions must be driven by a markedness constraint that disallows [-cont, -son] segments to precede a [lar] specification. Such an analysis is completely stipulative. The relevant distinction between stops and non-stops in ordering restrictions is that stops are minimally contrastive for laryngeal features and non-stops are not. Plain stops cannot be underspecified, they must be specified for [-cg] and [-sg] under the laryngeal node in order to account for the ordering restriction in Quechua. Mackenzie's contrastive underspecification analysis discussed above also crucially makes use of the fact that plain stops are specified for the negative value of laryngeal features. If plain stops *have* a laryngeal node, which they must, then dissimilation cannot be driven by a constraint against multiple laryngeal nodes, as this would disallow roots with two plain stops, as shown in (65) and (66).

(65)   Representation of Quechua stops – revised

a. ejectives
K'

lar   place...
|
[+cg]

b. aspirates
Kʰ

lar   place...
|
[+sg]

c. plain stops
K

lar   place...
|
[-cg, -sg]
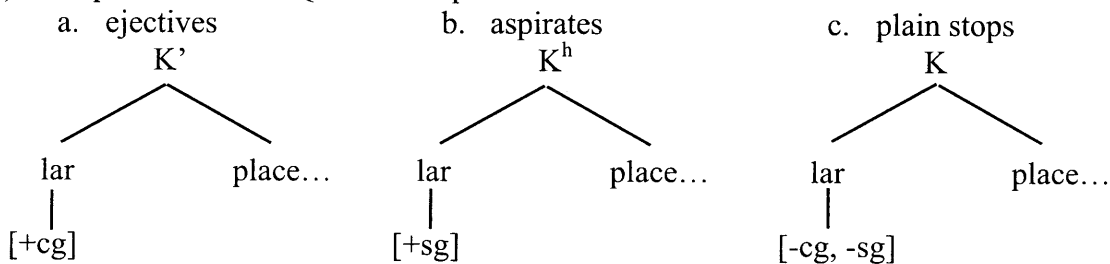
(66)   Pairs of plain stops – wrong result

/kapi/	*[lar][lar]	IDENT
a. ← kapi	* !	
b. → kami		*

While the laryngeal node allows a way of referring to both ejectives and aspirates as a class, it cannot be employed in the case of Quechua to group ejectives and aspirates to the exclusion of plain stops. This is the crucial distinction that must be made in order to analyze the Quechua data, showing the inadequacy of the laryngeal node hypothesis.

The second problem with the laryngeal node hypothesis, as mentioned above, is that it incorrectly predicts that any laryngeally marked segment can pattern with any other laryngeally marked segment. This is far from true. There are no known cases where voiced stops pattern in coccurrence restrictions with ejectives, aspirates or implosives. Moreover, the interaction between ejectives and aspirates or ejectives and implosives is shown in this sub-section and the next is shown to correlate with whether the two classes of segments share an auditory dimension.

45

Languages may treat articulatory disparate sounds as a single phonological class because they share an auditory feature, not because they share a specified laryngeal node.

2.2.3 Ejective and implosive interactions

This section looks at cooccurrence restrictions on ejectives and implosives in two languages where they consitute a single contrastive series, Hausa (Afro-Asiatic) and Tz'utujil (Mayan). As with ejectives and aspirates, ejectives and implosives may pattern together as a single class, or ejectives may pattern independently. The uniform patterning of ejectives and implosives provides support for the phonological relevance of the auditory feature [creak], which groups ejectives and implosives produced with creaky phonation.

Ejective and implosive interactions do not provide direct evidence for auditory features, as the attested patterns are amenable to either articulatory or auditory representations. The decisive argument for auditory representations was made in the previous section. The interaction of ejectives and aspirates necessitates auditory representations because ejectives and aspirates share auditory but not articulatory features. The purpose of this section is thus to show that the ejective and implosive patterns *can* be accounted for with perceptual dispersion constraints on auditory dimensions, not that they *must* be.

In Hausa, ejectives and implosives are non-contrastive and are both produced with creaky phonation. There is a single series of glottalic consonants, realized as implosive at the labial and coronal places of articulation, and as ejective for the coronal affricate and velars. The consonantal inventory is given in (67), adapted from MacEachern (1999). The original source is Kraft and Kraft (1973).

(67) Hausa consonant inventory

	labial	alveolar	palato alveolar	velar	palatalized velar	labialized velar	glottal
voiced	b	d	dʒ	g	g^j	g^w	
plain		t	tʃ	k	k^j	k^w	
glottalic	ɓ	ɗ ts'		k'	$k^{j'}$	$k^{w'}$	ʔ
fricative	ɸ	s z	ʃ				h
nasal	m	n					
liquid	w	l r ɾ	ɥ ɥ				

As can be seen in (67), the glottalic series of stops in Hausa contrast with both a voiceless and a voiced series. For the present discussion, the relevant distinction is between glottalic and non-glottalic consonants. Cooccurrence restrictions target the entire glottalic series; no distinction is made between ejectives and implosives. Ejectives and implosives may cooccur with plain or voiced stops (68a), but pairs of ejectives, pairs of implosives and pairs of one ejective and one implosive are all unattested (68b). Voiced and voiceless stops freely coocur (68c).

(68) Hausa cooccurrence restrictions

a. k'uta   'displeasure'[8]   ✓ K'-T
    bak'i   'black'   ✓ K'-D
    ɓati   'spoiled'   ✓ ɓ-T
    ɗige: 'filter'[9]   ✓ ɓ-D

b. *k'ut'a   *K'-T'
    *ɓaɗi   *ɓ-ɗ
    *ɓak'i / *k'aɓi   *K'-ɗ

c. ke:tʃè   'is split, torn'   ✓ K-T
    bùgu   'to be drunk'[10]   ✓ G-D
    do:ki   'horse'   ✓ K-D

Besides forming a single contrastive series in the inventory or Hausa, ejectives and implosives form a natural class in both articulatory and auditory terms. Both ejectives and implosives are produced with a constricted glottis, and are both realized with creaky phonation. The study of Lindau (1984) found that both ejectives and implosives are primarily characterized by creaky phonation in Hausa. The closure phase of a Hausa implosive is creaky, while in an ejective creaky voice is found in the transition between the closure and the following vowel.

Hausa ejectives are thus quite different from the ejectives in a language like Quechua, as discussed in the acoustic survey in Chapter 3. In Hausa, ejectives have a short VOT lag and creaky phonation in the following vowel, as opposed to the long VOT and modal phonation found in Quechua. Hausa implosives similarly contrast with implosives in other languages. While Hausa implosives have a creaky voiced closure, implosives in the other Niger-Congo languages studied by Lindau are modally voiced throughout closure. The phonetics of the glottalic series of consonants in Hausa supports the proposed auditory feature [creak]. The Hausa cooccurrence pattern reflects a restriction on [creak], which distinguishes ejectives and implosives on one hand from voiced and voiceless stops on the other.

As in Hausa, ejectives and implosives in Tz'utujil form a single series, contrasting with voiceless unaspirated stops. The consonantal inventory of Tz'utujil is given in (69).

(69) Tz'utujil consonant inventory

	labial	alveolar	palato alveolar	velar	uvular	glottal
plain	p	t ts	tʃ	k	q	
glottalic	ɓ	ɗ ts'	tʃ'	k'	q'/ɠ	ʔ
fricative		s	ʃ			h
nasal	m	n				
liquid	w	l r	j			

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[8] Taken from an online Hausa-English dictionary: http://www.websters-online-dictionary.org/translation/Hausa/.

[9] Taken from an online Hausa-English dictionary: http://www.websters-online-dictionary.org/translation/Hausa/.

[10] Taken from an online Hausa-English dictionary: http://www.websters-online-dictionary.org/translation/Hausa/.

Tz'utujil cooccurrence restrictions apply to the ejectives. The labial and coronal implosives are not subject to laryngeal cooccurrence restrictions. Pairs of ejectives may not cooccur in a Tzutujil root, but pairs of implosives and pairs of one ejective and one implosive are attested.

(70)   Tz'utujil cooccurrence restrictions
    a.   tʃ'aːk   'flesh'   ✓ K'-T
         ɓatsʼ   'thread'   ✓ K'-ɗ
         ɗeɓeli   'thick (of liquid)'   ✓ ɓ-ɗ

    b.   *tʃ'aːk'   *K'-T'

    c.   tik   'sewn'   ✓ K-T

The phonetics of glottalic consonants in Tz'utujil provide a clear explanation for the variation in the phonological patterning between the labial and coronal implosives on one hand and the ejectives on the other. The study of Pinkerton (1986) measured intraoral air pressure of stops in several languages in the Quichean subgroup of the Mayan family, including Tz'utujil. Her findings are that the labial and alveolar glottalic stops in Tz'utujil are pre-voiced and involve a sharp drop in intraoral air pressure during the closure. These are thus true voiced, ingressive implosives, as opposed to the creaky voiced implosives of Hausa. The glottalic series in Tz'utujil contains modally voiced implosives [ɓ, ɗ], ejectives [ts', tʃ', k', q'], and only the ejectives are subject to a cooccurrence restriction. The precise realization of ejectives in Tz'utujil is not of deep import. The relevant point is that regardless of whether Tz'utujil ejectives are creaky voiced like ejectives in Hausa, or have a loud burst and long VOT like ejectives in Quechua, they do not share an auditory property with the modally voiced implosives. The split in the phonology of ejectives and implosives in Tz'utujil thus mirrors the split in auditory properties between these two types of segments.

The discussion of Quechua, Bolvian Aymara, Hausa and Tz'utujil has shown that different types of laryngeally specified consonants pattern together phonologically when they share an auditory feature. While ejectives may pattern with aspirates, as in Quechua, or with implosives, as in Hausa, the groupings of laryngeal categories correlates with auditory properties of ejectives, aspirates and implosives across languages. In Quechua, where ejectives pattern with aspirates, ejectives have a long VOT comparable to that of the aspirates. The ejectives that pattern with implosives in Hausa have a shorter VOT and are crucially characterized by creaky phonation in the following vowel.

2.3   The Dispersion Theory of Contrast

This section provides the theoretical background underlying the formal analysis of laryngeal cooccurrence restrictions. The section first gives some general background on the Dispersion Theory of Contrast (henceforth DT) (Flemming 1995, 2004, 2006; Padgett 2003; Sanders 2002), and then addresses the application of DT to positional or contextual neutralization and to laryngeal cooccurrence restrictions specifically.

2.3.1 Dispersion constraints and inventories of contrasts

Typological generalizations about the structure of phonemic inventories provide evidence for constraints on the distinctness of contrasts. A good example is the distribution of backness and rounding contrasts, analyzed in detail in Flemming (2004, 2006). There is a cross-linguistic tendency for non-low vowels to either be front and unrounded or back and rounded, as in the canonical 5 vowel inventory in (71).

(71)　　　i　　　u
　　　　　　e　　　o
　　　　　　　　a

This covariation has a straightforward perceptual explanation. The difference between front and back vowels is primarily that the frequency of the second formant (F2) is high in front vowels and low in back vowels. Lip rounding lowers F2, and thus contrasts along the dimension of F2 are maximally distinct when rounding covaries with backness (Liljencrants and Lindblom 1972; Stevens, Keyser and Kawasaki 1986).

　　　From this perspective, languages with an inventory like that in (71) disallow front rounded and back unrounded vowels because these vowels would create insufficiently distinct contrasts. This analysis is formalized as a fixed ranking of constraints on minimal contrasts. The figure in (72a) plots high vowels in F2, assigning the five vowels to a value 1 thru 5. The constraints in (72b) refer to this hierarchy and penalize smaller differences in F2 more than larger differences in F2. The fixed ranking of constraints is such that less distinct contrasts violate more constraints that more distinct contrasts. A constraint like MinDist=F2:4, for example, requires that contrasting vowels differ in at least 4 on the F2 dimension, a requirement satisfied only by the contrast [i-u].

(72)　　F2 scale and systemic constraints (Flemming 2006:2)
　　　a.　5　　　4　　　3　　　2　　　1
　　　　　◄─────────────────────────────
　　　　　i　　　y　　　ɨ　　　ɯ　　　u

　　　b.　MinDist=F2:1　>>　MinDist=F2:2　>>　MinDist=F2:3　>>　MinDist=F2:4

The constraint set in (72) predicts that more distinct contrasts will be preferred over less distinct contrasts. The cross-linguistic preference for the maximally distinct contrast between back rounded and front unrounded vowels, [i-u], is due to the fact that this contrast violates the lowest ranked constraint on the hierarchy in (72b). The analysis in (72) competes with fixed ranking of contrast insensitive markedness constraints, as shown in (73).

(73)　　contrast insensitive markedness constraints (Flemming 2006:2)
　　　*[front, +round], *[back, -round], *[central] >> *[front, -round], *[back, +round]

The two constraint sets in (72b) and (73) make different predictions for the typology of backness and rounding in vowels. The segmental, contrast-insensitive markedness constraints in (73) predict that central vowels like [ɨ] are inherently marked, whereas the systemic constraints in

(72b) predict that central vowels are only marked when they contrast with peripheral vowels, e.g. the contrast [i-ɨ] is marked. While the segmental markedness constraints predict a general dispreference for central vowel qualities, the systemic constraints predict that central vowels will only be disprefered when they contrast with a peripheral vowel. Flemming (2004) shows that the predictions of the contrast based analysis are correct. While central vowels are relatively uncommon in languages with front-back contrasts, they are common in languages without a front-back contrast. Languages like Kabardian (Kuipers 1960; Choi 1991) and Marshallese (Bender 1968; Choi 1992) have so-called 'vertical' vowel inventories, which contrast only for height. The backness and rounding of these vowels is contextually variable, but clusters around central qualities, [ɨ, ə] in Kabardian and [ɨ, ə, a] in Marshallese. While peripheral vowels like [i, u] are common cross-linguistically, they are unattested in languages without front-back contrasts. There are no languages with inventories like [i, e, a] or [u, o, a].

The example of vowel inventories sketched above shows that the markedness of a given vowel depends on what other vowels it contrasts with. Languages with a front-back contrast show a preference to have a maximally distinct contrast along this dimension, by requiring that backness and rounding covary. In languages without a front-back contrast, however, vowels take on a central vowel quality, reflecting a preference for minimizing articulatory effort. In DT, the inventory of a language is determined by the ranking of three types of constraints. Systemic markedness constraints (MINDIST constraints in (72)) favor maximally distinct contrasts along a given dimension, while articulatory markedness constraints (which are not contrast sensitive) favor less effortful segments. These two constraints interact with a positive constraint (or constraints) that favors more contrasting segments, MAXIMIZECONTRASTS. The interaction of these three types of constraints is illustrated in the three tableaux in (74), which derive three different inventories of high vowels. The constraint *EFFORT is used here as a generic articulatory markedness constraint, penalizing peripheral vowels.

(74) a. Maximally distinct contrasts

	MINDIST=F2:4	MAXCON	*EFFORT
i. i-ɨ-u	* !	✓✓✓	**
ii. → i-u		✓✓	**
iii. ɨ		✓ !	

b. Minimal effort

	MINDIST=F2:4	*EFFORT	MAXCON
i. i-ɨ-u	* !	**	✓✓✓
ii. i-u		** !	✓✓
iii. → ɨ			✓

c. More contrasts

	MAXCON	MINDIST=F2:4	*EFFORT
i. → i-ɨ-u	✓✓✓	*	**
ii. i-u	✓✓ !		**
iii. ɨ	✓ !		

In (74a), the maximally distinct pair of contrasting sounds [i-u] is chosen. The candidate in i with more contrasts violates a high ranked constraint on the distinctness of contrasts, while candidate iii does not allow for any contrast at all. In (74b), *Effort is ranked above MaxCon, preferring the articulatory simple inventory of a single central vowel over contrasting peripheral vowels. In (74c), we see that when MaxCon is high ranked, more contrasting sounds are preferred even though this necessitates less than maximally distinct contrasts.

The tendency of backness and rounding to covary in vowel inventories shows that markedness is a property of contrasts, as opposed to individual segments or features. While peripheral vowels are strongly favored in languages with a backness contrast, in the absence of such a contrast there is no preference for peripheral vowels. This is the basic argument for systemic markedness constraints in phonology.

Dispersion constraints play a role in positional neutralization, of which laryngeal cooccurrence restrictions are one type, as well as in inventory selection. The next section discusses DT and positional neutralization, first addressing the grammatical architecture proposed in Flemming (2006) and then applying this architecture to laryngeal cooccurrence restrictions specifically.

2.3.2 Positional neutralization in DT

A preference for more distinct contrasts can be seen in the structure of inventories, but also in the distribution of contrasts. Steriade (1997) shows that a variety of contrasts are neutralized precisely in those environments where the primary cues to the contrast are absent. A good example is positional neutralization of voicing in obstruents. Voiced and voiceless stops are primarily distinguished by VOT, a cue that is audible in pre-sonorant position but absent in pre-obstruent or final position. The distribution of voicing contrasts mirrors the distribution of VOT cues: some languages allow a voicing contrast in pre-sonorant position, but neutralize this contrast in pre-obstruent and final position. No language shows the opposite pattern, neutralizing a voicing contrast in pre-sonorant position but maintaining it in pre-obstruent or final position. This pattern is easily accounted for in DT when systemic markedness constraints evaluate contrasts in context.

To analyze positional neutralization of voicing contrasts with contrast markedness constraints, consider that in pre-sonorant position a voiced stop has a VOT of 0 and a voiceless stop a VOT of 1. In pre-obstruent position, both voiced and voiceless stops have an unspecified VOT, and thus do not differ on this auditory dimension. Further assume a constraint requiring that contrasting segments differ by at least a VOT difference of 1, MinDist=VOT:1. This constraint will penalize contrasts between voiced and voiceless stops in pre-obstruent position, where they do not contrast for VOT, but not in pre-sonorant position, where voiced and voiceless stops differ by 1 in VOT. The pattern is shown in the two tableau in (75). The outcome of neutralization of the voicing contrast in (75b) is determined by a low ranked articulatory markedness constraint against voiced stops.

51

(75)   Positional neutralization of voicing contrasts

a. Voicing contrast surfaces in pre-sonorant position

/__V	MɪɴDɪꜱᴛ=VOT:1	MᴀxCᴏɴ	*[+voi, -son]
i. → tV–dV		✓✓	*
ii. tV		✓!	
iii. dV		✓!	*

b. Voicing contrast is neutralized in pre-obstruent or final position

/__#	MɪɴDɪꜱᴛ=VOT:1	MᴀxCᴏɴ	*[+voi, -son]
i. t#–d#	*!	✓✓	*
ii. → t#		✓	
iii. d#		✓	*!

Laryngeal cooccurrence restrictions are similar in kind to the pattern in (75). Languages that have, for example, both ejectives and plain stops in the inventory may not allow these two types of sounds to contrast with one another in all positions or in all types of roots. It may be that ejectives and plain stops may not contrast in pre-obstruent position, or that they may not contrast in roots with another laryngeally marked stop. Long-distance restrictions on laryngeal features are not restrictions at the level of the inventory, but rather restrictions on the distribution of a contrast in a certain non-local context. Basic assimilation and dissimilation can be thought of as neutralization of a laryngeal contrast in the context of another laryngeally marked stop within the root, schematically *K'-K//[...K'...]$_{RT}$.

While markedness constraints on contrast clearly play a role both in deriving the segmental inventory of a language and positional neutralization of contrasts, MᴀxɪᴍɪᴢᴇCᴏɴᴛʀᴀꜱᴛꜱ and systemic markedness constraints make problematic predictions if they are allowed to freely evaluate contrasts in context. The architecture of a grammar with systemic markedness must be somewhat more complex than what has been shown so far. The basic problem is that perceptual distinctness constraints and MᴀxɪᴍɪᴢᴇCᴏɴᴛʀᴀꜱᴛꜱ can derive a language with radically different inventories of sounds in different contexts. If these constraints freely evaluate sounds in context, the number and strength of contrasts will be maximized relative to a given context, and thus we should find languages with substantially different inventories of segments in different environments. This is contrary to fact. Languages tend to be adequately characterized as having a single inventory of sounds. If contrasts are insufficiently distinct in a certain context, the result is neutralization of the contrast, not restructuring to a different contrast that is adequately distinct in the given environment.

The problem can be illustrated with an example from Cantonese. In this language, front rounded vowels do not occur adjacent to labials, *pø, *my, *øp, *yp, etc. (Kao 1971; Yip 1988). The perceptual explanation for this restriction is that coarticulation between a labial and an adjacent vowel decreases the perceptual strength of a rounding contrast on the vowel itself, making sequences like [pi] and [py] confusable. In Cantonese, the usual contrast between front unrounded, front rounded and back rounded vowels [i, y, u, e, ø, o] is reduced to a contrast between front unrounded and back rounded vowels [i, u, e, o] in the context of labials. Crucially, the insufficiently distinct contrast between front rounded and unrounded vowels is simply neutralized, no other contrast appears instead.

If MᴀxɪᴍɪᴢᴇCᴏɴᴛʀᴀꜱᴛꜱ and systemic markedness constraints interact freely in the evaluation contrasts in context, then languages are predicted where instead of neutralization, the

inventory of contrasting vowels is different adjacent and non-adjacent to labials. For example, adjacent to labials we could find the inventory [i, ɨ, u, e, ə, o], but [i, y, u, e, ø, o] elsewhere. In this type of language, the rounding contrast in front vowels is displaced to a contrast between front and central vowels in contexts where rounding is perceptually indistinct. No such language exists, and, moreover, Flemming claims that this type of inventory restructuring is not generally attested. A problematic prediction along these lines for laryngeal cooccurrence restrictions would be a language that generally contrasts voiceless unaspirated stops and ejectives, but in roots with two ejectives, one is realized as an implosive. In this scenario, the perceptual weakness of an ejective contrast in the context of another ejective is overcome by displacing the ejective-plain contrast to an implosive-plain contrast.

In order to restrict the possible effects of contrast markedness constraints, Flemming proposes a limited interaction model with three parallel evaluation modules: Inventory, Realization and Evaluation of Surface Contrasts (ESC). The Inventory component of the grammar selects an inventory of contrasting sounds, selected by the ranking of systemic markedness constraints, MAXIMIZECONTRASTS, and articulatory markedness constraints, as shown in §2.3.1 above. The phonetic properties of these sounds in context is determined in the Realization component of the grammar. These phonetically detailed representations are then evaluated by the ESC component, which determines whether the contrasts in context meet the distinctness requirements determined in the Inventory.

Importantly, the Inventory component selects a set of contrasting sounds that are specified for perceptual targets. For example, voiced and voiceless stops may be selected as contrasting sounds, but may also be specified for VOT targets of 0 and 1 respectively. The conditions for perceptual distance between contrasting sounds determined in the Inventory component are evaluated in context in the ESC component. Given the inventory of sounds selected in the Inventory component, underlying forms are constructed with all sequences of sounds. This limited, but still fairly rich base, serves as the input to ESC, where those forms that do not satisfy perceptual distance constraints or other metrical and prosodic constraints are eliminated as possible word forms in the language. In this model, systemic markedness constraints on perceptual distance in ESC can only drive neutralization of a contrast, they cannot drive a restructuring of the system of contrasts set by the Inventory component. This is because the Realization and ESC components of the grammar are distinct. The Realization component determines what cues are and are not realized in a given context. The ESC component evaluates whether a set of contrasting forms, with perceptual cues determined in Realization, are adequately distinct. ESC cannot influence the realization or inventory of contrasts, it can only evaluate and favor neutralization of contrasts.

To see how the model works, we return to the Cantonese example from above. The analysis given here is a simplified version of the analysis in Flemming (2006). The inventory of high vowels [i, y, u] is selected in the inventory component, as shown in (80). In the following tableau I adopt a shorthand formulation of the MINDIST constraints that select an inventory of high vowels contrasting in backness and rounding. While backness and rounding both effect F2, F3 distinguishes front rounded and unrounded vowels, and thus MINDIST constraints must refer to both of these dimensions. For a more formally developed analysis of Cantonese, see Flemming (2006).

(76)   Inventory – high vowel contrasts in Cantonese

	*y-ɨ	*y-ɯ	MAXCON	*ɨ-i	*y-i
a. {i, y, ɨ, u}	* !		✓✓✓✓	*	
b. {i, y, ɯ, u}		* !	✓✓✓✓		*
c. {i, ɨ, u}			✓✓✓	*	
d. → {i, y, u}			✓✓✓		*
e. {i, u}			✓✓!		

Inventories with four contrasting vowels in (76a,b) are eliminated by high-ranking systemic markedness constraints; contrasts between non-peripheral {y, ɨ, ɯ} vowels are insufficiently distinct in both F2 and F3. The maximally distinct contrast between two peripheral vowels {i, u} in (76e) is dispreferred due to the ranking of MAXCON over other systemic markedness constraints. The choice between (76c,d) is made by lower ranked systemic markedness constraints, which favor the combined contrast in F2 and F3 between {y, i} to the contrast in F2 between {i, ɨ}.

The input to the realization and ESC components of the grammar consist of all of the possible combinations of inventory segments. The tableau in (78) shows a set of forms with each of the three high vowels adjacent to a labial. Each of the output forms in the candidate sets in ESC are given full perceptual specifications relative to their particular context. The tableau in (77) shows how coarticulation with an adjacent labial alters the realization of a front unrounded vowel. In the context of a labial, an unrounded vowel in Cantonese is realized with some degree of rounding, indicated with a superscript beta. The Realization grammar in (77) shows that coarticulation is favored in Cantonese over faithfulness to the unrounded specification of /i/. The labialization on /i/ in the context of a labial is shown in the output candidate sets in (78). The ESC component of the grammar evaluates the strength of the phonetically detailed contrasts provided by the Realization component. In (78), coarticulation between a labial and /i/ renders front rounded and front unrounded vowels too similar. This contrast is neutralized to a binary contrast between front unrounded and back rounded vowels.

(77)   Realization – high vowels adjacent to labials in Cantonese

/pin/	LABCOART	IDENT
a. pin	* !	
b. → piᵝn		*
c. piᵝn		**!

(78)   Evaluation of Surface Contrasts – high vowels adjacent to labials in Cantonese

{/pin, pyn, pun/}	*ɨ-iᵝ	IDENT	*y-u
a. {/pin, pyn, pun/} {[piᵝn, pyn, pun]}	* !		*
b. → {/pin, pun/} {[piᵝn, pun]}		*	
c. {/pyn, pun/} {[pyn, pun]}		*	* !

The three component model outlined here gives a formal status to the inventory, and restricts the activity of contrast markedness constraints to deriving a set of contrasting sounds in the Inventory and evaluating and potentially neutralizing contrasts in ESC.

2.3.3 DT and laryngeal cooccurrence restrictions

Laryngeal cooccurrence restrictions are analyzed as a type of positional neutralization. A contrast in a given laryngeal feature is neutralized in certain non-local contexts, where the context is specified as a root with another laryngeally marked feature (the 1 vs. 2 contrast). This section describes the application of the three component model to this conception of laryngeal cooccurrence restrictions.

As described above, the Inventory component of the grammar derives a set of contrasting sounds, independent of context. It is in this component that laryngeal contrasts and the auditory dimensions along which they differ are defined. For example, whether a language distinguishes ejectives from plain stops based on creakiness, burst amplitude, long VOT, or a combination of these cues is determined in the Inventory and cannot be altered by the Realization or ESC components. It was shown in §2.2 that the language particular auditory properties of ejectives and implosives are relevant to the phonological patterning of these sounds, and thus whether a language has lax or tense ejectives or modal or creaky implosives is crucial. The Inventory component is responsible for specifying the auditory dimensions along which laryngeally marked stops must differ. The Realization component of the grammar specifies what auditory cues are realized in a given context, allowing ESC to determine whether the distinctness thresholds set in the Inventory are met by contrasts in context.

The analyses in Chapters 5-7 will show only the ESC component of the grammar, where the contrasting set of laryngeal configurations in roots is selected. The input to the ESC is the set of all possible forms made up of segments in the inventory of the language. The tableaux shown in the case studies consider a sub-set of all possible forms – those prosodically well-formed roots that minimally contrast in laryngeal features. In a language with CVC roots, ejectives and plain stops, an input set of forms would be something like {/k'ap', k'ap, kap', kap/}.

The discussion in the remainder of this dissertation largely abstracts over the role of Realization and focusses only on ESC, where the perceptual distinctness of laryngeal contrasts between roots is evaluated. The formal constraints that are proposed penalize contrasts in particular contexts. For example, the constraint against the 1 vs. 2 contrast penalizes a contrast in an auditory feature [F] in the context of another instance of [F]. Constraints of this type refer to contexts, as opposed to actual distances along particular auditory dimensions. It is this difference that makes the analysis of laryngeal cooccurrence restrictions different from the analysis of Cantonese or final devoicing shown above and allows for the bypassing of the Realization component of the grammar.

The reference to context in the formalization of constraints is a simplification of a somewhat complex and ill-understood effect. As will be documented in more detail in Chapter 4, while it is found that the 1 vs. 2 contrast in laryngeal features is perceptually weaker than the 1 vs. 0 contrast, the cues to the contrast are identical in both cases. The realization of [k'] in a form like [k'ap'i] is no different from the realization of [k'] in a form like [k'api]. The perceptual hierarchy of laryngeal contrasts is thus supported by perception experiments, but is not derivative of acoustic ambiguity. While the source of this perceptual asymmetry is not known, the asymmetry is still assumed to be derived and specified in the Realization component of the

grammar. While the actual acoustic cues to ejection are identical in a root with and without another ejective, the perceptibility of these cues is not the same, and it is this perceptual asymmetry that is computed and represented in auditory terms in the Realization component.

This computation is not shown in detail because it is not understood how the presence of one ejective influences the auditory cues to another ejective. All that is known is that there is a weakening effect. In very vague terms, the effect can be thought of as follows. Consider that in general a plain stop has a [long VOT] value of 0 and an ejective has a [long VOT] value of 1. In a root like [kap'i], the [long VOT] value of the ejective is fully realized, and thus the pair {[kap'i, kapi]} differs in 1 along the dimension of [long VOT]. In a root like [k'ap'i], however, the [long VOT] values of the ejectives are less perceptible, and the pair {[k'ap'i, k'api]} differs in only .8 along the dimension of [long VOT].

It is assumed that the auditory representation of a laryngeally marked stop is altered by the presence of another laryngeally marked stop in a root, and that this interaction and the resulting representation is determined in the Realization component of the grammar. What is not known is how or to what extent this interaction affects actual values along an auditory dimension. The formal constraints and analytical discussion refers simply to the relative weakness of a laryngeal contrast in the context of another laryngeally marked stop (as represented by the relative values 1 and .8 in the example above), but not to the exact values or amplitude of difference along particular dimensions.

Chapter 3   The acoustics of laryngeal contrasts

This chapter focusses on the acoustic properties of ejectives, aspirates and implosives cross-linguistically. The goal of the chapter is to identify the auditory dimensions that define laryngeal contrasts, providing support for the set of auditory features employed in the analysis of long-distance laryngeal restrictions developed in Chapters 5, 6 and 7.

The main finding that emerges from the survey is that there are broadly two kinds of ejectives and two kinds of implosives, as proposed by Lindau (1984) and Kingston (1985). While aspirates are uniformly associated with long VOT across languages, ejectives and implosives are variable in their realization. Ejectives may be "stiff", primarily characterized by a loud burst amplitude and long VOT (as in Quechua), or "slack", primarily cued by creaky phonation in the following vowel (as in Hausa). While ejectives in some languages combine properties of both types of ejectives, this broad dichotomy will prove useful in explaining the phonological patterning of ejectives. Lindau identifies modally voiced implosives in several Ijoid languages, and creaky voiced implosives in Hausa. In both types of implosive, the voicing amplitude increases throughout closure. In modally voiced implosives, closure duration is relatively long and closure voicing is modal. Creaky voiced implosives are shorter and have creaky phonation during closure. This variation in the realization of ejectives and implosives supports the following four auditory features.

(1)   [long VOT]   "stiff" ejectives, e.g. Quechua
                                       aspirates
         [loud burst]   "stiff" ejectives, e.g. Quechua
         [creak]   "slack" ejectives, e.g. Hausa
                                       creaky voiced implosives, e.g. Hausa
         [voicing amplitude]   creaky and modally voiced implosives, e.g. Hausa and Ijoid

The four auditory features above allow ejectives to be referenced as a class with aspirates, when both share [long VOT], or implosives, when both share [creak].

The analysis of laryngeal cooccurrence restrictions developed in later chapters is driven by perceptually grounded constraints on the distinctness of laryngeal contrasts. Auditory representations are important to the analysis in two ways. First, the distinctness of contrasts is determined based on perceptual similarity, which is assumed to reflect the perceived distance between two sounds on some auditory dimension(s). For example, an aspirate is confusable with a plain stop when the difference in VOT between the two types of segments is not accurately perceived.

Second, auditory representations allow for an understanding of the interaction between laryngeal categories in cooccurrence restrictions, as shown in Chapter 2. In languages with multiple laryngeal distinctions, cooccurrence restrictions may target multiple laryngeal categories. Ejectives are found to pattern as a class with implosives in Hausa and with aspirates in Quechua. In Hausa, pairs of ejectives and pairs of implosives are ungrammatical (*K'-T', *ɓ-ɗ), and ejective-implosive pairs are disallowed as well (*K'-ɗ). Similarly, in Quechua pairs of ejectives, pairs of aspirates, and ejective-aspirate pairs are all unattested (*K'-T', *Kʰ-Tʰ, *K'-Tʰ). The patterning of multiple laryngeal categories correlates strongly with the auditory properties of the segments in question. In Hausa, ejectives and implosives are both associated

with creaky phonation. In Quechua, ejectives are stiff, characterized by a loud burst and share long VOT with aspirates.

The dichotomy in the realization of ejectives and implosives is thus reflected in the phonological patterning of these segments. Ejectives pattern with implosives when both involve creaky phonation (Hausa); when ejectives are primarily characterized by a loud burst and long VOT, they may pattern with aspirates (Quechua). The Quechua pattern provides particularly striking support for auditory representations because it shows that articulatory disparate sounds like ejectives and aspirates may pattern together phonologically when they share an auditory property like long VOT.

This chapter documents the phonetics of laryngeal categories that underscore the auditory features in (1). The role of auditory groupings in the phonological patterning of laryngeally marked sounds is discussed in Chapter 5. The first section of the chapter summarize the findings of previous studies of laryngeal contrasts involving ejectives, aspirates and implosives, both in languages with and without cooccurrence restrictions on laryngeal features. The second two sections present detailed acoustic documentation of two of the languages analyzed in later chapters. §3.2 reports on fieldwork documenting the contrast between ejectives, aspirates and plain stops in Bolivian Quechua. The main correlates of this three-way contrast in laryngeal features are identified, along with a discussion of variation based on place of articulation and position. §3.3 reports on similar fieldwork conducted on Chol, which contrasts ejectives and plain stops. Summary and discussion of the cues to laryngeal contrasts cross-linguistically is presented in §3.4.

3.1 Previous acoustic studies of laryngeal contrasts

The acoustic correlates of laryngeal contrasts cross-linguistically have been the subject of many instrumental studies. This section presents a brief survey of the findings of these studies in order to a get a clear picture of the phonetic properties of those laryngeally marked consonants that commonly exhibit cooccurrence restrictions.

3.1.1 Ejectives and aspirates

A dichotomy in the realization of ejectives is identified by Kingston (1985) and Lindau (1984). Some ejectives, like those in Hausa and Tigrinya are characterized by a relatively short VOT, creaky voiced and slow amplitude rise in the following vowel. Other ejectives, like those in many Athabaskan languages, have longer VOT and a large burst amplitude and are followed by a modally voiced vowel. These two types of ejectives are usually referred to as 'weak' and 'strong' or 'slack' and 'stiff', respectively. The acoustic studies of ejectives presented in this chapter loosely correlate with this dichotomy. The discussion of Quechua, Hausa and Tz'utujil in Chapter 2 showed that the dichotomy between stiff and slack ejectives has phonological significance.

Many Athabaskan languages have been studied to determine the correlates of a three way laryngeal contrast between ejectives, aspirates, and plain stops (voiceless unaspirated or voiced). The general characterization of Athabaskan stop contrasts that emerges from these studies is that while aspirates and ejectives are characterized by longer VOT than the plain series, VOT is longer in aspirates than in ejectives. While this general pattern holds for all the languages studied, the absolute length of VOT varies from language to language, as does the difference in

VOT between the three series of stops. In addition to VOT, the studies of Wright et al. (2002) for Witsuwit'en and Ham (2008) for Tsilhqut'in tested for differences in the following vowel based on laryngeal category. In both of these languages, vowels following ejectives are characterized by creaky voice, depressed f0 and a slow energy rise. Each of the available studies is discussed in turn below.

Wright et al. (2002) recorded 11 adult native speakers of Witsuwit'en (Athabaskan) to collect tokens of root initial alveolar stops of the three laryngeal types: plain unaspirated, aspirated and ejective. The three laryngeal categories were differentiated by VOT, F0 perturbation, energy rise time and jitter perturbation (the degree of periodicity) in the following vowel. Both aspirated and ejective stops have a longer VOT than plain stops, but aspirates have a much longer VOT than ejectives. The difference between ejectives and plain stops is also much smaller than the difference between ejectives and aspirates.

(2)

laryngeal type	VOT
plain unaspirated	20 ms
ejective	30 ms
aspirate	60 ms

Ejectives were found to contrast with aspirated and plain stops in the pitch and voice quality of the following vowel. Ejectives are followed by a period of lowered F0 relative to the vowel midpoint, as opposed to the raised F0 found following the other series. Energy also increases more slowly in the vowel following ejectives than in aspirates and plain stops. Jitter perturbation is greater following ejectives (6.9) than either aspirate (1.8) or plain (1.6) stops, showing that the vowel following an ejective has a creaky voice quality. In terms of the auditory features proposed in (1), Witsuwit'en ejectives would be specified with the feature [creak] and aspirates with [long VOT]. Burst amplitude was not measured in this study, but I assume that it is not sufficiently distinct from the other two series as to warrant specifying Witsuwit'en ejectives as [loud burst], though this remains to be tested explicitly.

Ham (2008) analyzed the speech of three female speakers of Tsilhqut'in (aka Chilcotin). Ejective, aspirated and plain stops from all places of articulation were measured in stem-initial position. As in Witsuwit'en, both ejectives and aspirates have a longer VOT than plain stops. Unlike in Witsuwit'en, however, ejective and aspirate VOT are about the same length. Average values are given in (2).

(2) Witstuwit'en VOT

laryngeal type	VOT
plain unaspirated	45 ms
ejective	102 ms
aspirate	105 ms

Besides differences in VOT, Ham also found differences in the following vowel that distinguished the ejectives from the other series. Ejectives have a higher jitter perturbation at vowel onset (3.8) than either the aspirate (2.3) or plain (2) stops, indicating creaky voice. Ejectives were also followed by depressed F0. F0 rises from the onset to the midpoint of the vowel in ejectives (difference -5 Hz), as opposed to the fall found in aspirates (difference 8 Hz)

and plain (difference 8 Hz) stops. Additionally, ejectives have a slower rise time than the other stops. To measure rise time, intensity measurements were taken at the onset of the vowel, 30 ms into the vowel and at the midpoint. The amount of energy increase from the 30 ms point to the vowel peak is largest in ejectives (4.5 dB as opposed to 1.4 dB for aspirates and plain stops). Tsilhqut'in ejectives have a comparable VOT to aspirates and creaky phonation in the following vowel. Based on these acoustic measures, ejectives in Tsilhqut'in are hypothesized to bare the auditory features [long VOT] and [creak], while aspirates are specified as [long VOT]. Burst amplitude measures were not taken, and thus it is not known whether ejectives should also be specified as [loud burst].

The VOT of stops in Tlingit is studied by Maddieson et al. (1996) with data from 3 female and 1 male speaker. They found that while aspirated and ejective stops both have significantly longer VOT than the unaspirated series of stops, there is no significant difference between aspirates and ejectives. Average VOTs for the three laryngeal categories across subjects and places of articulation are given in (3).

(3) Tlingit VOT

laryngeal type	VOT
plain unaspirated	25 ms
ejective	103 ms
aspirate	128 ms

A similar pattern for VOT length is found in Hupa (Gordon 1996). Average VOT is given separately in (4) for stops and affricates; VOT for the affricates includes both frication and any aspiration or glottal closure before the onset of voicing in the vowel.

(4) Hupa VOT

laryngeal type	VOT stops	VOT affricates
plain unaspirated	25 ms	71 ms
ejective	88 ms	104 ms
aspirate	83 ms	160 ms

Potter et al. (5) measured VOT and closure duration in the production of 3 female and 5 male speakers of Apache. In general, VOT is longest for the aspirates, intermediate for the ejectives, and shortest in the plain unaspirated series. VOT is generally much longer in the affricates than in the stops, as can be seen from the average values given in (5). Potter et al. do not give details about how the measured VOT, but the longer VOT in affricates shows that this measure includes frication. This method of measuring VOT in affricates, used in the studies of both Hupa and Apache, contrasts with the method of employed in the description of Chol in §X.3, where frication and VOT were considered two distinct periods.

(5) Apache VOT

	plain unaspirated	ejective	aspirated
stops	25 ms	55 ms	70 ms
affricates	120 ms	90 ms	107 ms

Closure duration is significantly longer in aspirated stops than in plain stops. Ejective stops have an average closure duration in the middle between aspirated and plain stops. This same trend holds for affricates, though none of the differences are satistically significant.

The studies of Tlingit, Hupa and Apache do not measure properties of the surrounding vowels. In Hupa, however, it is mentioned that pre-glottalization and pre-aspiration is possible with ejectives and aspirates, respectively.

Lindau (1984) measured velar ejectives in 10 speakers of Navajo, and found an average VOT of 80 ms and average closure duration of 120 ms. While she does not give any quantifying measurements, Lindau reports that the vowel following an ejective in Navajo is not creaky voiced. The rise in amplitude is fast and the vowel is modally voiced. McDonough and Ladefoged (1993) measured VOT and closure duration in voiceless unaspirated, aspirated and ejective Navajo stops and affricates. Their data come from 5 female and 2 male speakers. Closure duration in Navajo follows the general pattern cross-linguistically that aspirated stops have shorter closure durations than unaspirated stops. Ejective stops have an intermediate closure duration. Average VOT for stops and affricates are given in (6). VOT measures for affricates again include the frication period.

(6) Navajo VOT

	plain unaspirated	ejective	aspirated
stops	21 ms	101 ms	142 ms
affricates	67 ms	148 ms	150 ms

For both stops and affricates, aspirated and ejective consonants have a significantly longer VOT than unaspirated consonants. The difference between ejectives and aspirates is small, but significant, for the stops but insignificant for the affricates.

Finally, McDonough and Wood (2008) present data from six Athabaskan languages, Dene Suline (Cold Lake), Dene Suline (FC), Dogrib, North Slavey, Tsilhqut'in, and Navajo. As in the studies reported so far, they found that aspirates and ejectives are distinct from plain stops in having long VOT, and that aspirates have a longer voicing lag than ejectives. These studies of Athabaskan languages suggest that ejectives and aspirates should be specified as [long VOT]. It is likely that ejectives with long VOTs also have an increased burst amplitude, and are specified as [loud burst].

Studies of ejectives and aspirates of non-Athabaskan languages have also been conducted. Flemming et al. (2008) provide a phonetic description of Montana Salish (Salishan) relying on data from 3 females and 2 males. Montana Salish contrasts ejective and plain stops and affricates at several places of articulation. Approximate VOT values, which are much longer in the ejective than in the plain series, are reported in (7), supporting the representation of ejectives in this language as [long VOT].

(7) Montana Salish VOT

plain stops		Ejective stops and affricates	
p	20 ms	p'	80 ms
t	25 ms	t'	65 ms
		ts'	125 ms
		tl'	90 ms
		tʃ'	100 ms
k	45 ms	k'	85 ms
kʷ	60 ms	kʷ'	85 ms
q	55 ms	q'	80 ms
qʷ	60 ms	qʷ'	85 ms
average	44 ms		88 ms

Turkish Kabardian (Caucasian) is studied by Gordon and Applebaum (2006). Kabardian has a three way laryngeal contrast between ejective, aspirated and voiced stops, which are differentiated by burst intensity, closure duration and VOT. Ejectives are reported to have a greater burst intensity than stops in the other two series and closer duration is slightly longer, 111 ms as compared to the 92 ms for voiced stops and 94 ms for aspirates. VOT values were measured for stops in both initial and intervocalic position. In both positions, ejectives and aspirates have a longer VOT than the voiced stops (which have negative VOT), and aspirates have a longer VOT than ejectives. Average values for each position and averaged across positions are reported in (8).

(8) Turkish Kabardian VOT

laryngeal type	initial	intervocalic	average
voiced	-6 ms	-93 ms	-50 ms
aspirate	62 ms	48 ms	55 ms
ejective	37 ms	28 ms	33 ms

The acoustic measures in (8) show relatively short VOT periods for both aspirates and ejectives, as compared with the values seen for Athabaskan languages. In terms of contrast, however, ejectives and aspirates as a group contrast with the negative VOT found in voiced stops, suggesting that ejectives and aspirates are specified as [long VOT] in this language.

Lindau (1984) finds that velar ejectives in Hausa (Afro-Asiatic: Chadic) have a VOT of about 35 ms, and are followed by a creaky voiced vowel with a slow energy rise. Measurements for the contrastive plain stops are not reported. Ladefoged (1968) reports a VOT lag of 50-60 ms in Hausa ejectives and VOT of 35-45 ms in the plain series. These measurements cause MacEachern (1999) to analyze the plain series as aspirated, instead of the usual voiceless unaspirated. Regardless of phonological classification, the difference in VOT between the ejective series and the plain or aspirated series is smaller than in other languages, and thus in auditory terms the contrasting feature seems to be [creak].

3.1.2 Xhosa and Zulu

The laryngeal systems of the Southern Bantu languages Xhosa and Zulu have been subject to phonetic study. In both languages, there is a three way contrast between a plain or ejective series, voiceless aspirate and voiced or breathy voiced stops. At the labial place, there is also an implosive stop. I discuss the realization of each of these series in turn.

Jessen (2002) reports measurements from four male and four female speakers of Xhosa. The production of the ejective or plain series is found to vary greatly from speaker to speaker, and could be audibly either ejective or plain. Audible ejectives have either long VOT, high burst amplitude, or both. VOT for this series of stops could be below 30 ms in the plain articulation, or as high as 50-70 ms for the ejective articulations. Doke (1926) claims that in normal Zulu speech, ejection is barely audible, but becomes very pronounced in more careful or emphatic speech. Giannini et al (1988) analyzed the speech of two speakers of Zulu, and found a loud burst and a VOT of about 50 ms in the alveolar and velar ejectives; there was no audible or spectrographically visible release of the tokens of labial ejectives.

The aspirated stops in Xhosa are characterized by a very long VOT ranging from 45-164 ms, but are over 100 ms for most speakers. Aspiration in Zulu is similarly realized with a VOT of between 50-100 ms depending on place of articulation. The consistent realization of aspiration supports specifying this series as [long VOT], while the shorter and more variable VOTs in the ejectives series suggest that this series is not specified as [long VOT].

Voiced stops in Xhosa have very short VOT, 11-17 ms, and show only a small amount of closure voicing in some tokens for some speakers. Jessen and Roux (2002) found that the voiced series of stops (and clicks) in Xhosa are characterized by depressed F0 in the following vowel, as well as low F1 (as compared with voiceless stops). Additionally, some speakers produced some amount of breathy voice. Jessen and Roux propose that the voiced series of stops in Xhosa should be described as "slack voice", as the characteristic properties result from larynx lowering and vocal fold slackening. Voiced stops in Zulu have a similar realization. Giannini et al. found little to no closure voicing in this series of stops and a slight lowering of F0 at the vowel onset. Traill et al. (1987) similarly find that the 'voiced' series of stops is in fact voiceless, but has a substantial effect on the tone of the following vowel, depressing both low and high tones.

In Xhosa, implosives are most often fully voiced. One speaker in Jessen's study produced partially devoiced implosives. Giannini et al. found the sound typically described as a voiced implosive to be a plain voiced stop, realized with voicing during the closure and an explosive burst at release. The implosive does not have a depressing effect on the tone of the following vowel.

Jessen further remarks that while creaky phonation in vowels occurs in Xhosa, it is not consistently associated with the glottalic consonants (the ejectives and implosive), and thus should not be considered a cue to these sounds. The final dimension that differentiates the three series of stops is closure duration, which is generally shortest for aspirates, intermediate for ejectives and longest for voiced stops. The differences in closure duration between the laryngeal categories is small, however.

3.1.3 Implosives

The realization of implosives varies somewhat dramatically from language to language, as is the case for ejectives. Lindau (1984) finds that in Hausa implosives have a more creaky phonation

than implosives in four Niger-Congo languages (three Ijoid languages, Kalabari, Orika and Bumo and the Edoid language Degema). Hausa implosives are shorter with aperiodic noise throughout the closure, while implosives in the Niger-Congo languages are longer and show periodic voicing throughout. While both types of implosives involve an increase in amplitude of vocal fold vibrations throughout the closure, this increase is much more dramatic in the Hausa implosives than in the Niger-Congo implosives.

The ratio of voicing amplitude at the mid- and end-points of the stop closure were taken in order to quantify the degree of voicing throughout the implosive. Implosives generally contrast with plosives in that voicing amplitude increases throughout the closure, resulting in a ratio well above 1. The ratios of endpoint to midpoint amplitude for bilabial and alveolar implosives are given in (9).

(9) Voicing amplitude in implosives, endpoint:midpoint

	Okrika	Kalabari	Bumo	Degema	Hausa
bilabial	1.25	1.6	1.6	2	2.4
alveolar	1.25	1.25	1.3	1.3	2

For both bilabial and alveolar implosives, the increase in voicing amplitude is significantly greater for Hausa than for the Niger-Congo languages. For the bilabial implosives, Okrika has a significantly smaller increase than the other languages (except Kalabari). Lindau also measured closure duration, which is reported in (10).

(10)   Closure duration for implosives

	Okrika	Kalabari	Bumo	Degema	Hausa
bilabial	95 ms	105 ms	130 ms	125 ms	65 ms
alveolar	80 ms	100 ms	115 ms	100 ms	55 ms

Phonation type in the implosives was determined qualitatively from waveform examination. Implosives in the four Niger-Congo languages transition from laryngealized phonation to modal phonation. Hausa implosives, by contrast, show creaky voice throughout, along with highly aperiodic vibrations which Lindau hypothesizes is due to incomplete closure of the vocal folds. Based on Lindau's measurements, Ijoid implosives should bear the feature [v-amp], representing the increased voicing amplitude during closure, while Hausa implosives are specified as both [v-amp] and [creak].

Ladefoged and Maddieson (1996) identify four phonation types in implosives, modal voice, tense voice and complete glottal closure. Similarly, Ladefoged (1968) identifies two kinds of implosives in his study of West African languages. The implosives of Igbo and Kalabari he classifies as voiced. These sounds involve a downward movement of the glottis and creakiness at the onset of stop closure may or may not occur. The implosives of Hausa, Margi and Bura are consistently accompanied by creaky voice. These sounds need not be strictly implosive, but are mainly distinguished from their voiced counterparts by creakiness during closure.

Finally, the study of Pinkerton (1986) measured intraoral air pressure in order to determine the voiced or voiceless character of implosives in Mayan languages of the Kichean subgroup. Her findings are that both modally voiced and creaky voiced implosives are attested in Mayan

languages, and that voicelessness or creaky voice is more likely farther back in the oral cavity. Kaqchikel, Q'eqchi, and Coban Q'eqchi each have modally voiced labial implosives but creaky voiced uvular implosives; glottalized segments at the intermediate places of articulation are realized as voiceless ejectives. Tzutujil has modally voiced implosives at the labial and alveolar places, and a creaky voiced uvular implosive. San Cristobal Pocomchi and Tactic Pocomchi have only creaky voiced implosives.

3.1.4 Summary

Acoustic studies of laryngeal categories find cross-linguistic variation in the realization of ejectives and implosives. Both of these segment types can be associated with either creaky or modal phonation. In ejectives, creaky phonation loosely correlates with shorter VOT and modal phonation with longer VOT. Aspirates are consistently realized with a long VOT and aspiration noise, and tend to have a longer VOT than even long lag ejectives in languages that have both series. The next two sections present detailed acoustic studies of Quechua, which has a three way contrast between ejectives, aspirates and voiceless unaspirated stops, and Chol, which has a two way contrast between ejectives and voiceless unaspirated stops. The measurements support the representation of Quechua ejectives as [long VOT] and [loud burst], Quechua aspirates as [long VOT], and Chol ejectives as [long VOT], [loud burst] and [creak].

3.2　Laryngeal contrasts in Quechua

3.2.1 Background and recordings

Varieties of Quechua (Quechuan) are spoken throughout the Andes Mountains in Ecuador, Peru, Bolivia and Argentina. The fieldwork reported on in this section is concerned with South Bolivian Quechua, spoken by about 3.5 million people in Bolivia and Northern Argentina, as reported by Ethnologue (Gordon 2005). Quechua exhibits a three way laryngeal contrast between plain voiceless, ejective and aspirated stops at five places of articulation. Additionally, Quechua has three vowels [i, u, a]. The high vowels are lowered to [e, o] around uvulars. The full consonant inventory of Quechua is given in (11). The labial, alveolar and velar stops are the subject of the acoustic study reported in the rest of this section.

(11)   Quechua consonant inventory

	labial	alveolar	alveopalatal	velar	uvular	glottal
voiceless unaspirated	p	t	tʃ	k	q	ʔ[11]
ejective	p'	t'	tʃ'	k'	q'	
aspirate	pʰ	tʰ	tʃʰ	kʰ	qʰ	
fricative		s				h
nasal	m	n	ɲ			
liquid		r l	ʎ			
glide	w	j				

The shape of roots in Quechua is CV(C)CV. Ejectives and aspirates occur only in onset position, and may only appear as the onset of the second syllable in roots with an initial non-stop consonant (e.g. *satʃ'a* 'tree' **atʃ'a *patʃ'a*). The three way contrast between plain, ejective and aspirated stops is possible in the initial or medial onset position of a root.

Recordings for acoustic analysis were taken on-site in Cochabamba, Bolivia with 6 middle-aged female speakers of Bolivian Quechua. All speakers were literate and accustomed to reading written Quechua. Speakers were asked to read sentences of Quechua from a computer screen. Each sentence consisted of a target word in one of three randomly varied carrier sentences, given in (12).

(12)   *Noqa X simita qellqani.*   'I read the word X.'
       Qam X simita qellqanki.   'You read the word X.'
       Pay X simita qellqan.   'He read the word X.'

Recordings were done in a quiet room at the offices of the Sustainable Bolivia organization in Cochabamba using a Marantz PMD660 solid-state recorder and Audio Technica 831b microphone.

There were 170 target words, each of which fell into one or more of three categories for analysis. The set of words that is analyzed in this section was designed to document the realization of the three laryngeal categories in all of the phonotactically permissable positions, initial pre-vocalic (#CV...), intervocalic (...VCV...) and post-consonantal pre-vocalic (...CCV...).

Target words for documentation contrasted three laryngeal categories (plain, ejective, aspirate) at three places of articulation (labial, alveolar, velar) in three positions (initial, post-vocalic, post-consonantal). Examples of minimally contrasting labial stops are given in (13).

(13)

	#C		VCV		CCV	
plain	paka	'eagle'	napay	'greeting'	lampa	'spade'
ejective	p'akiy	'to break'	map'a	'stain'	ʎimp'a	'full to the top'
aspirate	pʰaka	'groin'	mapʰa	'wax'	lampʰay	'to walk'

---

[11] Glottal stop only occurs word-initially, and is proposed by MacEachern (1999) to explain the inability of ejectives to occur in orthographically vowel initial words (under the assumption that both ejectives and glottal stop at [+constricted glottis]. Glottal stop is the first consonant in orthographically vowel initial words.

Effort was made to find words that were as similar as possible other than the laryngeal category and position of the target consonant. When possible, words with the vowel [a] following the target consonant were chosen instead of words with either of the high vowels [i,u]. The low vowel is the longest and loudest of the three vowels, as well as the most resistant to devoicing, making it easiest to measure for voice quality. Words with uvulars anywhere were avoided because of potential lowering effects on vowels. In post-consonantal position, the target consonant was preceded most often by a nasal [m, n], but the laterals [l, ʎ] and [s] were also common. Other consonants that occurred once or twice were [χ, t, r, w].

For each unique combination of three factors, six stimuli were chosen where the lexicon premitted. Certain sequences simply do not occur six times in the available dictionary (Ajacopa et al. 2007). The target sequences that appear less than six times in the stimuli are listed in (14), along with the number of times that they do appear.

(14) Vp'V   5   Vt^{h}V   4   Vk'V   5
      Cp^{h}V   4   Ct^{h}V   3   Vk^{h}V   5

3.2.2 Measurements

Several aspects of each target consonant were measured using the Praat software (Boersma and Weenink 2010). For all consonants, voice onset time (VOT), burst amplitude and voice quality of the following vowel were measured. For medial stops, closure duration was also measured. Voice quality in the preceding vowel was measured for post-vocalic consonants only.

VOT is measured from the beginning of the burst to the onset of periodicity in the following vowel. Burst amplitude is measured in arbitrary units directly off of the waveform by calculating the difference between the highest and lowest points in the waveform. Voice quality is quantified as the difference between the amplitude of H1 and H2 in the first 30 ms of the vowel (Ladefoged 2003). The three spectra below give a sample of an intervocalic plain, ejective and aspirate velar stop. The recordings were not done in a soundbooth, and there is thus some reverberation and background noise visible in the spectra.

(15)   [aka] from *paka*

0 ms.   300 ms.
      closure = 84 ms.   VOT = 17 ms.

(16) [uk'u] from *muk'uy*

0 ms.   300 ms.

closure = 76 ms.   VOT = 94 ms.

(17) [akʰa] from *sakha*

0 ms.   300 ms.

closure = 87 ms.   VOT = 110 ms.
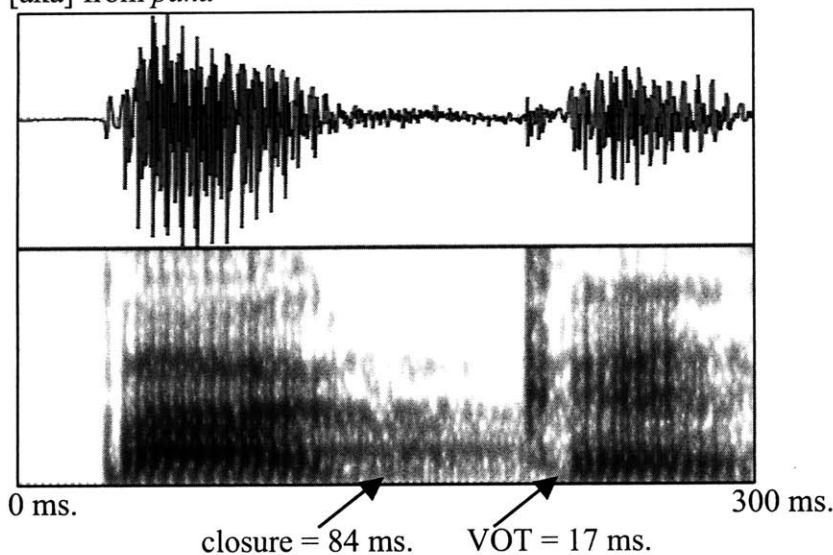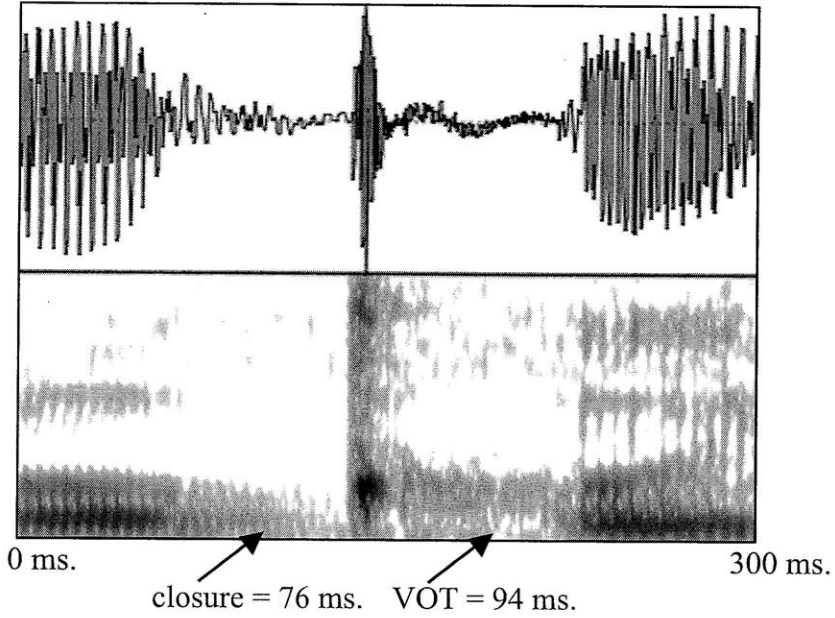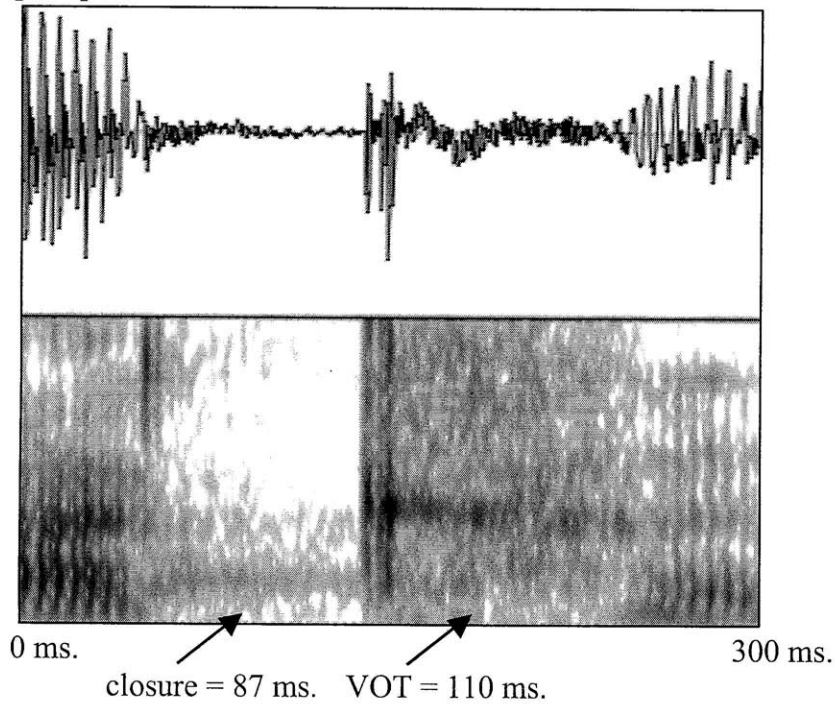
To measure burst amplitude, the difference between the highest and lowest points in the burst was taken, regardless of whether the high and low points were adjacent. A sample burst from an ejective velar where the high and low points are not adjacent is shown in (18).

68

(18)   burst of [k'] in *k'ata*
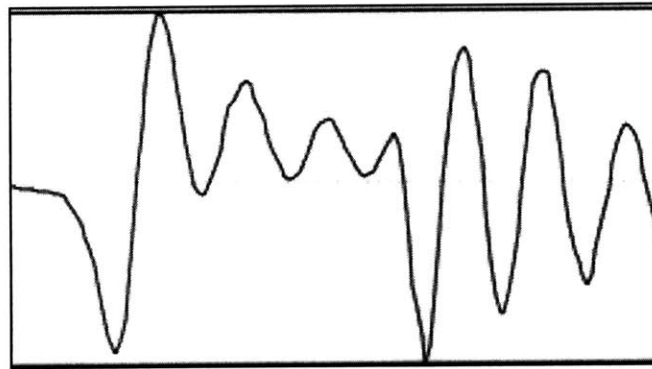
3.2.3 Results

This section reports the results of acoustic analysis of Quechua stops at three places of articulation (labial, alveolar, velar), in three positions (initial, medial post-vocalic, medial post-consonantal) in three laryngeal categories (plain, ejective, aspirate).

For each of the six subjects, certain tokens were not measurable. A token was excluded either because the subject misread the word, paused while reading the word, or background noise was judged excessive. The resulting number of measurements for each unique combination of the three factors is given in (19), summing across all subjects.

(19)

	labial			alveolar			velar		
	#CV	VCV	CCV	#CV	VCV	CCV	#CV	VCV	CCV
plain	36	36	36	36	36	35	36	34	36
ejective	36	30	34	35	31	34	35	28	35
aspirate	34	34	24	33	29	18	36	30	36

The main results of this section, summarized in §3.2.4, are that VOT, burst amplitude and voice quality in the following vowel distinguish the three laryngeal categories in Quechua. In §X.2.3.1, I report on the acoustic dimensions that distinguish ejective, aspirate and plain stops as well variation along these dimensions based on position (initial, medial post-vocalic and medial post-consonantal). In §3.2.3.1 I discuss differences between stops at the three places of articulation.

3.2.3.1 Laryngeal categories and interactions with position

The three laryngeal categories in Quechua are distinguished primarily by VOT, burst amplitude and voice quality of the following vowel and there is also a small effect of closure duration. Voice quality of the preceding vowel was not found to be significant. Each of these measures is now discussed in turn.

VOT is significantly longer in ejectives and aspirates than in plain stops, across all three positions, as shown in Figure 1.

Voice Onset Time

Figure 1:   VOT of ejective, aspirate and plain stops, in initial, post-vocalic and post-consonantal position, averaged across all subjects and tokens. Error bars indicate 95% confidence interval.

A Linear Mixed Effects Model testing for effects of laryngeal category (ejective, aspirate or plain) and position (initial, medial post-vocalic and medial post-consonantal) was run on VOT with subject as a random effect. VOT is significantly longer in both ejectives and aspirates than in plain stops (ejectives: $\beta = 135$, $t = 31$, $p < .0001$; aspirates: $\beta = 116$, $t = 27$, $p < .0001$). Additionally, VOT in ejectives and aspirates is significantly shorter in medial position than in initial position (ejectives: $\beta = -50$, $t = -8$, $p < .0001$; aspirates: $\beta = -38$, $t = -7$, $p < .0001$). In initial position, VOT in aspirates differs significantly from that of ejectives ($\beta = -19$, $t = -10$, $p < .0001$); there is no difference in medial position. For aspirates, post-consonantal VOT is longer than post-vocalic VOT ($\beta = 14$, $t = 2$, $p < .02$). The mean VOT values, along with one standard deviation, are given in (20).

(20)   VOT by position, mean and one standard deviation

	initial	post-vocalic	post-consonantal	all positions
ejective	159 (54)	106 (32)	112 (29)	127 (47)
aspirate	140 (53)	101 (47)	120 (45)	121 (51)
plain	23 (16)	23 (14)	22 (13)	23 (15)

Burst amplitude distinguishes ejectives from aspirates and plain stops, as shown in Figure 2. A Linear Mixed Effects Model reveals that ejectives have significantly greater burst amplitude than aspirates and plain stops ($\beta = .4$, $t = 13$, $p < .0001$).

70
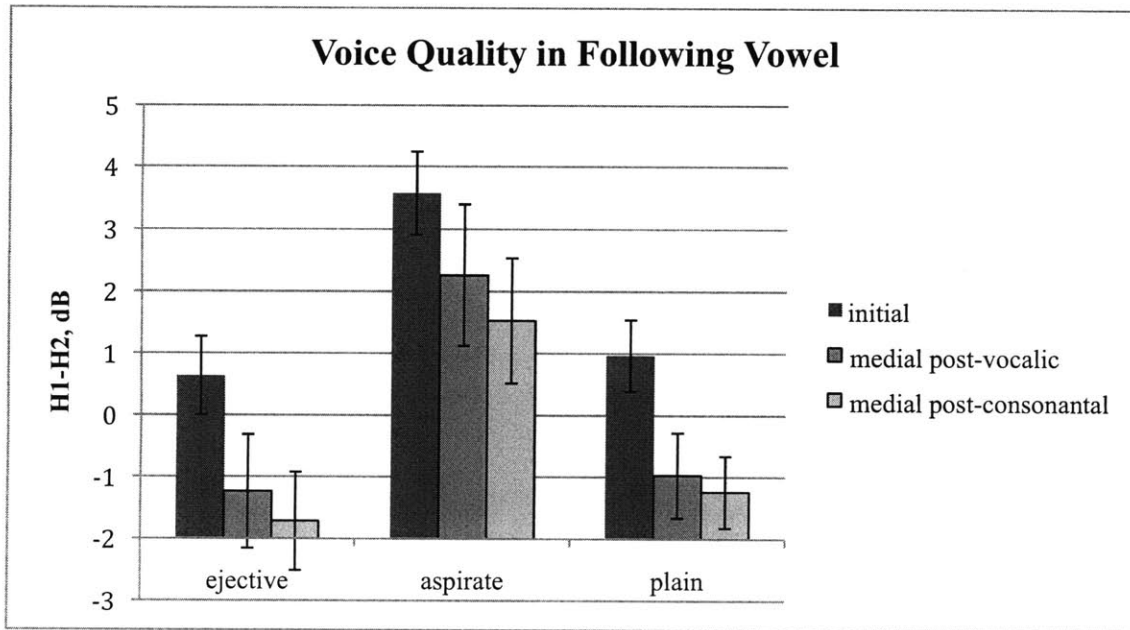
Figure 3: Voice quality in the vowel following ejective, aspirate and plain stops, in initial, post-vocalic and post-consonantal position, averaged across all subjects and tokens. Error bars indicate 95% confidence interval.

Average values of H1-H2 for each laryngeal series in each of the three positions are given in (22).

(22) H1-H2 in following vowel by position, mean and one standard deviation

	initial	post-vocalic	post-consonantal	all positions
ejective	.6 (3.3)	-1.2 (4.4)	-1.7 (4.1)	-.7 (4.1)
aspirate	3.6 (3.4)	2.3 (5.6)	1.5 (4.5)	2.5 (4.6)
plain	1 (3.1)	-1 (3.6)	-1.2 (3.1)	-.4 (3.4)

Closure duration was measured only in post-vocalic and post-consonantal stops. Ejectives and have a significantly longer closure duration than plain stops and aspirates across positions (β = 22, t = 3, p < .004). Additionally, post-consonantal stops are significantly shorter than post-vocalic stops for all three series (β = 43, t = 6, p < .0001). The graph below compares the closure duration of all three series of stops in both positions.
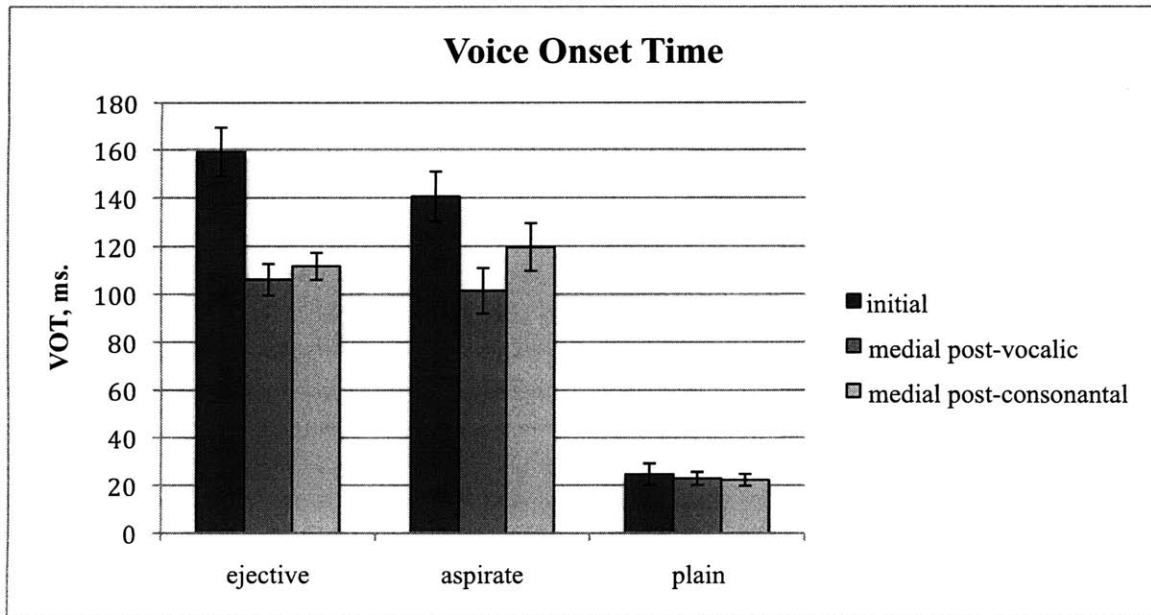
Figure 2: Burst amplitude of ejective, aspirate and plain stops, in initial, post-vocalic and post-consonantal position, averaged across all subjects and tokens. Error bars indicate 95% confidence interval.

Ejective stops have significantly higher burst amplitudes than the other two series, regardless of position. Burst amplitude of ejectives is significantly lower in medial than in onset position ($\beta = -.09$, $t = -2$, $p < .02$), as can be seen from the chart below. There is no difference between medial ejective bursts in post-vocalic vs. post-consonantal position. The burst amplitudes of plain and aspirated stops does not vary with position. While burst amplitude does differ in ejectives between initial and medial position, this difference is small compared to the difference between ejectives overall and the other two series of stops. In all positions, burst amplitude is a good determiner of whether a stop is ejective or not. Average values in arbitrary units for each of the three series of stops in each position are given in (21).

(21) Burst amplitude by position, mean and one standard deviation

	initial	post-vocalic	post-consonantal	all positions
ejective	.62 (.33)	.54 (.35)	.52 (.35)	.56 (.35)
aspirate	.24 (.14)	.23 (.14)	.25 (.13)	.24 (.14)
plain	.25 (.12)	.22 (.11)	.21 (.11)	.23 (.12)

Voice quality in the following vowel is breathy after aspirates, but modal after ejectives and plain stops. A Mixed Linear Effects Model found that voice quality is significantly different in aspirates than in ejectives and plain stops ($\beta = 3$, $t = 5$, $p < .0001$). Voice quality is also significantly different between initial and medial position ($\beta = -2$, $t = -5$, $p < .0001$), but there is no interaction with laryngeal category. Ejectives are not associated with creaky phonation in the following vowel.
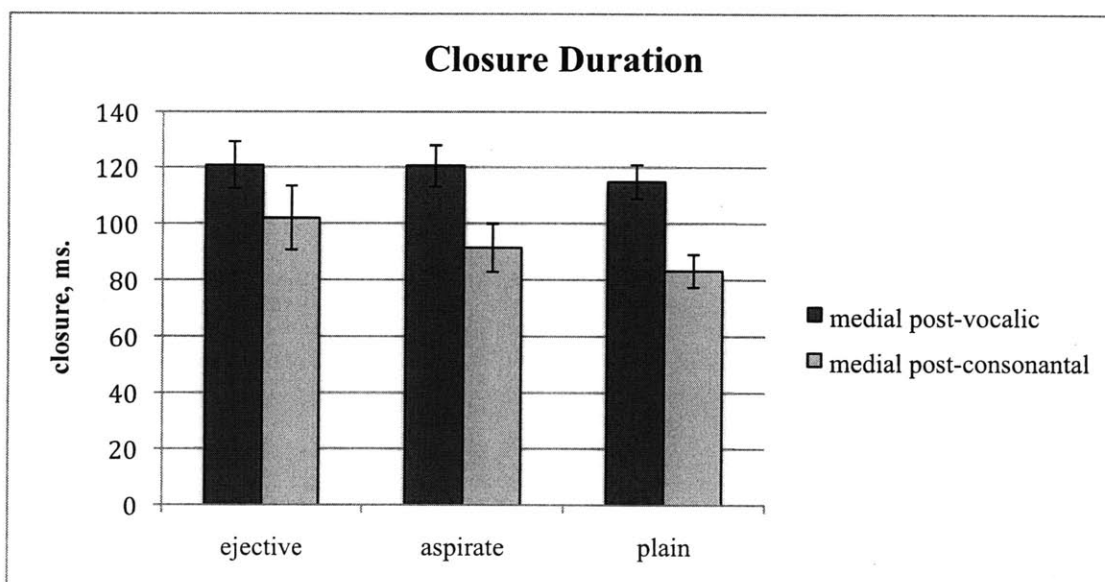
Closure Duration

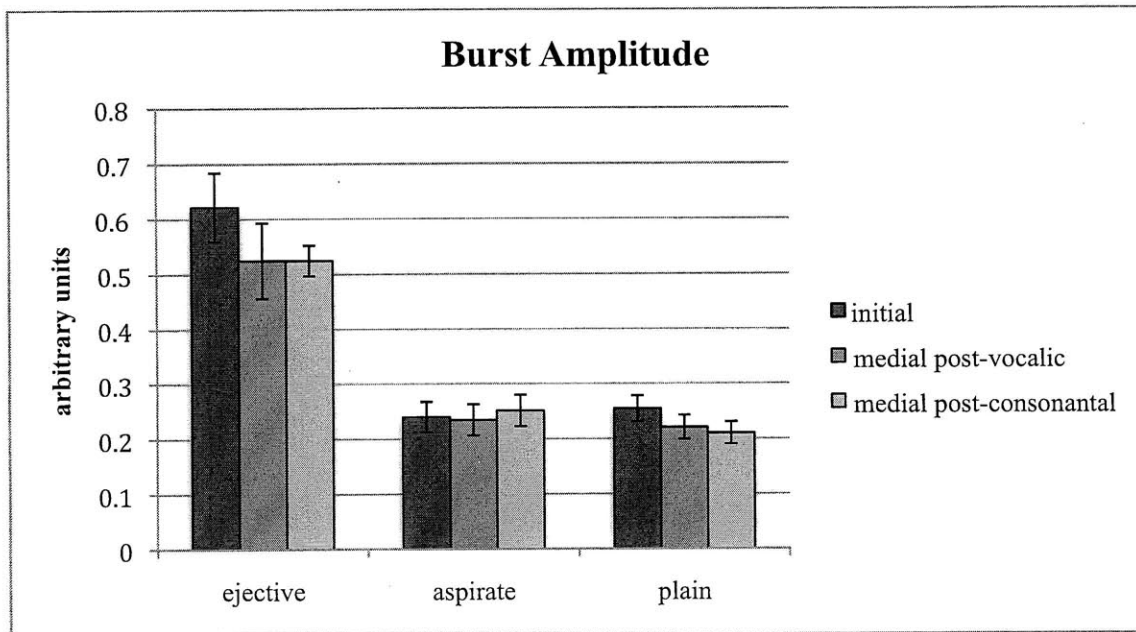Figure 4:   Closure duration of ejective, aspirate and plain stops, in post-vocalic and post-consonantal position, averaged across all subjects and tokens. Error bars indicate 95% confidence interval.

While closure duration varies depending on the preceding segment, it is not a strong determinant of whether a stop is ejective, aspirate or plain. Ejectives and aspirates have only slightly longer average durations than plain stops, as can be seen by comparing the values in (23) below.

(23)   Closure duration by position, mean and one standard deviation

	post-vocalic	post-consonantal	all positions
ejective	121 (41)	102 (59)	111 (52)
aspirate	121 (36)	91 (39)	107 (40)
plain	115 (31)	83 (31)	99 (35)

Finally, there was no signficant effect of V_1 voice quality.

3.2.3.2 Laryngeal categories and interactions with place

So far, variation in the acoustic cues to laryngeal contrasts has only be analyzed with respect to the position in the root and the type of preceding segment. This section summarizes differences between the three places of articulation that were measured, labial, alveolar and velar. The measures that were found to vary significantly by place of articulation are VOT, burst amplitude and closure duration. Voice quality in either the preceding or following vowel is not affected by place of articulation.

A Mixed Linear Effect Modal with the three-valued factors of place (labial, alveolar, velar) and laryngeal category (plain, ejective, aspirate) showed that VOT is significantly shorter in labial stops than in alveolar or velar ($\beta = -19$, t = -4, p < .0001), regardless of laryngeal category. The following graph compares VOT at each place of articulation for each of the three laryngeal categories.

Voice Onset Time by place

Figure 5:   VOT of ejective, aspirate and plain stops at three places of articulation, averaged across all subjects and tokens. Error bars indicate 95% confidence.

Average VOT values and one standard deviation are given in (24).

(24)   VOT by place, mean and one standard deviation

	labial	alveolar	velar
ejective	120 (40)	132 (46)	129 (54)
aspirate	115 (56)	126 (50)	123 (47)
plain	15 (9)	21 (16)	34 (21)

Burst amplitude also varies signficantly by place. Velar stops have a larger burst amplitude than alveolar or labial stops ($\beta = .06$, $t = 2$, $p < .03$), across all three categories. Alveolar ejectives are also significantly different from labial and velar ejectives ($\beta = .1$, $t = 3$, $p < .006$). Amplitude is plotted in arbitrary units below.

74

Figure 6:   Burst amplitude of ejective, aspirate and plain stops at three places of articulation, averaged across all subjects and tokens. Error bars indicate 95% confidence interval.

Average burst amplitude values with one standard deviation are given in (25).

(25)   Burst amplitude by place, mean and standard deviation

	labial	alveolar	velar
ejective	.54 (.41)	.45 (.21)	.71 (.34)
aspirate	.2 (.1)	.21 (.11)	.3 (.16)
plain	.2 (.12)	.23 (.09)	.26 (.13)

Finally, closure duration also shows an effect of place. Velars and alveolars have a slightly shorter closure than labials (velars: $\beta = -25$, $t = -6$, $p < .0001$; alveolars: $\beta = -8$, $t = -2$, $p < .04$). Closure duration is graphed in Figure 7 below.

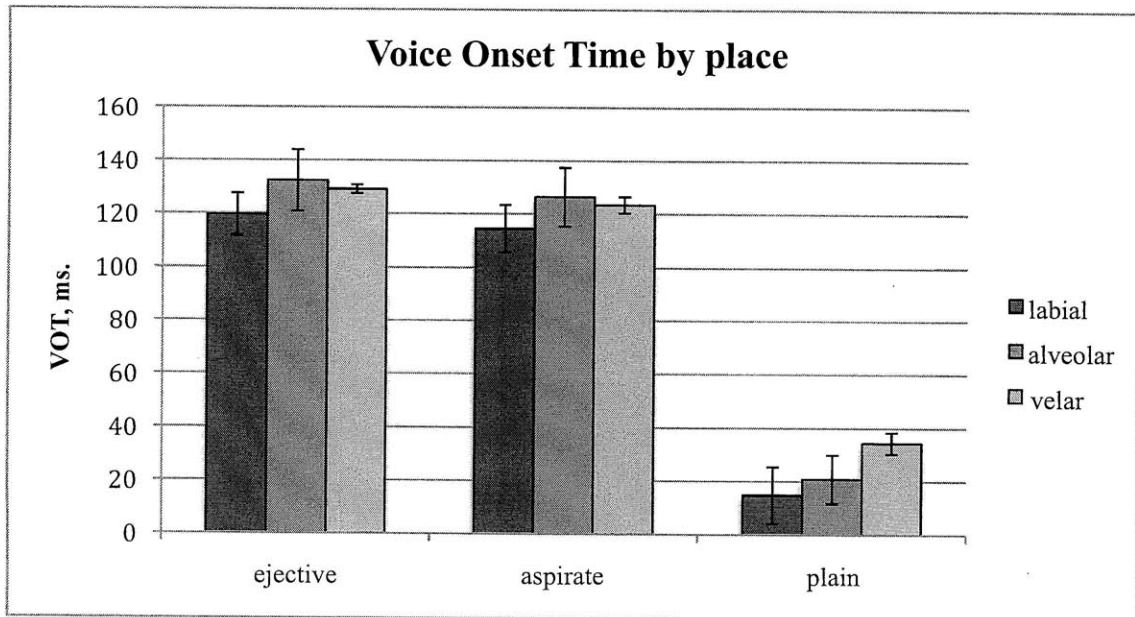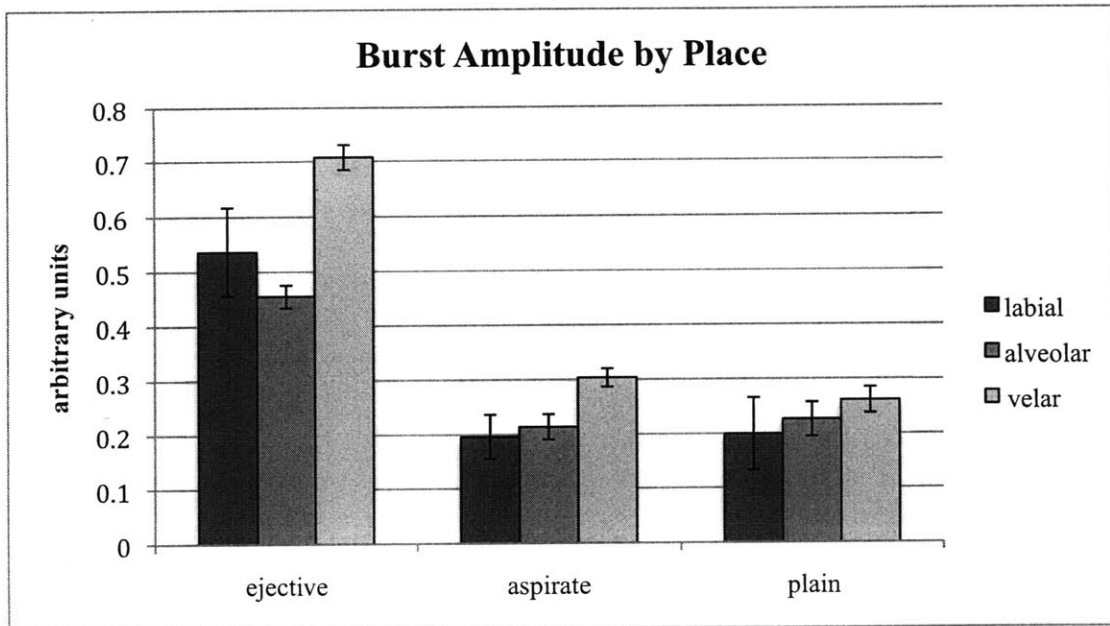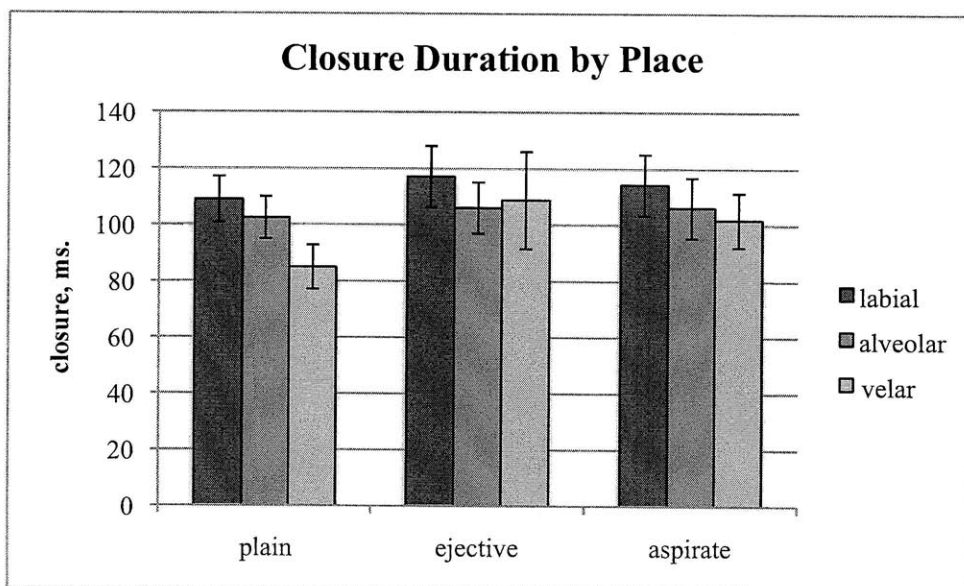Figure 7:   Closure duration of ejective, aspirate and plain stops at three places of articulation, averaged across all subjects and tokens. Error bars indicate 95% confidence interval.

Average closure duration in ms with one standard deviation is given in (26).

(26)   Closure duration by place, mean and one standard deviation

	labial	alveolar	velar
ejective	117 (11)	106 (37)	109 (70)
aspirate	114 (42)	106 (37)	102 (40)
plain	109 (35)	103 (32)	85 (33)

3.2.4 Summary

The results summarized in this section determine the acoustic correlates of the three way laryngeal contrast in Quechua, as well as variation based on position, preceding segment and place of articulation. Plain, ejective and aspirated stops are distinguished in Quechua by VOT, burst amplitude and the voice quality of the following vowel. VOT distinguishes ejectives and aspirates, the two laryngeal categories subject to distributional and cooccurrence restrictions, from plain stops. VOT is substantially longer in ejectives and aspirates than in plain stops. Ejectives are further distinguished from the other two series by their greater burst amplitude and aspirates are characterized by breathy voice in the onset of the following vowel.

The three laryngeal categories are distinguished by VOT, burst amplitude and following vowel quality in all positions. There is some variation, however, in the size of these distinctions. VOT is somewhat shorter in medial stops than in initial stops for both aspirates and ejectives. Similarly, burst amplitude in ejectives is a bit smaller in medial than initial position. This means that the acoustic differences between ejectives, aspirates and plain stops are smaller in medial position than in initial position. It is important to note, however, that the contrast is still robust in medial position. VOT in ejectives and aspirates is 6 times longer than in plain stops in initial position, and almost 5 times greater in medial position. Similarly, burst amplitude in ejectives is

76

2.5 times greater than in plain and aspirated stops in initial position, and 2.3 times greater in medial position. While VOT and burst amplitude are indeed shorter and weaker in medial position than in initial position, these differences are tiny compared to the differences between laryngeal categories.

Stops at different places of articulation also vary along the relevant dimensions for laryngeal contrasts. Importantly, however, place does not interact with laryngeal contrast. While VOT is shorter in labials than in alveolars and velars, it is shorter in all three laryngeal categories. Similarly, burst amplitude is greater in velars than in labials and alveolars, regardless of laryngeal category. Thus while the places of articulation do differ from one another, the contrast between the three laryngeal categories is more or less the same at all places of articulation.

3.3 Laryngeal contrasts in Chol[12]

3.3.1 Background and recordings

Chol is a Mayan language spoken by about 150,000 people in Chiapas, Mexico. Chol belongs to the Greater Tzeltalan group of the Mayan family, along with Chontal, Ch'orti', Tzeltal and Tzotzil. The phoneme inventory of Chol consists of the twenty consonants in (27), along with the six vowels [i, ɨ, u, e, o, a] and their lengthened aspirated counterparts [i^h, ɨ^h, u^h, e^h, o^h, a^h] (Vázquez Álvarez 2002).[13] There are three ejective stops and two ejective affricates, which contrast with plain voiceless stops and affricates. These segments are the subject of the acoustic study and are given in bold.

(27) Chol consonantal inventory

	labial	coronal	velar	glottal
implosive	ɓ			
ejective	**p'**	**ts' tʃ' t^{j}'**	**k'**	
voiceless	**p**	**ts tʃ t^{j}**	**k**	ʔ
fricative		s ʃ		h
nasal	m	ɲ		
approximant	w	l j		

While Chol has the palatalized coronal stops [t^{j}', t^{j}] and the palatal nasal [ɲ], it lacks the non-palatalized counterparts. Ejective consonants occur only in roots in Chol; no affixes or clitics contain ejectives. Roots are predominantly CVC, and ejectives may contrast with their non-ejective counterparts in both C_1 and C_2, as can be seen from the examples in (28) and (29).

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[12] I am very grateful to Jessica Coon for her help in the elicitation and recording of the Chol data analyzed in this section.

[13] Consonants found only in Spanish loanwords, such as [d], [g] and [r], are not included.

(28) a. piʃ   'to wrap'   b. p'iʃel   'to wake up'
          tsil   'break'   ts'iɲ   'a little bit'
          t'aɲ   'lime (calcium oxide)'   t'aɲ   'word'
          tʃiɓ   'sweet'   tʃ'iɓ   'type of large filament'
          kahel   'to start'   k'ah   'to harvest'

(29) a. hop   'to treat'   b. hop'   'to fasten'
          ɓuts   'sprout'   ɓuts'   'smoke'
          hot'   'to cut'   hot''   'to start'
          ɓetʃ   'to tilt'   ɓetʃ'   'to roll'
          tʃik   'without grass'   tʃik'   'dripping'

The goal of this acoustic study is to document the acoustic correlates of the ejective-plain contrast in Chol. The study additionally tests for variation in the production of these two laryngeal categories between environments. The two environments that are compared are the position in the root, C_1 or C_2, and the preceding segment, consonant or vowel.

Four native speakers of Chol were recorded, two male and two female. The two male speakers are both speakers of the Tumbalá dialect of Chol, while the females speak the Tila dialect. While these two dialects have some lexical distinctions, the phoneme inventory is the same.

Speakers were asked to read sentences in Chol orthography from a computer screen. Each sentence contained a target CVC root, with affixed/cliticized material preceding and/or following the root. For each of the 10 target consonants (5 plain and 5 ejective), 6 roots were chosen with that consonant in C_1 and 6 with that consonant in C_2. Target consonants in C_1 were recorded preceded by both a vowel and a consonant, while target consonants in C_2 were recorded followed by both a vowel and a consonant. Target consonants were thus in one of the four environments in (30).

(30) a. VCVC   c. CVCV
      b. CCVC   d. CVCC

Preceding vowels were either [i-] '3rd person genitive/ergative' or [a-] '2nd person genitive/ergative'. The preceding consonant was [k-] '1st person genitive/ergative' before non-velar consonants and [h-] '1st person genitive/ergative' before velar consonants. The following vowel was always [-i], which appears on intransitive verbal roots. Following consonants were either [t'] (from [-t'il] 'nominalizer/positional'), [l] (from [-le] 'passive/intransitive'), [t] (from [-tʃokoɲ] '') or [ɓ] (from [-ɓet'] 'applicative absolutive 2sg' or [-ɓoɲ] 'applicative absolutive 1sg'). This variety of consonant-initial suffixes/enclitics was necessary, as no one suffix can sensibly combine with all roots.

Carrier sentences were constructed around the target CVC root and affixed/cliticized material. Sentences differed from one another in order to allow each sentence to make sense. The variety of roots (nominal, adjectival, transitive and intransitive verbs) and affixes (agreement, inflectional and aspectual markers) made a standard carrier phrase for all target words impossible. The position of the target consonant in the sentence was thus variable. However, roots where C_1 was the target were never initial in the sentence, and roots where C_2 was the target were never final in the sentence.

78

3.3.2 Measurements

Acoustic analysis was conducted using the Praat software for speech analysis (Boersma and Weenick 2010). The acoustic properties that were measured varied depending on whether the target consonant was a stop or an affricate, and on whether the preceding and following segments were consonants or vowels. Given a preceding or following vowel, the voice quality of this vowel was measured. For stops, the closure duration, burst amplitude and VOT were measured. For affricates, the closure duration, frication duration, frication intensity and post-frication VOT were measured.

Voice quality is quantified as the difference between the amplitude of H1 and H2 in the 30 ms of the vowel closest to the consonant (final 30 ms for preceding vowels, initial 30 ms for following vowels). VOT is measured from the beginning of the burst to the onset of periodicity in the following vowel in stops. For affricates, the period from the release of the stop closure to the onset of vowel voicing may have two distinct periods. For plain affricates, there is almost always a single period of frication. For ejective affricates, however, the frication period is followed by a period of silence corresponding to the glottal closure. This silent period is measured separately from the frication period, and is referred to as VOT. Examples of the periods that were measured in plain and ejective stops and affricates are given in (31) and (32).

(31)   a. [aka] from *akajel*

0 ms.   300 ms.

closure = 80 ms.   VOT = 85 ms.

b. [ɨk'a] from *ityäk'añ*

0 ms.   300 ms.

closure = 80 ms.   VOT = 85 ms.

(32)   a.   [utʃu] from *akuchu*

0 ms.   300 ms.

closure = 74 ms.   frication = 94 ms.

b. [itʃi] from *ich'ip*

0 ms.   300 ms.
clos. = 89 ms. fric. = 61 ms. VOT = 59 ms.
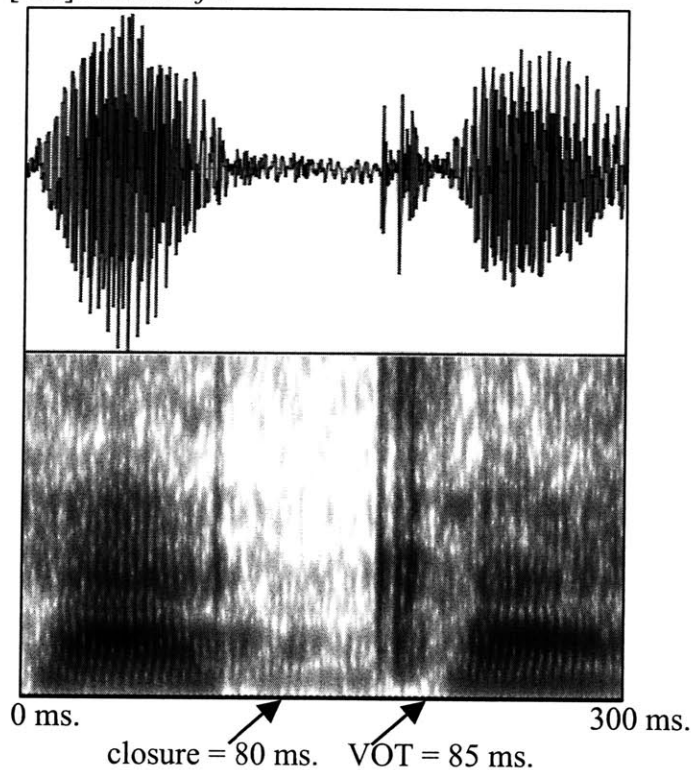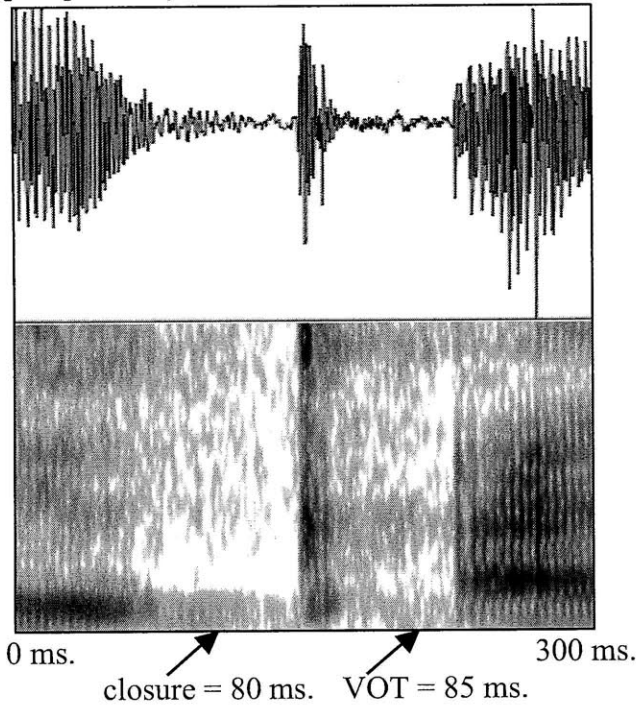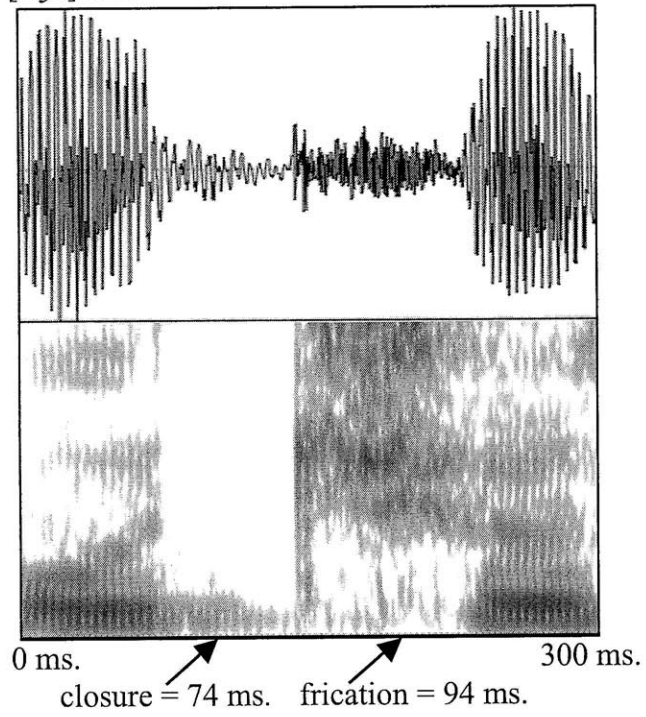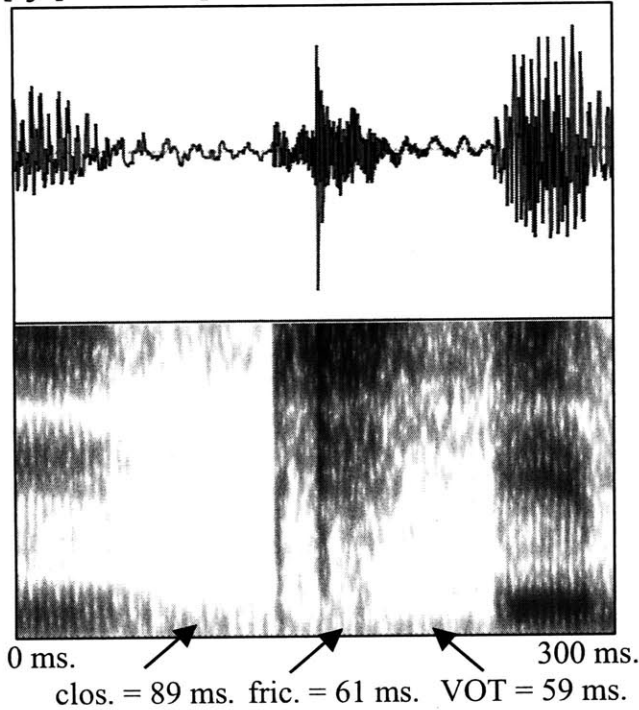
Burst amplitude is measured by subtracting the amplitude of the lowest point in the waveform from the highest point. The highest and lowest points in the burst period were measured, regardless of whether these two points were non-adjacent, as was done for Quechua. An example of a burst with non-adjacent high and low points is given in (33).

(33)   [p'] burst: highest point   lowest point
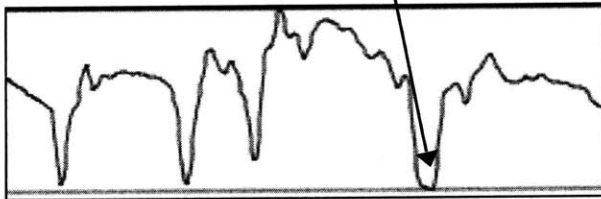
Burst amplitude is not measured for the affricates and palatalized coronals. Instead, the average intensity throughout the frication period is taken.

3.3.3 Results

Results of the acoustic measurements are reported for target consonants in three of the four positions recorded. Instances of C_2 followed by a consonant could not be reliably measured or analyzed. While burst and VOT measurements were clear for consonants followed by [l], those followed by one of the three possible stops [tʲ, tʃ, ɓ] often did not have an easily recognizable burst or VOT period, and thus could not be measured in any consistent fashion. The inconsistent

81

realization of pre-consonantal consonants resulted in a very small amount of data (0-2 tokens per stop per subject), and thus these measurements were excluded from the overall statistical analysis.

For each acoustic measurement a one way, repeated measures ANOVA was run on the data from all subjects and places of articulation to determine what measures significantly distinguish plain from ejective consonants. Significant effects were found for the voice quality of the preceding and following vowel and VO. For the stops, burst amplitude was also a significant determiner of laryngeal category. For the affricates and the palatalized alveolar stop, duration and intensity of frication were significant. Average values for these significant factors are given in (34) for the two laryngeal categories.

(34)

	plain	ejective
V_1 voice quality	-.2 dB	-3 dB
burst intensity	.3	.4
frication intensity	62 dB	63
frication duration	75 ms	54 ms
VOT	15 ms	62 ms
V_2 voice quality	-2.1 dB	-3.6 dB

Significant differences in these determining factors between consonants in different prosodic positions (C_1 v. C_2 and post-vocalic v. post-consonantal) and at different places of articulation are discussed in the following two sub-sections.

3.3.3.1 Laryngeal categories and interactions with position

The only significant variation based on position are differences in voice quality of surrounding vowels. Voice quality is significantly different in medial than in initial position for both preceding ($\beta = -2$, t = -4, p < .001) and following ($\beta = -2$, t = -2, p < .02) vowels, with phonation being on average breathier later in the word than earlier.

3.3.3.2 Laryngeal categories and interactions with place

Several measures vary significantly depending on place of articulation. Frication duration and intensity vary between the affricates [ts, tʃ, ts', tʃ'] and the palatalized stops [tʲ, tʲ']. Burst amplitude differs in velar and labial stops. Finally, VOT length is variable across all consonants.

First, the palatalized stops [tʲ, tʲ'] are grouped with the affricates [ts, ts', tʃ, tʃ'] with respect to what acoustic properties were measured. The palatalized stops pattern with the affricates in that they have no distinct burst that can be measured, since the stop closure is released into an offglide, and in that they have a period of aperiodic noise (the offglide) between the closure and the following vowel. Palatalized stops and affricates were thus all measured for the duration and intensity of the offglide/frication. There are, however, differences between the frication period of the affricates and the offglide/frication of the palatalized stop. A Linear Mixed Effects Model finds that the offglide/frication period is generally longer for the affricates than for the palatalized stops (($\beta = 35$, t = 11, p < .0001). Across places, the offglide/frication period is shorter in the ejective than in the plain series ($\beta = -10$, t = -3, p < .0001). The difference in

82

frication duration is significant for the palatalized stops ((β = 18, t = 4, p < .0002), though it is smaller than for the affricates. This difference can be seen in the graph below.

Frication Duration
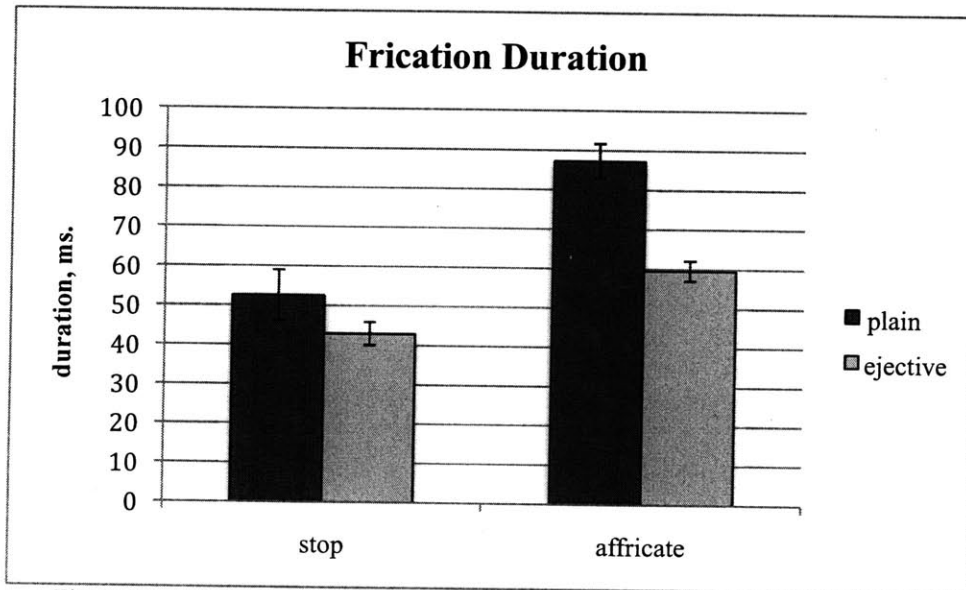
Figure 8: Frication duration in milliseconds (averaged across all tokens and speakers) for plain and ejective palatalized stops and affricates. Error bars indicate 95% confidence interval.

Intensity of frication also varies between the palatalized stops and the affricates. A Linear Mixed Effects Model finds that frication intensity for ejective affricates is significantly greater than for plain affricates or palatalized stops (β = 3, t = 4, p < .0003). Frication intensity does not distinguish the plain and ejective palatalized stops. Frication intensity is thus only a correlate of the ejective-plain contrast for affricated stops.

Frication Intensity
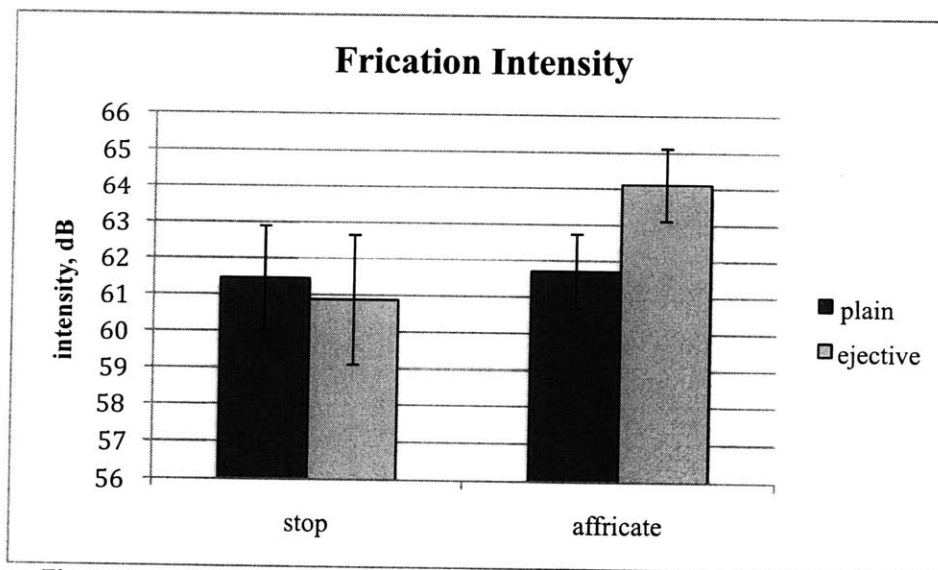
Figure 9: Frication intensity in dB for plain and ejective palatalized stops and affricates, averaged across all tokens and speakers. Error bars indicate 95% confidence interval.

The labial and velar stops differ from one another in burst amplitude. A Linear Mixed Effects Model shows that burst amplitude is greater in ejectives than in plain stops ($\beta = .2$, $t = 6$, $p < .0001$), and that burst amplitude is weaker in labials than in velars (($\beta = -.1$, $t = -3$, $p < .02$).
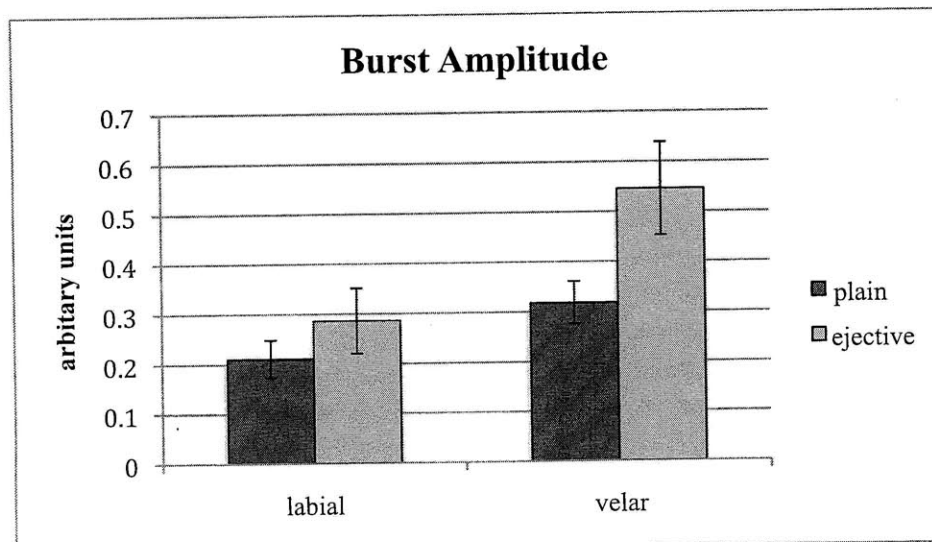
Burst Amplitude

Figure 10:   Burst amplitude in arbitrary units (averaged across all tokens and speakers) for plain and ejective labial and velar stops. Error bars indicate 95% confidence intervals.

VOT also varies between consonants at different places of articulation. VOT is longer in the ejective than in the plain series ($\beta = 46$, $t = 15$, $p < .0001$), but is also longer in stops than in affricates ($\beta = 24$, $t = 11$, $p < .0001$), and is shorter in labial than in velar stops ($\beta = -24$, $t = -8$, $p < .0001$). VOT for the plain and ejective series for all five consonants is plotted in Figure 11.

Voice Onset Time
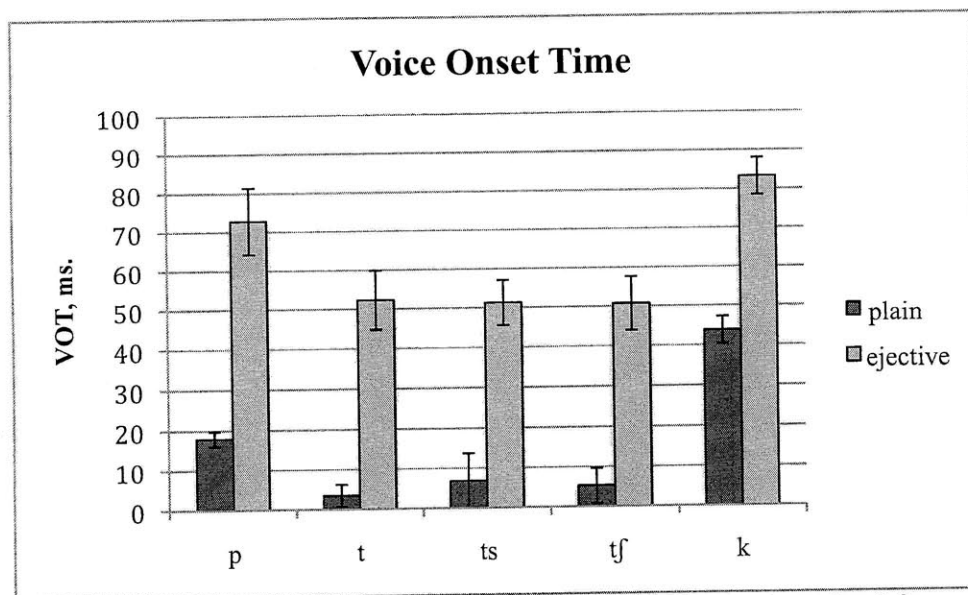
Figure 11:   VOT in milliseconds (averaged across all tokens and speakers) for all five plain and ejective stops. Error bars indicate 95% confidence intervals.

84

Average VOT values with one standard deviation are given in (35).

(35)

	plain	ejective
[p, p']	18 (7)	73 (28)
[k, k']	44 (12)	83 (17)
[tʲ, tʲ']	4 (10)	52 (27)
[ts, ts']	7 (24)	51 (21)
[tʃ, tʃ']	6 (15)	51 (24)

3.3.4 Summary

As in Quechua, ejectives in Chol are characterized by longer VOT and greater burst amplitude (in stops) than plain stops. Unlike in Quechua, Chol ejectives are additionally accompanied by creaky voice in the surrounding vowels. Ejective affricates in Chol are distinguished from their plain counterparts by greater frication intensity and shorter frication duration. The palatalized stops [tʲ, tʲ'] stand out somewhat from the other stops in not having a clear burst, and thus the ejective-plain contrast is not marked by a difference in burst amplitude. These stops also stand out from the affricates in that frication intensity does not mark the ejective-plain contrast and the difference in frication duration between the two series is much smaller.

3.4 Summary and discussion of laryngeal contrasts

The chart in (36) summarizes the results of all of the acoustic studies of ejectives discussed in this chapter. The VOT measurement given here is the difference between the average VOT of the ejective series and the average VOT of the plain series. For these purposes, in Turkish Kabardian and Xhosa, the voiced series was considered plain. The VOT of affricates was excluded for all languages except Chol, as this measurement often includes frication. For those languages where burst amplitude and phonation type in the vowel were not measured, these fields are either left blank or are filled in based on my own qualitative judgments from looking at waveforms included in the relevant studies. Where I have used my own judgment, it is given in parentheses.

(36)

Language	VOT ejective - plain	large burst amplitude	Creaky vowel / slow amplitude rise
Apache	30 ms	(yes)	-
Navajo	80 ms	yes	no
Witsuwit'en	10 ms	-	yes
Hupa	63 ms	-	(no)
Tlingit	78 ms	-	(no)
Tsilhqut'in	57 ms	(yes)	yes
Hausa	15 ms	no	yes
Tigrinya	?	no	yes
Chol	46 ms	yes	yes
Bolivian Quechua	103 ms	yes	no
Montana Salish	36 ms	-	-
Turkish Kabardian	83 ms	yes	-
Xhosa	85 ms	yes	no

85

Aspirates are characterized by a long period of noise between release of the stop and onset of voicing in the following vowel. The length of VOT varies greatly from language to language, both in absolute and in relative terms. Aspirates in Quechua are accompanied by breathy phonation in the following vowel. Phonation in vowels surrounding aspirates is not measured in many of the studies reported here. In Witsuwit'en and Tsilhqut'in, however, where vowel phonation was measured, aspirates did not stand out from the plain stops. In these languages, ejectives were characterized by creaky voice, but aspirates and plain stops did not differ. This is in contrast then to the pattern found in Quechua, where aspirates stand out from ejective and plain stops. Ejectives and aspirates contrast with other types of stops in having a VOT lag, but may differ from one another both in burst amplitude and in the phonation type of the surrounding vowels.

The acoustic correlates to aspirates are long VOT and possibly breathy phonation in the following vowel. Ejectives are characterized by long VOT, loud burst amplitude and in some cases creaky phonation in the following vowel. In all of the languages surveyed the VOT of ejectives was longer than in voiceless unaspirated stops, though in Hausa and Witsuwit'en this difference was very small. Measurements of vowel quality show some correlation between the length of VOT and whether the following vowel is creaky. While extremely long VOT correlates with modally voiced vowels, as in Quechua and Navajo, and very short VOT correlates with creaky voiced vowels, as in Hausa and Witsuwit'en, creaky voice is also possible in ejectives with moderate to long VOT, as in Chol and Tsilhqut'in. Sounds classified as implosive may be modally voiced or creaky voiced, and involve a rush of air into the mouth upon release or not. In both modally and creaky voiced implosives, voicing amplitude rises throughout the closure. These acoustic cues are summarized in (37).

(37)   Summary of dimensions of contrast for ejectives, aspirates and implosives

<u>ejectives</u>:	long VOT	burst amplitude	creaky/modal phonation
<u>aspirates</u>:	long VOT	aspiration noise	breathy/modal phonation
<u>implosives</u>:	voicing amplitude rise	rush of air into the mouth	creaky/modal phonation

The dimensions of contrast in (37) underly the auditory features for laryngeal contrasts proposed at the beginning of this chapter and argued for earlier in Chapter 2. The case studies in Chapters 5-7 make use of four auditory features, [loud burst], [long VOT], [creak], and [v-amp], which represent a sub-set of the dimensions of contrast for laryngeal features.

Chapter 4   The perception of ejective and aspirate contrasts

The central claim of this thesis is that laryngeal cooccurrence restrictions are driven by grammatical pressures to neutralize perceptually indistinct contrasts. This chapter establishes the substantive basis of this claim. The perceptual experiments reported on here provide evidence that the contrast neutralizations found in languages with laryngeal cooccurrence restrictions correlate with asymmetries in the perceptual strength of laryngeal contrasts between roots.

There are two basic patterns in languages with laryngeal cooccurrence restrictions, schematized in (1). In dissimilation, pairs of stops in a root may not share the same laryngeal feature, while in assimilation pairs of stops in a root must share the same laryngeal feature.

(1) Dissimilation: *K'-P'   ✓K'-P   ✓K-P
    Assimilation: ✓K'-P'   *K'-P   ✓K-P

Dissimilatory and assimilatory restrictions are opposites – the laryngeal configuration that is disallowed in one type of language is required in the other. The contradictory nature of cooccurrence restrictions makes it impossible to claim that a given laryngeal configuration is more marked than another. That is, while dissimilatory restrictions suggest that forms with two laryngeally marked segments are more marked than forms with only a single laryngeally marked segment, assimilatory restrictions suggest exactly the opposite. The unifying property of laryngeal cooccurrence restrictions is neutralization of the same *contrast* between forms. The contrast between forms with one and forms with two laryngeally marked segments is neutralized in both dissimilatory and assimilatory restrictions.

The general hypothesis is that the contrast between forms with one and forms with two instances of a laryngeal feature is perceptually confusable, and thus neutralized. In a language with a dissimilatory restriction, then, a form with two laryngeally marked segments is disallowed because it is not sufficiently distinct from a form with one laryngeally marked segment; in a language with an assimilatory restriction a form with one laryngeally marked segment is disallowed because it is not sufficiently distinct from a form with two laryngeally marked segments. There is thus nothing inherently marked about forms with a single laryngeally marked consonant K'-T or forms with two laryngeally marked consonants K'-T', what is marked is the contrast between these two types of forms {K'-T, K'-T'}.

This hypothesis is tested and supported by three discrimination experiments. Subjects are presented with pairs of CVCV nonce words that are either the same or differ only as to the laryngeal features of the consonants, and asked to judge whether the words are the 'same' or 'different' from one another.

The first two experiments test the perception of ejective-plain and aspirate-plain contrasts. These experiments compare three contrasts in laryngeal configurations between stimuli: 1 vs. 0 (*k'api-kapi*), 2 vs. 0 (*k'ap'i-kapi*) and 1 vs. 2 (*k'ap'i, kap'i*) for both ejectives and aspirates. The results show that for both ejective and aspirate contrasts, the 1 vs. 2 contrast is more difficult than the 1 vs. 0 contrast, which is in turn more difficult than the 2 vs. 0 contrast.

The key result of these two experiments is that the perceptibility of a laryngeal contrast varies depending on other, non-adjacent segments. Pairs of roots in both the 1 vs. 0 and 1 vs. 2 conditions differ in whether one segment is laryngeally marked or not, e.g. the pair *k'api-kapi* (1 vs. 0) and the pair *kap'i-k'ap'i* (1 vs. 2) both differ in whether the initial consonant is [k] or [k']. Despite the fact that the difference between the roots in these two pairs is acoustically

identical, the pair showing a 1 vs. 0 contrast (*k'api-kapi*) is more perceptually distinct than the pair showing a 1 vs. 2 contrast (*kap'i-k'ap'i*). Thus, it is found that the strength of the contrast between an ejective and a plain stop or an aspirate and a plain stop is degraded when there is another ejective or aspirate in the root.

The hypothesis about laryngeal cooccurrence restrictions, and long-distance phonological interactions more generally, is that those segments that exhibit long-distance phonological restrictions are just those segments that exhibit long-distance perceptual interactions, as is found for ejectives and aspirates. The classes of sounds referred to by the terms "ejective" and "aspirate", however, are characterized by a variety of articulatory and auditory properties, and thus the question remains what it is about ejectives and aspirates that is prone to long-distance perceptual asymmetries.

The third experiment tests the hypothesis that long VOT is the auditory dimension that is subject to long-distance interactions. If this hypothesis is correct, it follows that both ejectives and aspirates show long-distance effects, as is supported by the first two experiments, and moreover that ejectives and aspirates interact with one another. The third experiment looks at the contrast between an ejective and a plain stop in words with another aspirate (*k'ap^hi-kap^hi*), and at the contrast between an aspirate and a plain stop in words with another ejective (*k^hap'i- kap'i*), and finds that these contrasts are less perceptible than the same contrasts in words with another plain stop (*k'api-kapi* and *k^hapi-kapi*). These results support the idea that it is the perception of contrasts in long VOT that is affected long-distance. The contrast between a long VOT stop (ejective or aspirate) and a plain stop is degraded in the context of another long VOT stop (ejective or aspirate), regardless of whether the two long VOT stops are drawn from the same series.

The results of the experiments presented in this chapter motivate the analysis of laryngeal cooccurrence restrictions in the next chapter. The hierarchy of perceptual strength in laryngeal contrasts between roots found in the first two experiments projects a set of systemic markedness constraints, favoring neutralization of relatively perceptually weak contrasts. These constraints target the individual auditory dimensions that define laryngeal contrasts, as opposed to the more abstract or articulatory categories of "ejective", "aspirate" and "implosive", as supported by the third experiment. The rest of this chapter discusses each of these three experiments in detail.

4.1 Experiment 1: ejectives

The experiment presented in this section tests the relative perceptability of contrasts in ejection between roots.

4.1.1 The hypotheses

In all types of laryngeal restrictions, the contrast between forms with 1 and 2 instances of a laryngeal feature is neutralized. This observation leads to Hypothesis 1, given in (2).

(2) Hypothesis 1   Pairs of roots that contrast 1 vs. 2 ejectives are less distinct than pairs of roots that contrast either 1 vs. 0 or 2 vs. 0 ejectives.

$$\Delta([T'...K']\text{-}[T'...K]) \;<\; \Delta([T'...K]\text{-}[T...K]), \Delta([T'...K']\text{-}[T...K])$$

Hypothesis 1 predicts the existence of cooccurrence restrictions, motivated by a pressure to neutralize the contrast between forms with one and forms with two laryngeal features. A more ambitious hypothesis about the role of perception in laryngeal restrictions is that not only the existance of restrictions, but also the variation in types of restrictions is perceptually based. The neutralization of the 1 vs. 2 contrast is neutralized to a form with one laryngeally marked segment in languages with dissimilatory restrictions, and a form with two laryngeally marked segments in languages with assimilatory restrictions. The second hypothesis is that the variation between the outcome of neutralization in dissimilatory and assimilatory restrictions reflects different thresholds for the distinctness of allowable contrasts. Neutralization to a form with two laryngeally marked segments results in a stronger contrast with roots with no laryngeally marked segments (2 vs. 0) than neutralization to a form with a single laryngeally marked segment (1 vs. 0).

(3) Hypothesis 2   Pairs of roots that contrast 1 vs. 0 ejectives are less distinct than pairs
                     of roots that contrast 2 vs. 0 ejectives.

$$\Delta([\text{T'}...\text{K}]-[\text{T}...\text{K}]) \quad < \quad \Delta([\text{T'}...\text{K'}]-[\text{T}...\text{K}])$$

The third and final hypothesis tests for a perceptual explanation of place-dependent assimilation. While some languages show a general assimilatory restriction on laryngeal features, other languages show dissimilation in roots with heterorganic stops and assimilation in roots with homorganic stops.

(4) Hypothesis 3   Pairs of roots with homorganic stops that contrast 1 vs. 0 ejectives are
                     less distinct than pairs of roots with heterorganic stops that contrast
                     1 vs. 0 ejectives.

$$\Delta([\text{T'}...\text{T}]-[\text{T}...\text{T}]) \quad < \quad \Delta([\text{T'}...\text{K}]-[\text{T}...\text{K}])$$

The three hypotheses above are summarized in the four-tiered perceptual hierarchy in (5), which can also be stated as in (6).

(5)   1 vs. 2   <   1 vs. 0 hom.   <   1 vs. 0   <   2 vs. 0
        k'api-k'ap'i   *k'aki-kaki*   *k'api-kapi*   *k'ap'i-kapi*

(6) $\Delta([\text{T'}...\text{K'}]-[\text{T'}...\text{K}]) \quad < \quad \Delta([\text{T'}...\text{T}]-[\text{T}...\text{T}]) \quad <$
       $\qquad\qquad\qquad\qquad\qquad \Delta([\text{T'}...\text{K}]-[\text{T}...\text{K}]) \quad < \quad \Delta([\text{T'}...\text{K'}]-[\text{T}...\text{K}])$

The hypotheses center around claims about the relative distinctness or strength of a contrast. For some contrast category A to be "weaker" than some contrast category B, subjects should have more difficulty discriminating pairs of forms that fall into category A than B (i.e. incorrectly think that pairs of different words are the same or that pairs of same words are different). The experiment tests these hypotheses by presenting subjects with pairs of CVCV nonce words that differ only in whether the consonants are ejective or plain. Subjects are then asked to decide whether the words they hear are the same or different from one another (an AX discrimination task). If Hypothesis 1 is true, subjects will perform better on pairs like *k'ap'i-kapi* (2 vs. 0),

k'api-kapi (1 vs. 0 heterorganic) and *k'aki-kaki* (1 vs. 0 homorganic) than on pairs like *k'api-k'ap'i* (1 vs. 2). If Hypothesis 2 is supported, subjects should be better at accurately distinguishing pairs like *k'ap'i-kapi* (2 vs. 0) than pairs like *k'api-kapi* (1 vs. 0). Finally, if Hypothesis 3 is true, subjects will perform better on pairs like *k'api-kapi* (1 vs. 0) than on pairs like *k'aki-kaki* (1 vs. 0 homorganic).

4.1.2 Stimuli

The stimuli for this experiment are pairs of CVCV disyllables manually spliced together from recordings of South Bolivian Quechua. The stops in pairs of stimuli differ only as to whether the consonants are plain or ejective.

4.1.2.1 Creating the stimuli

The target stimuli have one of four laryngeal configurations: CVCV (0 ejectives), C'VCV (1 ejective, initial position), CVC'V (1 ejective, medial position), or C'VC'V (2 ejectives). Three places of articulation (labial, alveolar and velar) and two vowel patterns (a-i and i-u) were used. Not all four of these desired laryngeal configurations are grammatical in Quechua, however, so it was not possible to record all four types of words. Quechua is a dissimilating language that does not allow pairs of ejectives in a word. Additionally, Quechua does not allow non-initial ejectives in words with two stops (e.g. *sap'a* 'a kind of basket', but *tap'a), as mentioned in Section 1. Consequently, nonce words were constructed which conformed to the phonotactics of Quechua for the purposes of recording, and the experimental stimuli were made by splicing together individual syllables. The recorded words took one of three grammatical laryngeal configurations in Quechua: CVCV (two plain stops), C'VCV (initial ejective, medial plain stop) or sVC'V (initial [s], medial ejective). Stress consistently fell on the initial syllable of the nonce root.

Recordings of a middle-aged female speaker of South Bolivian Quechua were made in Cochabamba, Bolivia using a Marantz PMD660 solid-state recorder and Audio Technica 831b microphone. The speaker was asked to read the phonotactically legal nonce words from a computer screen, embedded in the carrier phrase *Noqa X simita qellqani* 'I wrote the word X'.

The experimental stimuli were made by splicing together CV sequences from the original recording. Stimuli were spliced together during the closure of the second C, keeping VC transitions intact and resulting in natural sounding stimuli. A stimulus like *k'api*, for example, was made by splicing the first CV and the VC transition of *k'api* with the second CV of *kapi*; *k'ap'i* was made by splicing the first CV and VC transition of *k'api* with the second CV of *sap'i*. Initial and final syllables in the stimuli were always spliced from original initial and final syllables in the recorded speech.

Stimuli with two heterorganic stops were made in all four laryngeal patterns (CVCV, C'VCV, CVC'V, C'VC'V) while stimuli with two homorganic stops were only made in three (CVCV, C'VCV, CVC'V). Stimuli are put in pairs that fall into one of nine categories in (7) based on the type of laryngeal contrast.

(7)　　a.　same　　0 vs. 0 heterorganic　　e.g. *kapi-kapi*
　　　　　　　　　　0 vs. 0 homorganic　　e.g. *kaki-kaki*
　　　　　　　　　　1 vs. 1 heterorganic　　e.g. *k'api-k'api*　or　*kap'i-kap'i*
　　　　　　　　　　1 vs. 1 homorganic　　e.g. *k'aki-k'aki*　or　*kak'i-kak'i*
　　　　　　　　　　2 vs. 2 heterorganic　　e.g. *k'ap'i-k'ap'i*

　　　　b.　different　1 vs. 0 heterorganic　　e.g. *k'api-kapi*　or　*kap'i-kapi*
　　　　　　　　　　1 vs. 0 homorganic　　e.g. *k'aki-kaki*　or　*kak'i-kaki*
　　　　　　　　　　2 vs. 0 heterorganic　　e.g. *k'ap'i-kapi*
　　　　　　　　　　1 vs. 2 heterorganic　　e.g. *k'api-k'ap'i*　or　*kap'i-k'ap'i*

The 'different' pairs were presented in both possible orders (1–0 and 0–1, 2–0 and 0–2, 1–2 and 2–1). In stimuli pairs where one stimulus has only one ejective, the ejective could be in either initial or medial position (C'VCV or CVC'V). There are different numbers of unique stimulus pairs for each of the categories in (7), depending on whether the pairs have homorganic or heterorganic pairs of stops and whether order of presentation (for "different" pairs) or position of ejection (for pairs with a form with a single ejective) is variable. Stimulus pairs were repeated if necessary so that the total number of stimuli in each category was 48, resulting in a total of 432 pairs presented to each subject.

4.1.2.2　Acoustic properties of the ejective-plain contrast in the stimuli

This experiment tests the perceptibility of the contrast between ejectives and plain stops, using stimuli from spoken Quechua. To see what acoustic cues potentially underlie the results of the study, acoustic analysis was conducted on the edited stimuli. Acoustic analysis serves two purposes. First, it verifies that cues to the ejective-plain contrast are present in all of experimental stimuli, ensuring that the perceptual results are truly perceptual, and not the result of acoustic irregularities. Second, if subjects show difficulty in perceiving the ejective-plain contrast in certain categories, as is predicted, we will know what acoustic properties are not being accurately perceived.

　　For each initial and medial syllable used in stimulus creation VOT, burst amplitude and voice quality of the vowel were measured. VOT was measured in milliseconds from the beginning of the burst to the onset of periodicity in the following vowel. Burst amplitude was measured in arbitrary units directly off of the waveform by calculating the difference between the highest and lowest points in the waveform. Voice quality is quantified as the difference between the amplitude of H1 and H2 in the first 30 ms of the vowel (Ladefoged 2003).

　　Each unique sequence was measured once. For example, while *k'i* from *sak'i* was spliced into multiple stimuli (e.g. *pak'i* and *tak'i* and *kak'i*), this sequence was only measured one time. For all initial sequences, as well as medial sequences with an ejective, there were 6 unique tokens to measure. For medial sequences with a plain stop, there were 12 tokens. This asymmetry arises because no initial and medial sequence from the same natural utterance were spliced together. All medial syllables with ejectives were taken from an utterance with initial *s*. Medial syllables with plain stops were cross-spliced so that *ki* in the stimulus *taki* was spliced from *t'aki* and *ki* in the stimulus *t'aki* was spliced from *taki*.

　　The measurements for each place of articulation were subjected to a two way ANOVA with position and laryngeal type as factors. For all three places of articulation, there was a significant

effect of VOT and burst amplitude along with a significant interaction between laryngeal category and position. For the alveolars, there was also a small main effect of vowel voice quality (p < .04) but no interaction with position. The statistical results are reported in (8).

(8)

velar	VOT	amplitude	voice quality
laryngeal type	$F(1,26) = 413$ $p < .0001$	$F(1,26) = 113.9$ $p < .0001$	$p > .05$
laryngeal type x position	$F(1,26) = 12.4$ $p < .002$	$F(1,26) = 46.1$ $p < .0001$	$p > .05$
alveolar			
laryngeal type	$F(1,26) = 302$ $p < .0001$	$F(1,26) = 95.8$ $p < .0001$	$F(1,26) = 5.3$ $p < .04$
laryngeal type x position	$F(1,26) = 5.4$ $p < .03$	$F(1,26) = 18.5$ $p < .0003$	$p > .05$
labial			
laryngeal type	$F(1,26) = 1235$ $p < .0001$	$F(1,26) = 30.5$ $p < .0001$	$p > .05$
laryngeal type x position	$F(1,26) = 74.9$ $p < .0001$	$F(1,26) = 7.9$ $p < .01$	$p > .05$

Mean values for amplitude and VOT for each consonant in initial and medial positions are given in (9).

(9)

initial	VOT	amplitude	medial	VOT	amplitude
p'	163	.5	p'	95	.6
p	14	.3	p	23	.3
t'	148	.5	t'	114	.8
t	21	.3	t	24	.3
k'	149	1.5	k'	117	.5
k	40	.3	k	41	.3

Acoustic analysis shows, as summarized in (8) and (9), that ejective and plain stops are distinguished by burst amplitude and VOT. These cues are reliably preserved in the spliced stimuli, since CV transitions are kept intact.[14] Any difficulty in accurately discriminating between ejectives and plain stops, then, cannot be attributed to conflicting cues in the signal. Sample spectrograms are given in (10) for the syllables *k'a* and *ka*.

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[14] Any cues to the ejective-plain contrast in the preceding vowel (relevant for medial contrasts only) were not preserved in the stimuli. In the stimuli, vowels preceding medial ejectives were spliced from stimuli where they preceded plain stops, e.g. the [a] in the stimulus *kap'i* is spliced from *kapi*. The reverse situation never obtains; vowels preceding medial plain stops were never spliced from stimuli where they preceded ejectives. If there are significant cues to the ejective-plain contrast in the preceding vowel, these cues are conflicting for medial ejectives but not for medial plain stops.
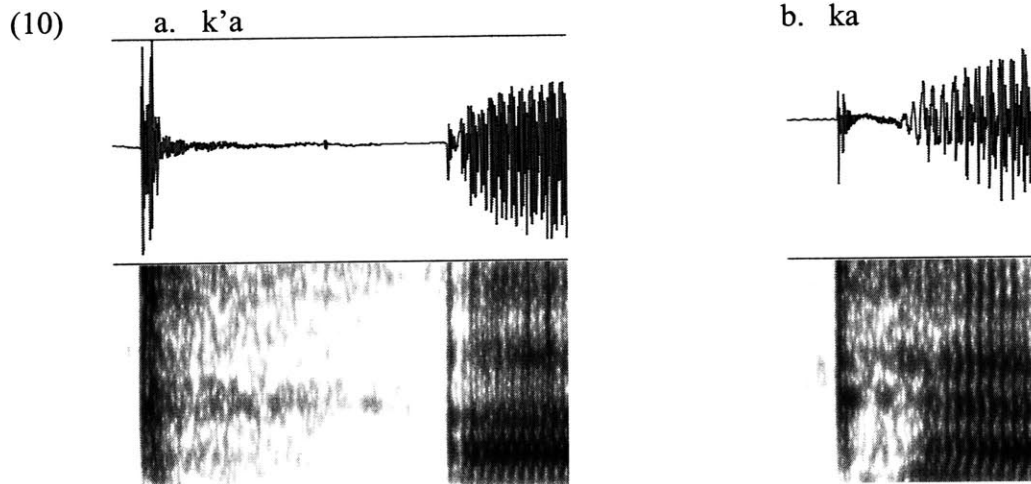
(10)   a. k'a   b. ka

Differences in the acoustics of contrasts depending on place of articulation and position are taken into account in the analysis of the perceptual results, presented below.

Finally, the original sound files from which the stimuli were made were tested for any long-distance interaction between ejective and plain stops. The main hypothesis is that the ejective-plain contrast is perceptually weaker in roots with another ejective stop. One possible explanation for such an effect could be acoustic – an ejective may alter the production of a stop elsewhere in the word, making ejectives and plain stops acoustically more similar. In theory, the acoustic effect could be that ejectives following other ejectives have weaker bursts and shorter VOTs than other ejectives (e.g. [p'] in [k'ap'i] vs. [kap'i]), or that plain stops following ejectives have louder bursts and longer VOTs than other plain stops (e.g. [p] in [k'api] v. [kapi]). Given the phonotactics of Quechua, only the latter possibility can be tested; forms with two ejectives are absent in the Quechua lexicon, as are forms with medial ejectives following plain stops. The VOT and burst amplitude of plain stops in medial position were compared, depending on whether the initial stop was ejective or plain. Neither measure was significantly different in the two contexts, according to a two-tailed paired t-test ($p > .05$ for both measures). The differences in VOT between the two contexts showed a slight trend ($p < .09$) for longer VOTs following ejectives than plain stops. The average values between the two contexts, however, differed by only four milliseconds (28 ms following an ejective stop vs. 24 ms following a plain stop). It seems unlikely that such a small difference would have any perceptual effect, especially considering that the contrasting ejectives in medial position have an average VOT of 108 ms.

4.1.3 Procedure

Subjects were presented auditorily with pairs of nonce roots and asked to decide whether the roots they heard were the same or different from one another. Subjects indicated their response by pressing one of two clearly marked keys on a standard USB keyboard. Subjects listened to the stimuli through a pair of high-quality headphones, while looking at a computer screen. The stimuli were presented while the computer screen was black, with a 300 ms inter-stimulus interval. After the second stimulus, a green line appeared on the screen. Subjects were told to indicate their response as quickly as possible once the green line appeared, but not before. All subjects thus listened to both stimuli in their entirety before indicating their choice of "same" or

"different". Response time was limited to 1500 ms. If subjects did not respond within this time, they automatically went on to the next trial.

The subjects were 19 speakers of American English with no exposure to a language with ejectives. English speakers were chosen as subjects instead of native Quechua speakers to avoid a phonological bias in perception. Quechua speakers, or any speaker of a language with restrictions on ejectives, is cognizant of restrictions or trends in the distribution of these sounds, and this knowledge may effect their perception of nonce words. Thus, while Quechua speakers may perform in a way consistent with the hypotheses, it would not be clear if this performance was due to the Quechua speakers' grammar, or to some basic property of the perceptual properties of ejectives in different environments. The English subjects were told that the sounds they were hearing were not from English, and would sound foreign. That English speakers were generally good at hearing ejectives can be seen by looking at their performance on "same" pairs, on which all subjects made very few mistakes. Each subject listened to five trial pairs to accustom themselves to the stimuli and task. The experiment took about 20 minutes, including a break halfway through, and subjects were compensated for their participation.

4.1.4 Results

Subjects' performance supports two of the three hypotheses. The 1 vs. 2 contrast is indeed weaker than other laryngeal contrasts, supporting Hypothesis 1. Additionally, the 1 vs. 0 contrast is significantly weaker than the 2 vs. 0 contrast, supporting Hypothesis 2. No difference was found between the 1 vs. 0 contrast in heterorganic and homorganic pairs of stops, and thus Hypothesis 3 is not supported.

A contrast coded Mixed Logit Model, with "correct" as the dependent variable and random effects of first stimulus, second stimulus and subject, shows a significant difference between 1 vs. 2 and 1 vs. 0 (both 1 vs. 0 and 1 vs. 0 H) contrast categories (β = 1.38079, Z = 11.686, p < .0001), as well as a significant difference between 1 vs. 0 (both 1 vs. 0 and 1 vs. 0-H) and 2 vs. 0 contrast categories (β = -1.34879, Z = -9.718, p < .0001). There is no significant difference between 1 vs. 0 and 1 vs. 0 H contrast categories (β = .08424, z = .607, p > .05), revealing that subjects' performance on the 1 vs. 0 contrast is not affected by the homo- or heter-organicity of the consonants. For discussion of Mixed Models and why this is the appropriate model for binary forced choice tasks see Jaeger (2008). The statistical model only tested for differences between subjects' performance on the different categories. Performance on same trials was very high across the board, showing both that subjects were able to accurately perceive ejectives and that subjects do not generally misperceive pairs of same tokens as different. Performance on the same trials for all subjects is shown in the graph in Figure 1; different trials are shown in Figure 2.
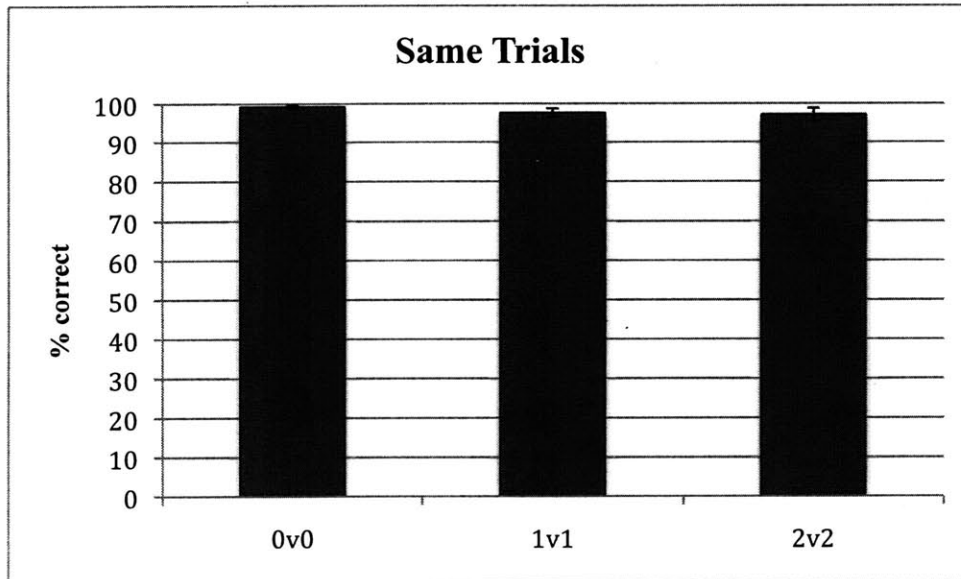
Same Trials

Figure 1: Ejectives – percent correct on same trials, averaged across all subjects. Error bars indicate 95% confidence interval.

Different Trials
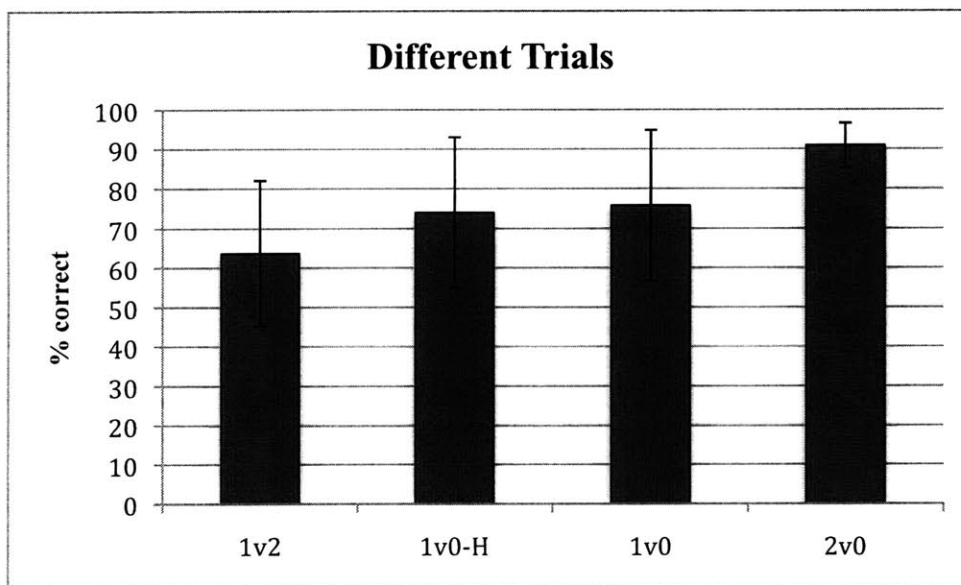
Figure 2: Ejectives – percent correct by contrast category, averaged across all subjects. Error bars indicate 95% confidence interval.

There are two factors other than the category of laryngeal contrast that could have influenced performance. First, it is possible that subjects' discrimination of the ejective-plain contrast varies depending on the place of articulation of the stop in question. Ejective bursts are much louder and VOT longer for stops at the velar place of articulation than at the labial or coronal places, as can be seen from the measurements in (9). Figure 3 below shows that while performance within a category differs somewhat depending on place of articulation, the hierarchy of 1 vs. 2 < 1 vs. 0 holds for all places of articulation. Only the 1 vs. 0 and 1 vs. 2 categories are compared here, since only in these categories is there a single locus of contrast. Token pairs are categorized corresponding to whether the contrast between the two stimuli is on a labial, coronal or velar. For example, in the pair *k'api-kapi* the ejective-plain contrast is on a velar, while in *tip'u-t'ip'u* it is

95

on a coronal. The graph in Figure 3 shows that the overall effect is not a result of contrasts on a single place of articulation, but rather holds across places of articulation.
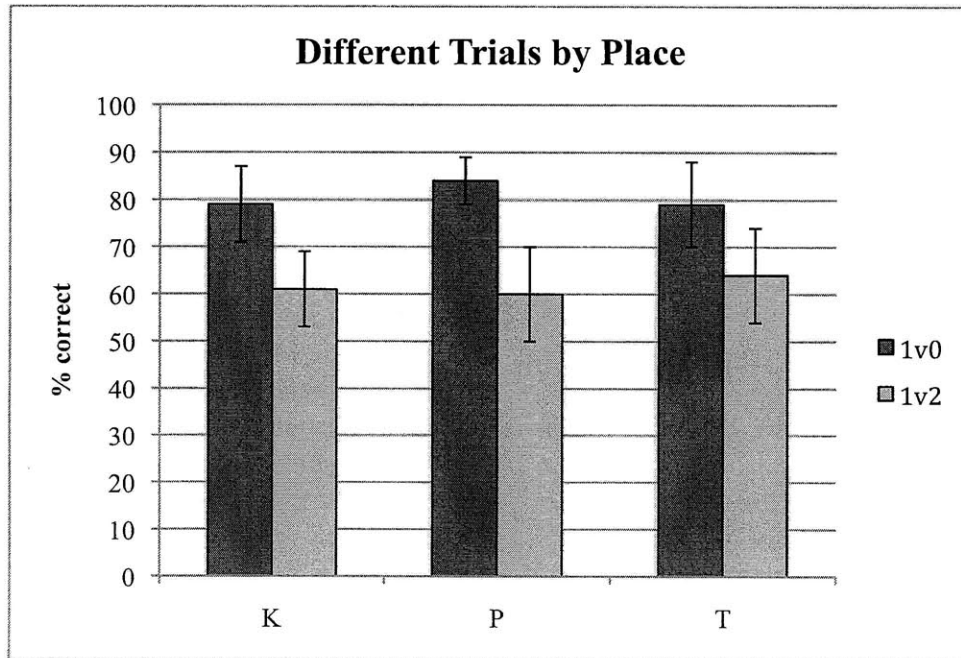
Figure 3:   Ejectives – percent correct for 1 vs. 0 and 1 vs. 2 contrast categories by place of articulation, averaged across all subjects. Error bars indicate 95% confidence interval.

The second possible factor that could have affected the overall outcome is the position of the contrast. In the 1 vs. 0 and 1 vs. 2 conditions, the contrast that subjects were being asked to discriminate may be in either initial or medial position (e.g. *k'api-kapi* or *kap'i-kapi)*. Figure 4 shows that while subjects' are much better at discriminating initial contrasts than medial contrasts within a category, within each position performance on the 1 vs. 2 condition is worse than on the 1 vs. 0 condition. Across contrast positions, however, the hierarchy of contrast categories is affected. While overall 1 vs. 2 is more difficult than 1 vs. 0, a 1 vs. 2 contrast in initial position (***k'ap'i-kap'i***) is in fact easier than a 1 vs. 0 contrast in medial position (*kap'i-kapi*). This reversal poses interesting questions for a theory of how constraints are projected from raw perceptual or other phonetic data, an issue that is discussed briefly in §4.4.
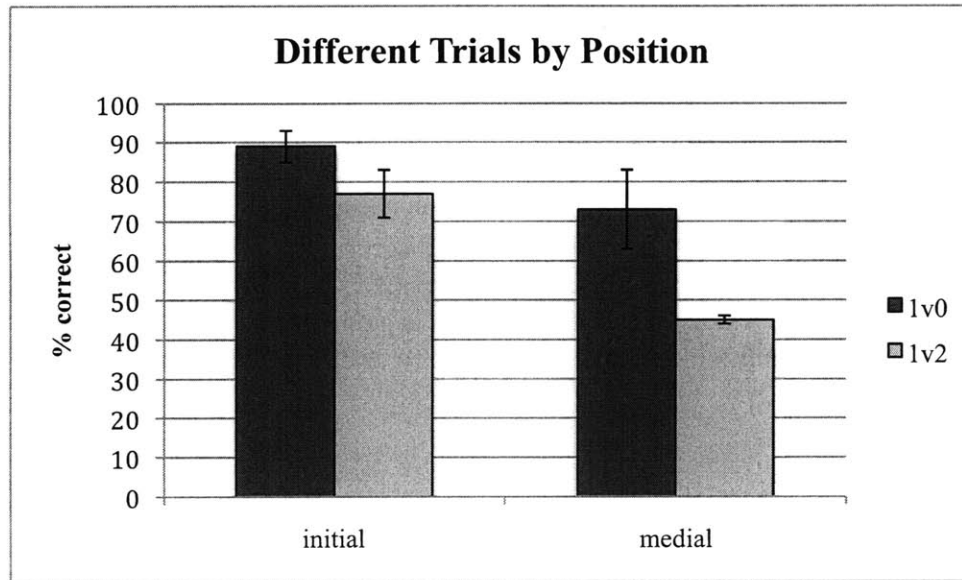
Figure 4: Ejectives - Percent correct for 1 vs. 0 and 1 vs. 2 contrast categories by contrast position, averaged across all subjects. Error bars indicate 95% confidence interval.

Subjects' difficulty on the 1 vs. 2 contrast is thus a function of the contrast category (1 vs. 0 or 1 vs. 2), and is not significantly affected by place of articulation or the position of the contrast in the word.

4.2 Experiment 2: aspirates

4.2.1 The hypotheses

The second experiment aims to confirm the pattern found for ejective contrasts for aspirate contrasts. This experiment tests the two hypotheses in (11).

(11)   Hypothesis 1   Pairs of words that contrast 1 vs. 2 aspirates are less distinct than pairs of words that contrast either 1 vs. 0 or 2 vs 0 aspirates.

$$\Delta([T^h...K^h]-[T^h...K]) \ < \ \Delta([T^h...K]-[T...K]), \Delta([T^h...K^h]-[T...K])$$

Hypothesis 2   Pairs of words that contrast 1 vs. 0 aspirates are less distinct than pairs of words that contrast 2 vs. 0 aspirates.

$$\Delta([T^h...K]-[T...K]) \ < \ \Delta([T^h...K^h]-[T...K])$$

The three-tiered perceptual hierarchy in (12), summarizes the two hypotheses above. (12) can also be stated as in (13).

(12)   1 vs. 2   <   1 vs. 0   <   2 vs. 0
        k^hapi-k^hap^hi k^hapi-$kapi$ k^hap^hi-$kapi$

97

(13) $\Delta([T^h...K^h]-[T^h...K])$ < $\Delta([T^h...K]-[T...K])$ < $\Delta([T^h...K^h]-[T...K])$

The second experiment tests these hypotheses in the same manner as the first experiment. Subjects are presented with pairs of CVCV nonce words that differ only in whether the consonants are aspirate or plain. Subjects are then asked to decide whether the words they hear are the same or different from one another (an AX discrimination task). If Hypothesis 1 is true, subjects will perform better on pairs like k^hap^hi-kapi (2 vs. 0) and k^hapi-kapi (1 vs. 0) than on pairs like k^hapi-k^hap^hi (1 vs. 2). If Hypothesis 2 is supported, subjects should be better at accurately distinguishing pairs like k^hap^hi-kapi (2 vs. 0) than pairs like k^hapi-kapi (1 vs. 0).

4.2.2 Stimuli

4.2.2.1   Creating the stimuli

The stimuli for the second experiment are like those for the first experiment, only with aspirates instead of ejectives. The recording and splicing methods are the same. Stimuli are put in pairs that fall into one of six categories in (14) based on the type of laryngeal contrast. Only heterorganic pairs of stops were used in constructing stimuli for the second experiment, no nonce words had homorganic stops.

(14)   a.   same   0 vs. 0   e.g. *kapi-kapi*
                        1 vs. 1   e.g. k^hapi-k^hapi or kap^hi-kap^hi
                        2 vs. 2   e.g. k^hap^hi-k^hap^hi
        b.   different 1 vs. 0   e.g. k^hapi-kapi   or kap^hi-kapi
                        2 vs. 0   e.g. k^hap^hi-kapi
                        1 vs.2   e.g. k^hapi-k^hap^hi or kap^hi-k^hap^hi

As in the first experiment, the 'different' pairs were presented in both possible orders (1–0 and 0–1, 2–0 and 0–2, 1–2 and 2–1). In stimuli pairs where one stimulus has only one aspirate, the aspirate could be in either initial or medial position (C^hVCV or CVC^hV). There are different numbers of unique stimulus pairs for each of the categories in (14), depending on whether order of presentation (for "different" pairs) or position of aspiration (for pairs with a form with a single aspirate) is variable. Stimulus pairs were repeated if necessary so that the total number of stimuli in each category was 48, resulting in a total of 288 pairs presented to each subject.

4.2.2.2   Acoustic properties of the aspirate-plain contrast in the stimuli

As with the stimuli with ejectives, the acoustic correlates of the aspirate-plain contrast in the experimental stimuli were measured. The methods were the same. For each initial and medial syllable used in stimulus creation VOT, burst amplitude and voice quality of the vowel were measured. VOT was measured in milliseconds from the beginning of the burst to the onset of periodicity in the following vowel. Burst amplitude was measured in arbitrary units directly off of the waveform by calculating the difference between the highest and lowest points in the waveform. Voice quality is quantified as the difference between the amplitude of H1 and H2 in the first 30 ms of the vowel (Ladefoged 2003).

The measurements for each place of articulation were subjected to a two way ANOVA with position and laryngeal type as factors. For all three places of articulation, there was a significant effect of laryngeal type on VOT and no effect of laryngeal type on burst amplitude. The effect of laryngeal type on voice quality in the following vowel is also significant for the velars and alveolars, and consitutes a trend for the labials ($F(1,16) = 4.2$; $p < .06$) The statistical results are reported in (15).

(15)

velar	VOT	amplitude	voice quality
laryngeal type	$F(1,16) = 171.3$ $p < .0001$	$p > .05$	$F(1,16) = 37.1$ $p < .0001$
laryngeal type x position	$p > .05$	$p > .05$	$p > .05$
alveolar			
laryngeal type	$F(1,16) = 384.6$ $p < .0001$	$p > .05$	$F(1,26) = 10.4$ $p < .0001$
laryngeal type x position	$p > .05$	$p > .05$	$p > .05$
labial			
laryngeal type	$F(1,16) = 773.2$ $p < .0001$	$p > .05$	$p > .05$
laryngeal type x position	$p > .05$	$p > .05$	$p > .05$

Mean values for amplitude and VOT for each consonant in initial and medial positions are given in (16). The difference in VOT between an aspirate and a corresponding plain stop ranges between 100-140 ms.

(16)

initial	VOT	H1-H2	medial	VOT	H1-H2
p^h	138	2.5	p^h	156	.5
p	16	-1.4	p	24	-.1
t^h	147	3.2	t^h	162	.3
t	20	.23	t	26	-1.7
k^h	167	2.9	k^h	159	.9
k	53	1	k	59	-2.4

Acoustic analysis shows, as summarized in (15) and (16), that aspirate and plain stops are distinguished by VOT and voice quality in the following vowel. These cues are reliably preserved in the spliced stimuli, since CV transitions are kept intact. Sample spectrograms are given in (17) for the syllables $k^h a$ and ka.
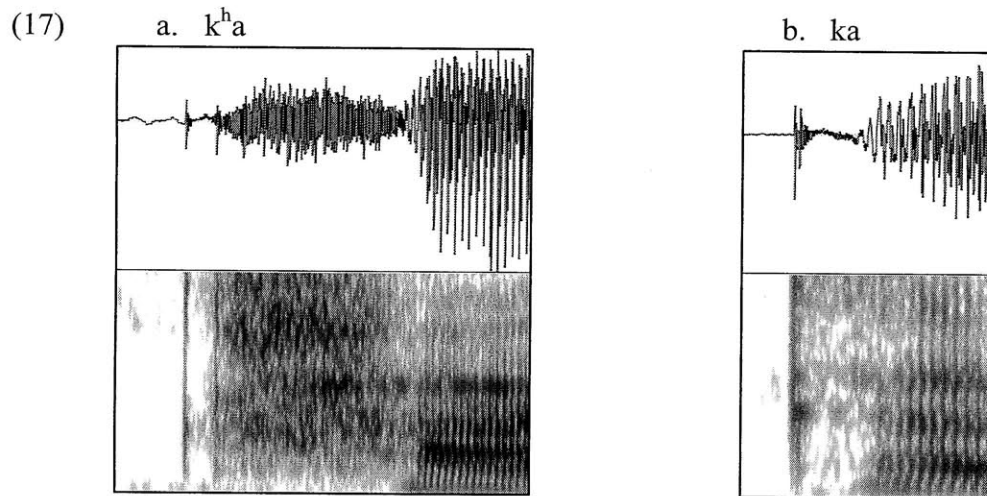
(17) a. kʰa b. ka

Differences in the acoustics of contrasts depending on place of articulation and position are taken into account in the analysis of the perceptual results.

4.2.3 Results

Subjects' performance supports both of the hypotheses. The 1v2 contrast is indeed weaker than other laryngeal contrasts, supporting Hypothesis 1. Additionally, the 1v0 contrast is significantly weaker than the 2v0 contrast, supporting Hypothesis 2. Aspirate contrasts thus pattern in the same way as the ejective contrasts in experiment 1.

A contrast coded Mixed Logit Model, with "correct" as the dependent variable and random effects of first stimulus, second stimulus and subject, shows a significant difference between 1 vs. 2 and 1 vs. 0 contrast categories ($\beta = .98229$, $Z = 12.66$, $p < .0001$), as well as a significant difference between 1 vs. 0 and 2 vs. 0 contrast categories ($\beta = -1.33318$, $Z = -12.78$, $p < .0001$). As with the ejective stimuli, performance on same stimuli was high overall. The results for same stimuli are shown in the graph in Figure 5; different trials are given in Figure 6.
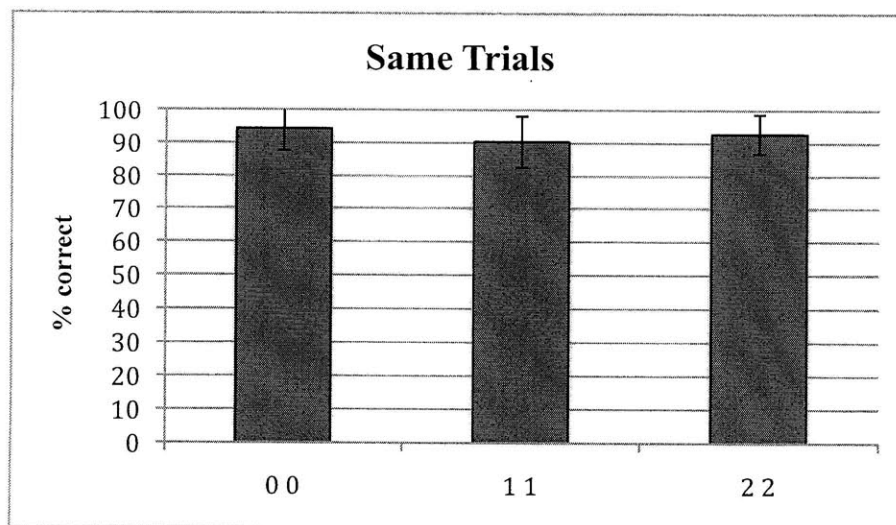
Figure 5:   Aspirates - Percent correct by contrast category, averaged across all subjects. Error bars indicate 95% confidence interval.

100
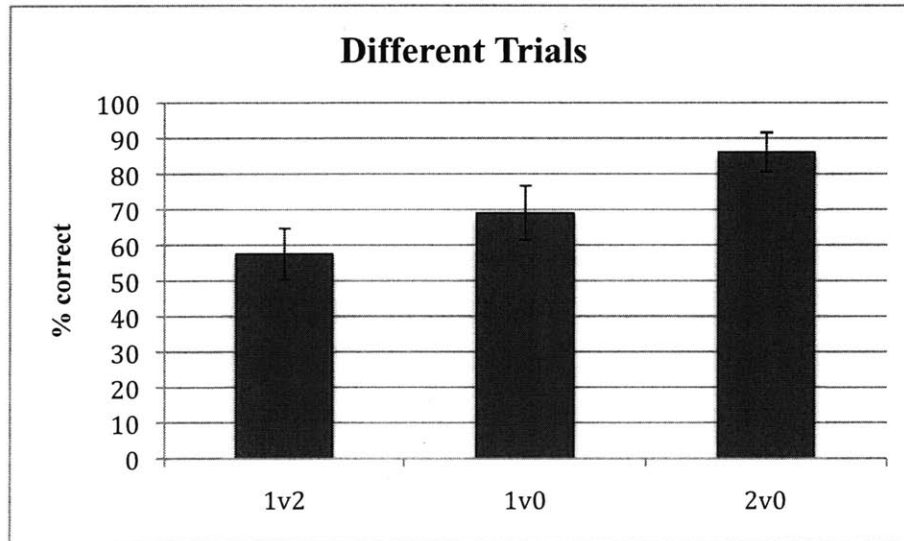
Figure 6: Aspirates - Percent correct by contrast category, averaged across all subjects. Error bars indicate 95% confidence interval.

As in the first experiment, place of articulation and position of contrast in the word are possible factors in subjects' performance. Only the 1 vs. 0 and 1 vs. 2 categories are compared here, since only in these categories is there a single locus of contrast. Token pairs are categorized corresponding to whether the contrast between the two stimuli is on a labial, coronal or velar. For example, in the pair $k^h api$-$kapi$ the ejective-plain contrast is on a velar, while in tip^hu-t^hip^hu it is on a coronal. Figure 7 below shows that while performance within a category differs somewhat depending on place of articulation, the hierarchy of 1 vs. 2 < 1 vs. 0 holds within all places of articulation. Overall differences in the relative strength of contrasts at certain places of articulation lead to a reversal in this hierarchy across places of articulation, however. Performance on the 1 vs. 2 contrast on alveolars is better than on the 1 vs. 0 contrast on velars.
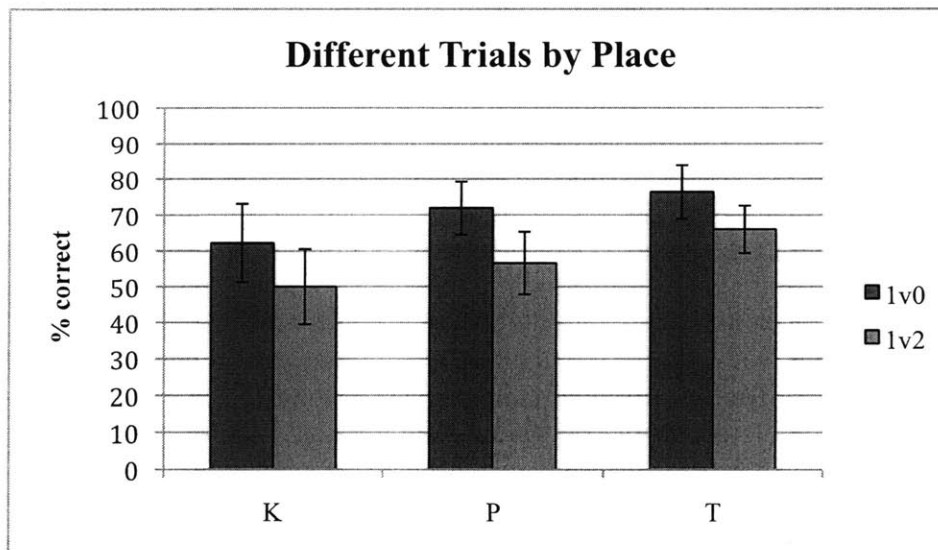
Figure 7: Aspirates - Percent correct for 1 vs. 0 and 1 vs. 2 contrast categories by place of articulation, averaged across all subjects. Error bars indicate 95% confidence interval.

Figure 8 shows subjects' performance on 1 vs. 0 and 1 vs. 2 contrasts depending on the position of contrast. Position of contrast is only variable for 1 vs. 0 and 1 vs. 2 categories, where the contrast may be on the initial consonant (e.g. *kʰapi-kapi* or *kapʰi-kapi*) or the medial consonant (e.g. *kʰapʰi-kapʰi* or *kʰapʰi-khapi*). Subjects' performance on the 1 vs. 0 contrast does not vary depending on position. Performance on the 1 vs. 2 condition is slightly worse in medial position than in initial position. The relative strength of the 1 vs. 0 and 1 vs. 2 contrasts holds both within and across positions.
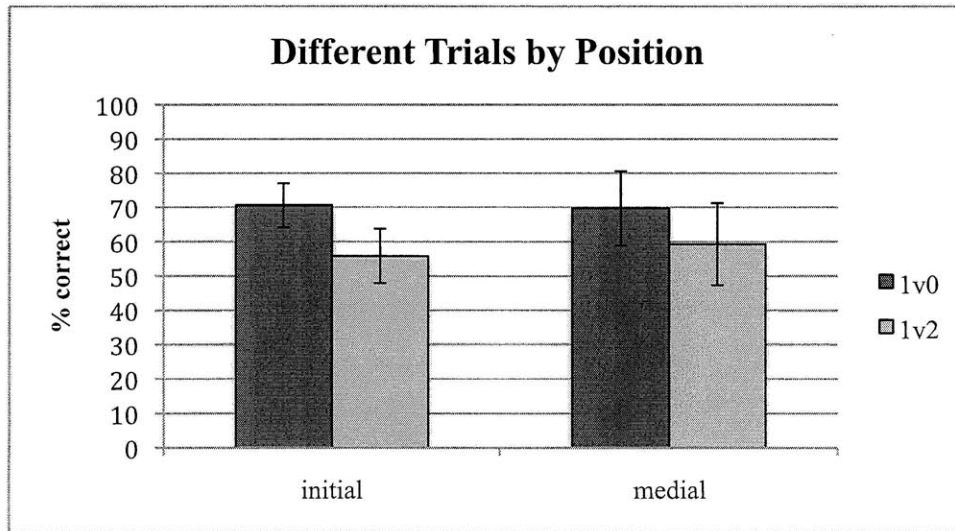
Figure 8:   Aspirates - Percent correct for 1 vs. 0 and 1 vs. 2 contrast categories by contrast position, averaged across all subjects. Error bars indicate 95% confidence interval.

The results of the aspirate experiment replicate the results of the ejective experiment, showing that the perceptual properties of contrasts in ejection and aspiration between roots are comparable. The perception of both of these laryngeal categories is affected by the laryngeal properties of a non-adjacent consonant.

4.3   Experiment 3: ejective and aspirate interactions

The first two experiments found that the perception of an ejective is degraded in a word with another ejective and that an aspirate is degraded in a word with another aspirate. The third experiment looks for an interference between ejectives and aspirates, ie. whether an ejective interferes with the perception of an aspirate contrast and an aspirate interferes with the perception of an ejective contrast.

This experiment tests the hypothesis that the perceptual asymmetry found in the first two experiments reflects a difficulty in perceiving contrasts along the auditory dimension of long VOT. The goal is to isolate one of the various auditory correlates of the ejective-plain and aspirate-plain contrast in order to see what it is about these two laryngeal categories that is subject to long-distance perceptual interference. If the hypothesis is correct, then the effects found for ejectives and aspirates in the first two experiments are both attributable to the perceptual difficulty of perceiving a contrast in long VOT in the context of another long VOT segment.

102

This experiment tests a claim at the heart of the proposal in this dissertation. The idea that laryngeal cooccurrence restrictions are restrictions on relatively weak contrasts necessitates that contrasts be defined along some auditory dimension. This experiment tests for the perceptual relevance of one potential auditory feature, long VOT, which bears on the analysis of the interaction of ejectives and aspirates in the restrictions in Quechua and Peruvian Aymara. In these two languages, ejectives and aspirates pattern as a class; pairs of ejectives, pairs of aspirates, and pairs of one ejective and one aspirate are all unattested. The proposed analysis of this pattern is that aspirates and ejectives are restricted as a class because the restriction in these languages is on the auditory feature long VOT, which both classes of segments share. Experiment 3 tests this analysis directly, by investigating whether long VOT has a status independent of the other auditory properties it is associated with. Specifically, this experiment tests whether long VOT interferes with the perception of another contrast in long VOT even when other cues are different. Ejectives and aspirates share long VOT, but in ejectives the VOT is silent while in aspirates it is noisy. Additionally, the acoustic analysis of Quechua in Chapter 3 showed that ejectives have a loud burst and aspirates are followed by breathy voice.

4.3.1 The hypotheses

The hypothesis is stated in (18).

(18) Hypothesis   Pairs of words that contrast 1 vs. 2 segments with long VOT are less distinct than pairs of words that contrast 1 vs. 0 segments with long VOT.

This hypothesis can be broken down into two parts, as stated in (19).

(19) Hypothesis Part 1:   A contrast in aspiration in a word with another ejective is less distinct than a contrast in aspiration in words without another ejective or aspirate.

$$\Delta([T^h...K']-[T...K']) \quad < \quad \Delta([T^h...K]-[T...K])$$

(20) Hypothesis Part 2:   A contrast in ejection in words with another aspirate is less distinct than a contrast in ejection in words without another ejective or aspirate.

$$\Delta([T'...K^h]-[T...K^h]) \quad < \quad \Delta([T'...K]-[T...K])$$

The design of experiment 3 is the same as for the first two experiments. Subjects are presented with pairs of CVCV nonce words that differ only in the laryngeal features of the consonants and asked to judge whether the words are the same or different from one another. If the hypothesis is true, subjects will perform better on pairs like *k'api-kapi* and *kʰapi-kapi* (1 vs. 0) than on pairs like *k'apʰi-kapʰi* and *kʰap'i-kap'i* (1 vs. 2).

4.3.2 Stimuli

The stimuli for the third experiment are like those for the first two experiments, only with both aspirates and ejectives. The recording and splicing methods are the same. Stimuli are put in pairs that fall into one of the nine categories in (21) based on the type of laryngeal contrast.

(21) a. same   0 vs. 0   e.g. *kapi-kapi*
                     1 vs. 1 ejective e.g. *k'api-k'api*   or *kap'i-kap'i*
                     1 vs. 1 aspirate e.g. *kʰapi-kʰapi*   or *kapʰi-kapʰi*
                     2 vs. 2 ejective e.g. *k'apʰi-k'apʰi*
                     2 vs. 2 ejective e.g. *kʰapʰi-kʰapʰi*

      b. different 1 vs. 0 ejective e.g. *k'api-kapi*   or *kap'i-kapi*
                     1 vs. 0 aspirate e.g. *kʰapi-kapi*   or *kapʰi-kapi*
                     1 vs. 2 ejective e.g. *kapʰi-k'apʰi*   or *kʰapi-kʰap'i*
                     1 vs. 2 aspirate e.g. *kap'i-kʰap'i*   or *k'api-k'apʰi*

As in the first experiment, the 'different' pairs were presented in both possible orders (1–0 and 0–1, 2–0 and 0–2, 1–2 and 2–1). In stimuli pairs where one stimulus has only one aspirate or ejective, the aspirate or ejective could be in either initial or medial position (C'VCV or CVC'V). There are different numbers of unique stimulus pairs for each of the categories in (21), depending on whether order of presentation (for "different" pairs) or position of contrast (for pairs with a form with a single aspirate or ejective) is variable. Stimulus pairs were repeated if necessary so that the total number of stimuli in each category was 48, resulting in a total of 432 pairs presented to each subject.

4.3.3 Results

Subjects' performance supports the hypotheses. The 1 vs. 2 contrast in VOT is weaker than the 1 vs. 0 contrast. The result holds for both contrasts in ejection and aspiration.

A contrast coded Mixed Logit Model, with "correct" as the dependent variable and random effects of first stimulus, second stimulus and subject, shows a significant difference between 1 vs. 2 and 1 vs. 0 contrast categories (β = .92514, Z = 16.571, p < .0001). The overall results are given in the graph in Figure 9. The results broken down for contrasts in ejection and aspiration are given in Figure 10. As was the case in experiments 1 and 2 reported above, overall performance on the aspirate contrast is worse than overall performance on ejective contrasts. More interestingly, the difference in performance on the 1 vs. 0 and 1 vs. 2 categories is greater for aspirate contrasts than ejective contrasts, showing that an ejective interferes with the processing of an aspirate contrast (*kʰap'i-kap'i*) more than an aspirate interferes with the processing of an ejective contrast (*k'apʰi-kapʰi*).
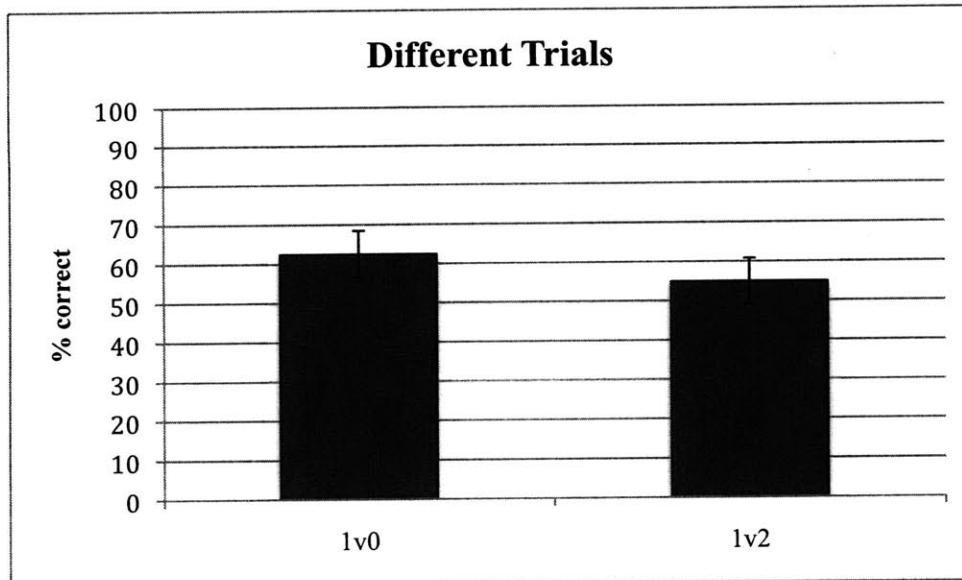
Figure 9:   VOT - Percent correct by contrast category, averaged across all subjects. Error bars indicate 95% confidence interval.
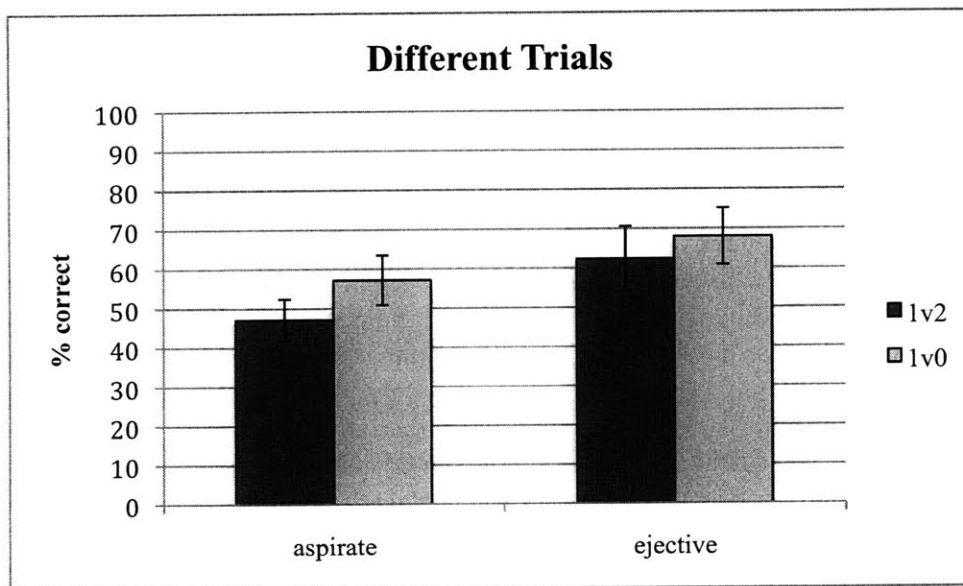
Figure 10:   VOT: Percent correct by laryngeal categry and contrast category, averaged across all subjects. Error bars indicate 95% confidence interval.

4.4   *Summary and discussion of results*

The three experiments in this chapter document long-distance perceptual asymmetries that mirror long-distance phonological interactions. It was found that the perception of both ejectives and aspirates, two classes of segments that are subject to non-local phonological restrictions, is degraded if there is another ejective or aspirate in the word. Experiment 3 further found support for the idea that it is the perception of the auditory dimension of long VOT that is sensitive to long-distance context, regardless of whether the long VOT is coupled with the other auditory

105

properties that make up and ejective or an aspirate. The three perceptual distance hierarchies in (22) are supported by the results reported above.

(22) Exp. 1: $\Delta([T'...K']\text{-}[T...K']) \; < \; \Delta([T'...K]\text{-}[T...K]) \; < \; \Delta([T'...K']\text{-}[T...K])$

Exp. 2: $\Delta([T^h...K^h]\text{-}[T...K^h]) \; < \; \Delta([T^h...K]\text{-}[T...K]) \; < \; \Delta([T^h...K^h]\text{-}[T...K])$

Exp. 3: $\Delta([T^h...K']\text{-}[T...K']) \; < \; \Delta([T^h...K]\text{-}[T...K])$

$\Delta([T'...K^h]\text{-}[T...K^h]) \; < \; \Delta([T'...K]\text{-}[T...K])$

The same asymmetries for ejectives and aspirates are found in experiments 1 and 2. The results of experiment 3 unifies these two sets of results, by showing that they can both be attributed to asymmetries in the perception of contrasts along the auditory dimension of long VOT. The experiments thus provide support for the hypothesis that laryngeal cooccurrence restrictions are driven by grammatical pressures to neutralize relatively indistinct contrasts in favor of more distinct contrasts. Additionally, there is experimental evidence that the distinctness of contrasts can be defined in auditory terms.

These results are generalized in two ways to form the basis of an analysis of laryngeal cooccurrence restrictions. First, it is assumed following the results of experiment 3 that perceptual asymmetries are defined over auditory dimensions like "long VOT", not abstract categories like "ejective" or "aspirate". Second, it is assumed that the range of auditory dimensions that are subject to long-distance phonological restrictions are also subject to long-distance perceptual interactions, as has been found for long VOT.

The analysis developed in the next chapter is based on the hypothesis that laryngeal cooccurrence restrictions are driven by the relative perceptual weakness of the 1 vs. 2 contrast relative to the 1 vs. 0 contrast. While this relative perceptual weakness has been documented for segments with long VOT (ejectives and aspirates), it is also assumed for the auditory dimensions that define other restricted classes of sounds, namely creaky and modally voiced implosives and creaky voiced ejectives. The range of auditory dimensions that define restricted laryngeal categories, and thus are predicted to show long-distance perceptual asymmetries, is laid out in the next chapter.

A major question that is left open in this dissertation is the source of the perceptual asymmetries. The results of the experiments presented in this chapter are both surprising and particularly interesting because they do not correlate with asymmetries in acoustic cues. In the experimental stimuli, the cues to a given contrast were identical across conditions. For example, the [t] vs. [t'] distinction is identical in the pair *kitu-kit'u* (1 vs. 0 condition) and in the pair *k'itu-k'it'u* (1 vs. 2 condition), given that the same [tu] and [t'u] sequences are spliced into both stimuli pairs. While there is no acoustic difference between the ejective-plain contrast in the two pairs, it is more perceptible in the 1 vs. 0 condition than in the 1 vs. 2 condition. The perceptual asymmetry documented in this chapter is thus a truly non-local effect, as it cannot be attributed to the availability of local cues, and must be attributed to some higher level processing difficulty. The presence of a long VOT stop (ejective or aspirate) diminishes the perceived auditory difference between another long VOT stop and a plain stop, despite the fact that the actual acoustic difference is unaffected.

The analysis of laryngeal cooccurrence restrictions presented in the following chapters relies on a fixed hierarchy of systemic markedness constraints projected from these auditory processing effects. Two families of constraints are proposed; one that penalizes the 1 vs. 2 contrast in a laryngeal feature, and another that penalizes the 1 vs. 0 contrast in laryngeal feature. These

constraints are projected from the asymmetries found between the 1 vs. 2, 1 vs.0 and 2 vs. 0 contrasts in laryngeal features. While the perception experiments support such distinctions based on contrast category, they also support distinctions that are not assumed to project constraints, namely distinctions in contrast strength based on place of articulation or position of a contrast.

The experimental results are taken to project a fixed hierarchy of constraints on contrast categories, relative to a particular feature. The general hierarchy is shown informally in (23).

(23)   *1 vs. 2   >>   *1 vs. 0   >>   *2 vs. 0

While the experiments show the asymmetries based on contrast category underlying the hierarchy in (23), there are also significant asymmetries based on place of articulation and position that could be expected to project markedness constraint hierarchies in their own right. Besides the general constraints on contrast categories, there could be more specific constraints referring to place of articulation or position of a contrast. The results support the three more fine grained hierarchies in (24), integrating asymmetries based on contrast category with asymmetries based on place of articulation and position.

(24)   a. place and contrast category - ejectives
        *1 vs. 2 – T'-T   >>   *1 vs. 2 – K'-K   >>   *1 vs. 2 – P'-P   >>
        *1 vs. 0 – T'-T   >>   *1 vs. 0 – K'-K   >>   *1 vs. 0 – P'-P

        b. place and contrast category - aspirates
        *1 vs. 2 – K^h-K   >>   *1 vs. 2 – P^h-P   >>   ***1 vs. 0 – K^h-K**   **>>**
        *1 vs. 2 – T^h-T   >>   *1 vs. 0 – P^h-P   >>   *1 vs. 0 – T^h-T

        c. position and contrast category - ejectives
        *1 vs. 2 – md.   >>   ***1 vs. 0 – md.**   **>>**   ***1 vs. 2 – in.**   >>   *1 vs. 0 – md.

The hierarchies in (24) integrate asymmetries based on place of articulation and position. In (24a), we see the hierarchy of place based constraints on contrasts in ejection, where the hierarchy of perceptual strength is coronal < velar < labial. This hierarchy of constraints predicts a language where the 1 vs. 2 contrast is only disallowed if it occurs on an alveolar stop. An example of a pattern predicted by such a constraint is one where roots with two ejectives are unattested if one stop is alveolar, but roots with two non-alveolar ejectives are attested, as shown in (25). This type of pattern is unattested.

(25)   *1 vs. 2 – T'-T >> IDENT >> *1 vs. 2 – K'-K

        a. *p'at'i   can't contrast with [p'ati]   b. ✓ p'ak'i   can contrast with
            *k'at'i   can't contrast with [k'ati]   [p'aki] or [pak'i]
            *t'ap'i   can't contrast with [tap'i]   ✓ k'ap'i   can contrast with
            *t'ak'i   can't contrast with [tak'i]   [k'api] or [kap'i]

Similarly undesirable predictions are made by the hierarchy in (24b). It should be noted that the hierarchy based on position in (24c) does not actually make any undesirable predictions. The 1 vs. 2 contrast in medial position {k'ap'i, k'api} can be neutralized either by eliminating the

form with two laryngeally marked stops (26a), the attested pattern for a language with dissimilation, or by eliminating the form with a single initial laryngeally marked stop (26b), an unattested pattern. The second candidate set of forms is harmonically bound by the first, and thus is not predicted to occur.

(26) *1 vs. 0-medial >> *1 vs. 2-initial >> *1 vs. 0-initial

    a. {k'api, kap'i, kapi}   violates   *1 vs. 0 medial {kap'i, kapi}
                                                *1 vs. 0 initial {k'api, kapi}
    b. {k'ap'i, kap'i, kapi}   violates   *1 vs. 0 medial {kap'i, kapi}
                                                *1 vs. 2 initial {k'ap'i, kap'i}

The position-sensitive hierarchy in (24c) does not make different predictions than a position-insensitive hierarchy.

To correctly account for laryngeal cooccurrence restrictions, systemic markedness constraints must refer to contrast category alone, and not to place or position or a contrast, or any other conceivable interacting factor. The question then is what princples govern the projection of grammatical constraints from perceptual asymmetries that predict this necessary distinction. One possibility is a principle of generality that prefers simple constraints over more complex constraints (Hayes and Wilson 2008). While systemic markedness constraints may refer to a context, penalizing a given contrast in a given context, more general statements of contrasts and contexts are preferred. Consider the formalization in (27), which says that a contrast between [+ejective] and [-ejective] is disallowed in a root with another [+ejective] segment. This constraint is simpler than the sample constraints in (27b,c). In (27b), two features are mentioned to isolate an ejective contrast on an alveolar; in (27c), the context mentions both another segment in the root but also the prosodic position of the contrast.

(27) a. *1 vs. 2 $*\{[+\text{ejective}], [-\text{ejective}]\} \Big/ [\ldots[+\text{ejective}]\ldots]_{RT}$

     b. *1 vs. 2 – T'-T $*\left\{\begin{bmatrix}+\text{ejective} \\ +\text{alveolar}\end{bmatrix}, \begin{bmatrix}-\text{ejective} \\ +\text{alveolar}\end{bmatrix}\right\} \Big/ [\ldots[+\text{ejective}]\ldots]_{RT}$

     c. *1 vs. 2 – medial $*\{[+\text{ejective}], [-\text{ejective}]\} \Big/ \left\{\begin{array}{l}[\ldots[+\text{ejective}]\ldots]_{RT} \\ \neg \# \underline{\quad}\end{array}\right\}$

The comparison of the three statements in (27) shows that a constraint referring only to the long-distance environment of a single feature contrast is simpler than referring to either place of articulation or position of a contrast in addition to the long-distance environement. Generality is thus a likely candidate for ruling out constraints based on asymmetries more specific than long-distance environment.

Chapter 5 Laryngeal dissimilation

This chapter and the two that follow develop the formal analysis of long-distance laryngeal restrictions, incorporating the perceptual and acoustic data presented in the previous two chapters. It is demonstrated that the range of assimilatory and dissimilatory phenomena is well-accounted for with systemic markedness constraints referring to the auditory dimensions along which laryngeal categories contrast. The insight of the anlysis is that the seemingly disparate phenomena of laryngeal dissimilation and assimilation are actually reflexes of the same underlying grammatical principle. Both phenomena derive from conditions on the perceptual distinctness of contrasting roots in a language, as outlined in Chapter 2. The analysis is cast in the Dispersion Theory of Contrast (Flemming 1995, 2004, 2006), a framework that formalizes the notion that less distinct contrasts are more prone to neutralization than more perceptually robust contrasts.

The family of systemic constraints responsible for laryngeal cooccurrence restrictions is projected from the perceptual asymmetries documented in Chapter 4. The series of perception experiments presented there shows that the strength of a laryngeal contrast varies depending on the laryngeal features of other segments in the root, and thus the perceptual distance between laryngeally marked segments must be evaluated at the level of the root. Cooccurrence restrictions on laryngeal features result from conditions on the distinctness of contrasting roots in a language.

This chapter analyzes three case studies of languages with dissimilation in laryngeal features, Chol (Mayan), Hausa (Afro-Asiatic) and Tz'utujil (Mayan). These three languages each show the cooccurrence pattern schematized in (1).

(1) Laryngeal dissimilation: *K'-T' ✓ K'-T ✓ K-T' ✓ K-T

In Chol, there is a binary contrast between ejectives and plain stops, and ejectives are prohibited from cooccurring with one another. The restrictions in Hausa and Tz'utujil are somewhat more complicated than that found in Chol. In both Hausa and Tz'utujil, there is a series of "glottalic" consonants that is realized as implosive at the labial and alveolar places of articulation, and as ejective further back in the vocal tract. In Hausa, all glottalic consonants are subject to laryngeal dissimilation, while in Tz'utujil only pairs of ejectives are restricted. These two patterns are schematized in (2).

(2) Dissimilation – Hausa: *K'-T'   *K'-ɗ   *ɓ-ɗ
    Dissimilation – Tz'utujil: *K'-T'   ✓ K'-ɗ   ✓ ɓ-ɗ

The difference between Hausa and Tz'utujil correlates with the realization of ejectives and implosives in the two languages. In Hausa, both ejectives and implosives are associated with creaky phonation. Their uniform patterning in this language is analyzed as a restriction on contrasts in the auditory feature [creak]. In Tz'utujil, however, implosives are modally voiced and ejectives are primarily characterized by their loud burst (as well as long VOT when prevocalic, and some degree of creaky phonation in surrounding vowels). The disparate patterning of ejectives and implosives in Tz'utujil shows that only [loud burst] is restricted in Tz'utujil. Ejectives and implosives do not share an auditory dimension of contrast in Tz'utujil, and thus do not pattern together phonologically. The comparison between Hausa and Tz'utujil

shows that auditory representations make the correct predictions for laryngeal cooccurrence restrictions, as discussed earlier in Chapter 2.

This chapter begins by outlining the basics of the systemic analysis of laryngeal dissimilation in §5.1 and §5.2. I introduce two families of systemic markedness constraints projected from the perceptual results in Chapter 4 and show a schematic analysis of dissimilation and assimilation. The constraint set will be further articulated in Chapter 6 to account for ordering restrictions on laryngeal features. The discussion of constraints in §5.1 and analysis in §5.2 is entirely schematic. Constraints on individual auditory features are defined and discussed in the context of each of the case studies in this and sub-sequent chapters. The analysis of Chol in §5.3 shows dissimilation resulting from systemic markedness constraints on contrasts in [loud burst]. Restrictions on [creak] in Hausa and [loud burst] in Tz'utujil are analyzed in §5.4 and §5.5 respectively.

5.1 Constraints

The analysis of laryngeal cooccurrence restrictions is based on systemic markedness constraints, which favor neutralization of perceptually indistinct contrasts. This section defines two families of perceptually grounded systemic constraints on laryngeal features. These two constraints are projected from the perceptual asymmetries found in the series of experiments presented in Chapter 4.

The experimental results from the previous chapter reveal asymmetries in the strength of laryngeal contrasts, depending on the long-distance context. The experiments reveal two asymmetries. First, a laryngeal contrast is weakened by the presence of another laryngeally marked segment in the word. Specifically, the contrast between a plain stop and and an ejective or aspirate is weaker in words with another ejective or aspirate than in words with another plain stop. Second, words that differ in two laryngeal features are more distinct than words that differ in only one laryngeal feature. This hierarchy of perceptual distinctness is given schematically in (3).

(3) $\Delta([T'...K']-[T...K])$ > $\Delta([T'...K]-[T...K])$ > $\Delta([T'...K]-[T'...K'])$
       2 vs. 0   1 vs. 0   1 vs. 2

The hierarchy in (3) projects two families of systemic markedness constraints, corresponding to the two asymmetries in the hierarchy of perceptual distinctness. I refer to these constraints as Laryngeal Distance or LARDIST constraints. The first constraint, defined in (4), penalizes the contrast between and 1 and 2 laryngeal features in a word, which is the weakest contrast in the hierarchy in (3).

(4)   LARDIST(1v2) – [F]   No minimal contrast in [F] between roots with another [F] segment.

Given two contrasting roots R_1, R_2 such that R_1 and R_2 each contain two segments that minimally contrast for [F], assign one violation mark if R_1 and R_2 each contain some [F] segment and are identical except for a minimal contrast in [F].

110

Informally, the constraint in (4) says that contrasting roots have to be more distinct than just the difference between one and two instances of a laryngeally marked segment. This constraint corresponds to a threshold of distinctness at the second 'greater than' sign in the hierarchy in (2). According to this constraint, contrasts to the left of the 'greater than' sign are preferred – that is, contrasts in either 1 vs. 0 instances of a feature, or 2 vs. 0 instances.

The second constraint imposes a higher threshold of distinctness, corresponding to the first 'greater than' sign in the hierarchy in (2). The 1 vs. 2 and 1 vs. 0 contrasts each differ in the laryngeal specifications of a single segment, and both of these contrasts are perceptually weaker than the contrast between 2 and 0 laryngeally marked segments. The second LARDIST constraint, defined in (5), penalizes a contrast in only one instance of a laryngeal feature, favoring the strongest contrast in the hierarchy.

(5) LARDIST(1v0) – [F]   No minimal contrast in [F] between roots with another segment that minimally contrasts for [F].

Given two contrasting roots R_1, R_2 such that R_1 and R_2 each contain two segments that minimally contrast for [F], assign one violation mark if R_1 and R_2 are identical except for a minimal contrast in [F].

The constraint in (5) is more general than that in (4), penalizing any contrast in just a single instance of a given feature in roots with two segments that could potentially bear that feature. This constraint penalizes contrasts like {[k'api, kapi]} but not contrasts like {[k'ami, kami]}, a distinction that will become important in Chapter 7.

The definitions in (4) and (5) are schema for constraints on individual auditory features, [F]. The range of features that LARDIST constraints may refer to is an empirical question, and one that is only partially answered here. LARDIST constraints are projected from the perceptual hierarchy in (3), and thus an individual LARDIST-[F] constraint can only be supported if that feature [F] shows the asymmetries in (3). The perception experiments in Chapter 4 provide support for LARDIST constraints on [long VOT] and [loud burst], as these are the auditory dimensions along which the aspirates and ejectives in the experimental stimuli differ from plain stops. The analyses of the case studies to follow invoke LARDIST constraints on four auditory features: [long VOT], [loud burst], [creak] and [v-amp]. These four features define the range of ejectives, aspirates and implosives that are subject to long-distance restrictions cross-linguistically, as discussed in Chapter 2. While explicit perceptual support is only available for LARDIST constraints on [long VOT] and [loud burst], the hypothesis is that contrasts in [creak] and [v-amp] exhibit comparable perceptual properties. It is left to future research to verify that [creak] and [v-amp] show the same perceptual asymmetries as [loud burst] and [long VOT], and to determine what, if any, other auditory features show long-distance perceptual asymmetries.

In addition to the variable [F], the constraint schema in (4) and (5) refer to a "minimal contrast in [F]", a phrase that needs further definition. While LARDIST constraints refer to individual auditory features, in very few cases does a single auditory feature define a contrast. In most cases, contrasting segments differ along several auditory dimensions. While two segments that differ in a single auditory dimension is a physical possibility, contrasting segments in a language that differ in only a single auditory dimension are uncommon. The concept of a minimal contrast in a given auditory feature, as employed here, is dependent on the auditory

111

properties of other segments in the language. The working definition of a minimal contrast in a feature [F] is given in (6).

(6)   Minimal contrast in [F]
              A set of features S that includes [F] such that no sub-set of S that includes [F] differentiates two contrasting sounds in the inventory.

This definition makes use of the inventory as a meaningful element of the grammar. For example, in a language with both aspirates and plain stops, these two series differ in both [long VOT] and [aspiration] (and potentially closure duration as well). It is not possible to contrast for [long VOT] alone; a difference in [long VOT] between two segments is always accompanied by a difference in [aspiration]. Given the definition in (6), in this type of language, a minimal contrast in [long VOT] is a contrast in [long VOT], [aspiration], and nothing else. The contrast between an aspirate and a plain stops involves the smallest set of differing features that includes [long VOT]. Contrasts between aspirates and other segments, like nasals or voiced stops, involve differences in [long VOT], [aspiration] as well as the other features corresponding to nasality or closure voicing. What constitutes a minimal contrast in a feature is language specific, and will be taken up in each of the case studies, with reference to the constraints and inventory in question.

The proposed systemic markedness constraints, LARDIST(1v2)-[F] and LARDIST(1v0)-[F], stand in a stringency relation (Prince 1997; de Lacy 2002, 2007). Any candidate that violates LARDIST(1v2)-[F] also violates LARDIST(1v0)-[F], but not vice-versa. LARDIST(1v0)-[F] penalizes any contrast in a single laryngeal feature, regardless of the laryngeal features of other segments in the root. LARDIST(1v2)-[F] is more specific; it penalizes a contrast in a single instance of a laryngeal feature only in those words with another laryngeally marked segment. The consequence of this formal relation between the two constraints is that a 1 vs. 2 contrast may be neutralized while maintaining a 1 vs. 0 contrast, the reverse is not true. This formulation of the constraints reflects a fundamental tenet of DT and other perceptually based phonological analyses, namely that less distinct contrasts are more prone to neutralization than stronger contrasts. Given the stringent formulation of LARDIST constraints, a restriction on the relatively stronger 1 vs. 0 contrast implies a restriction on the relatively weaker 1 vs. 2 contrast. Depending on the ranking of faithfulness constraints, then, a language may neutralize the 1 vs. 2 contrast in laryngeal features and maintain the 1 vs. 0 contrast, as in dissimilation, or a language may neutralize 1 vs. 0 contrasts more generally, as in assimilation.

5.2   Schematic analysis of dissimilation

Before delving into the case studies of laryngeal restrictions, it is instructive to consider a schematic analysis of dissimilation and assimilation. While the analyses of actual languages will turn out to be substantially more complex than what is sketched here, the goal is to understand how LARDIST constraints are evaluated and how they account for long-distance laryngeal restrictions. Consider a language with a binary contrast between ejectives and plain stops, [p, t, k, p', t', k'], and assume that these ejectives contrast with the plain stops in burst amplitude and VOT. In a language of this type, the two LARDIST constraints on the auditory feature [loud burst] given in (7) are relevant.

112

(7) LARDIST(1v2)-[loud burst]   No minimal contrast for [loud burst] between roots with another [loud burst] segment.

Given two contrasting roots R_1, R_2 such that R_1 and R_2 each contain two segments that minimally contrast for [loud burst], assign one violation mark if R_1 and R_2 each contain some [loud burst] segment and are identical except for a minimal contrast in [loud burst].

LARDIST(1v0)-[loud burst]   No minimal contrast in [loud burst] between roots with another segment that minimally contrasts for [loud burst].

Given two contrasting roots R_1, R_2 such that R_1 and R_2 each contain two segments that minimally contrast for [loud burst], assign one violation mark if R_1 and R_2 are identical except for a minimal contrast in [loud burst].

The constraints in (7) restrict the distribution of contrasts in [loud burst]. In a language with stiff ejective and voiceless unaspirated stops, a minimal contrast in [loud burst] is predictably accompanied by a contrast in [long VOT] in pre-sonorant position. A pair of roots like {[p'ati, pati]} differ in both [loud burst] and [long VOT], but are minimally contrastive because there is no possible contrast in just [loud burst] alone. Contrasts in place or nasality are not predictable from a contrast in [loud burst], and thus differences in these features render a contrast non-minimal. Throughout the case studies of to follow, LARDIST constraints will always be followed by a discussion of the features that may accompany a contrast in the restricted feature. The evaluation of the two LARDIST constraints in (7) is shown with a sample set of contrasting pairs in the tables in (8) and (9). The contrasting segment(s) in each pair are marked in bold.

(8)	contrasting pair	LARDIST(1v2)-[loud burst]	comments
a.	{k'a**p'**i, k'a**p**i}	*	1. both have an [loud burst] segment 2. differ in [loud burst] and [long VOT]
b.	{**k'**api, kapi}	✓	1. only *k'api* has a [loud burst] segment 2. differ in [loud burst] and [long VOT]
c.	{**k'**a**p'**i, kapi}	✓	1. only *k'ap'i* has a [loud burst] segment 2. differ in [loud burst] and [long VOT] twice
d.	{k'a**p'**i, k'a**t**i}	✓	1. both have a [loud burst] segment 2. differ in [loud burst] and [long VOT] as well as [place]

113

(9)	contrasting pair	LARDIST(1v0)- [loud burst]	comments
a.	{k'ap'i, k'api}	*	differ in [loud burst] and [long VOT]
b.	{k'api, kapi}	*	differ in [loud burst] and [long VOT]
c.	{k'ap'i, kapi}	✓	differ in [loud burst] and [long VOT] twice
d.	{k'api, tapi}	✓	differ in [loud burst] and [long VOT] as well as [place]

The tables in (8) and (9) show that only differences in [loud burst] and [long VOT] in a single segment constitute a minimal contrast and can violate LARDIST constraints. Multiple contrasts in [loud burst] and [long VOT] do not incur violations, as in (8,9c), nor do contrasts in [loud burst] and [long VOT] that are accompanied by a contrast in place, as in (8,9d). The contrasts considered in (8) and (9) also show that the stringency relation between the two constraints, the violations of LARDIST(1v2)-[loud burst] in (8) are a sub-set of the violations of LARDIST(1v0)-[loud burst] in (9).

The systemic LARDIST markedness constraints interact with standard input-output faithfulness constraints (McCarthy and Prince 1995), which penalize contrast neutralization. Consider the constraint in (10).

(10)   IDENT[cg]   Input and output correspondents have the same value for [cg].

Faithfulness constraints use the standard articulatory based features like [constricted glottis], though this is not crucial to the analysis. Faithfulness constraints could also be formulated in auditory terms. Whether faithfulness is computed over articulatory or auditory representations, or both, is not central to the analyses proposed here, and so the more standard notation is used. The role of faithfulness constraints in the analysis is to favor preservation of contrasts. Given a set of input forms that show minimal contrasts between ejectives and plain stops, contrast neutralization violates IDENT[cg] as shown in (11). Correspondence between input and output forms is indicated with subscripts.

(11)	{/k'ap'i$_1$, k'api$_2$, kap'i$_3$, kapi$_4$/}	IDENT[cg]
	a. {[k'ap'i$_1$, k'api$_2$, kap'i$_3$, kapi$_4$]}	
	b. {[k'api$_{1,2}$, kap'i$_3$, kapi$_4$]}	*
	c. {[k'ap'i$_{1,2,3}$, kapi$_4$]}	**
	d. {[kapi$_{1,2,3,4}$]}	****

In (11a), all contrasts are maintained and IDENT[ejective] is fully satisfied. In (11b), the input form /k'ap'i/ is merged with [k'api] (or [kap'i]), violating IDENT[cg] once due to the mapping of the ejective /p'/ in /k'ap'i/ to the plain [p] in [k'api]. In (11c), both forms with a single ejective are merged with [k'ap'i] (or [kapi]), incurring two violations of faithfulness due to the mapping of the plain stops in /k'api/ and /kap'i/ onto ejectives in [k'ap'i]. Collapsing all contrasts in ejection incurs even more violations of faithfulness, as seen in (11d).

It should be noted that IDENT is not exactly the same as *MERGE (Padgett 2003), a similar but distinct constraint that has been proposed to penalize contrast neutralization between forms. IDENT penalizes each individual featural mismatch between input forms and output forms, where as *MERGE assigns a violation mark for every entire form that is not realized in the output. Removing a single form from input to output could conceivably violate IDENT more than once, but could only violate *MERGE once. While these two constraints are formally distinct, this difference will not play a crucial role.

In a language with laryngeal dissimilation, the potential four way contrast is neutralized to a three way contrast between forms with one ejective and forms with no ejectives. The ranking of LARDIST(1v2)-[loud burst] over IDENT[cg] forces neutralization of the contrast between forms with one and two ejectives. Neutralization to forms with one ejective is more faithful than neutralization to a form with two ejectives, and is preferred if IDENT[ejective] outranks LARDIST(1v0)-[loud burst]. The analysis is illustrated in the tableau in (12).

(12)   Dissimilation in ejection

{/k'at'i, k'ati, kat'i, kati/}	LARDIST(1v2)-[loud burst]	IDENT[cg]	LARDIST(1v0)-[loud burst]
a. {[k'at'i, k'ati, kat'i, kati]}	** !		****
b. → {[k'ati, kat'i, kati]}		*	**
c. {[k'at'i, kati]}		** !	

In the tableau in (12), the full four-way contrast is disallowed because it incurs two violations of the highest ranked constraint, LARDIST(1v2)-[loud burst], due to the contrasting pairs {[k'ap'i, k'api]} and {[k'ap'i, kap'i]}. These two violations can be remedied either by eliminating the form with two ejectives [k'ap'i], as in candidate b, or the two forms with one ejective each [k'api] and [kap'i], as in candidate c. The former option is optimal because it allows more contrasting forms, despite incurring several violations of lower ranked LARDIST(1v0)-[loud burst], due to the contrasting pairs {[k'api, kapi]} and {[kap'i, kapi]}. The contrasts between forms in each of the candidates is represented visually in (13). Contrasts in 1 vs. 2 [loud burst] segments are indicated with solid lines, and contrasts in 1 vs. 0 [loud burst] segments with dotted lines.

(13)   a.

        b.

c.
$$\left\{\begin{array}{ccc} & \text{k'at'i} & \\ \text{k'ati} & & \text{kat'i} \\ & \text{kati} & \end{array}\right\}$$
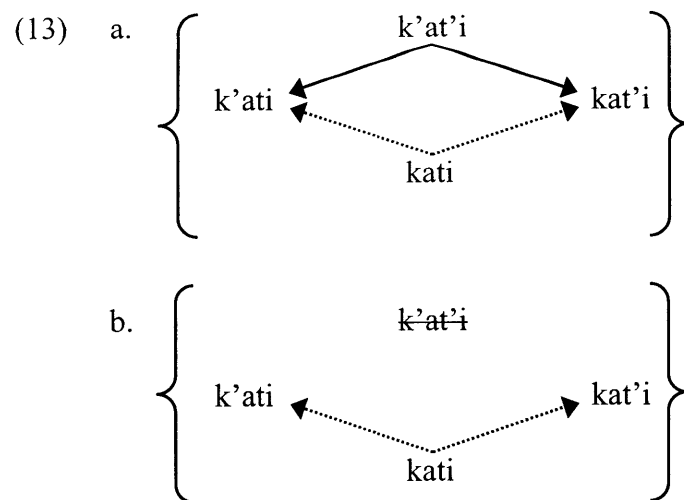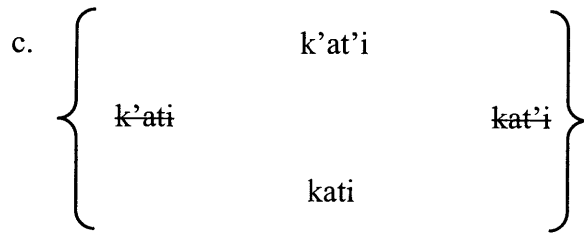
The schematic analysis of dissimilation above shows that the systemic LARDIST(1v2) constraint can force neutralization of contrasting laryngeal configurations. The choice between neutralizing the 1 vs. 2 contrast to forms with one or forms with two laryngeally marked segments is made by the ranking of faithfulness over LARDIST(1v0). Given this ranking, preference is given to the dissimilatory candidate with a greater number of contrasting forms over the assimilatory candidate with more distinct, but fewer contrasts.

The next three sections present three case studies of dissimilation. The most basic pattern is the restriction on ejectives in Chol, analyzed in §5.3. Dissimilation on ejectives and implosives in Hausa is analyzed in §5.4 and §5.5 looks at dissimilation in ejectives but not implosives in Tz'utujil.

5.3 Case study 1 – ejectives in Chol

The Mayan language Chol shows dissimilation between ejectives. There is a binary laryngeal contrast between ejectives and voiceless unaspirated stops at four places of articulation in Chol, and a three way contrast between an ejective, voiceless unaspirated and voiced implosive stop at the labial place. The consonantal inventory of Chol is given in (14), modified from Gallagher and Coon (2009).

(14) Chol consonant inventory

	labial	palatalized alveolar	alveolar	palatoalveolar	velar	glottal
implosive	ɓ					
voiceless	p	t^j	ts	tʃ	k	ʔ
ejective	p'	$t^{j'}$	ts'	tʃ'	k'	
fricative			s	ʃ		h
nasal	m		n	ɲ		
liquid	w		l	j		

Roots in Chol are standardly CVC. The examples in (15), from Aulie and Aulie (1978) show that while ejectives may cooccur with plain stops in either initial or final position of a root (15a,b), and pairs of plain stops freely cooccur, (15c), pairs of ejectives are unattested (15d).

(15) Chol cooccurrence restrictions
    a. **p'it^j**   'to tie a load'   ✓ K'-T
       k'atʃ   'to twist'

    b. **kets'**   'obstructed'   ✓ K-T'
       pak'   'seed'

c. tʃok   'pull'   ✓ K-T
    patʲ   'back'

d. *p'itʲ'/*k'ets'   *K'-T'

The acoustic study of Chol in Chapter 3 showed that ejectives in this language are characterized by a loud burst amplitude and long VOT as compared to the plain stops, as well as creaky phonation in surrounding vowels. At first glance, then, it seems that the cooccurrence restrictions in Chol could results from LARDIST constraints on [loud burst], [long VOT] and/or [creak]. Ejectives in Chol can appear in a variety of prosodic environments, however, which alter the cues that are available to the ejective-plain contrast, as shown in (16).

(16)	context	available cues
a.	[...VT'V...] v. [...VTV...]	preceding vowel phonation following vowel phonation burst amplitude VOT
b.	[#T'V...] v. [#TV...]	following vowel phonation burst amplitude VOT
c.	[...VT'#] v. [...VT#]	preceding vowel phonation burst amplitude

When intervocalic, ejectives and plain stops differ in all three auditory features (16a). In pre-vocalic position (16b), ejectives and plain stops differ in [loud burst] and [long VOT], as well as the difference in [creak] on just the following vowel. In pre-consonantal or final position (16c), ejectives and plain stops differ in [loud burst] and [creak] on the preceding vowel, but not [long VOT]. This distribution of cues shows that the grammar of Chol only requires contrasting stops to differ in burst amplitude; other cues are the result of positional enhancement or articulatory factors. If differences in VOT or creaky phonation were required by the grammar, final or pre-consonantal ejectives would be disallowed. The realization of pre-vocalic and pre-consonantal ejectives is shown in (17) and (18).

117

(17)   [...k'u...]

(18)   [...k'tʲ...]
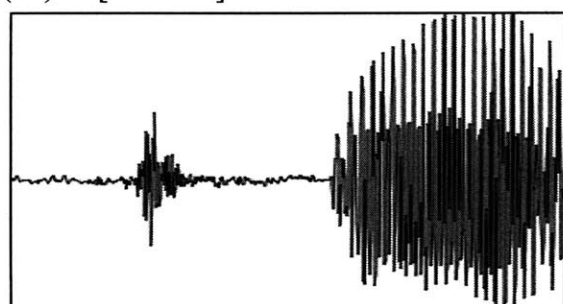
burst   VOT   [u]
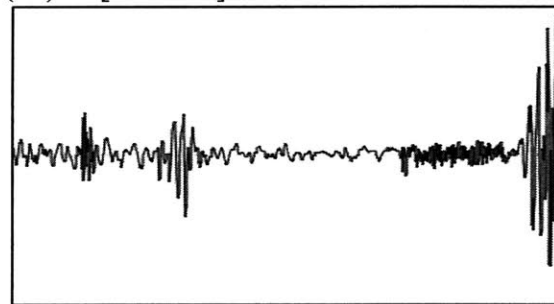
burst   [tʲ] closure   [tʲ] release

The only cue that is consistent across contexts is [loud burst], and I assume that this is the feature that is restricted in Chol. As mentioned above, the distribution of ejectives in Chol show that contrasts based solely on [loud burst] are grammatical, and therefore the presence of other cues must not be crucial to achieve an adequately distinct contrast. There is no direct evidence against an analysis of Chol dissimilation in terms of [creak]. I opt for an analysis based on [loud burst] contrasts since this cue is more stable across contexts, but this is not crucial. The LARDIST constraints active in Chol refer to [loud burst], and are repeated in (19) from the previous section.

(19)   LARDIST(1v2) – [loud burst]   No minimal contrast in [loud burst] between roots with another [loud burst] segment.

Given two contrasting roots R_1, R_2 such that R_1 and R_2 each contain twp segments that minimally contrast for [F], assign one violation mark if R_1 and R_2 each contain some [loud burst] segment and are identical except for a minimal contrast in [loud burst].

LARDIST(1v0) – [loud burst]   No minimal contrast in [loud burst] bewteen roots with another segment that minimally contrasts for [F].

Given two contrasting roots R_1, R_2 such that R_1 and R_2 each contain twp segments that minimally contrast for [F], assign one violation mark if R_1 and R_2 are identical except for a minimal contrast in [loud burst].

118

The constraints in (19) penalize contrasts in [loud burst]. A minimal contrast in [loud burst] in Chol is a contrast in [loud burst] and [creak] and/or [long VOT]. The contrast between ejectives and plain stops in Chol may include differences along these three dimensions, and thus contrasts in [loud burst] that are accompanied by differences in [creak] or [long VOT] are considered minimal. Contrasts in [loud burst] accompanied by differences in other auditory dimensions, like nasality or place, are non-minimal. To illustrate the minimal contrast in Chol, consider the pairs of roots in (20) that contrast 1 and 2 ejectives.

(20)

		LARDIST(1v2)-[loud burst]	
a.	{[k'ap', kap']}	*	1. each contain [loud burst] 2. differ in [loud burst], [long VOT], [creak]
b.	{[k'ap', k'ap]}	*	1. each contain [loud burst] 2. differ in [loud burst], [creak]
c.	{[k'ap', k'am]}	✓	1. each contain [loud burst] 2. differ in [loud burst], [creak], [nasal]

All three pairs of roots in (20) contrast for [loud burst] and at least one other auditory property. A contrast in [loud burst] is penalized in (20a,b), where it is accompanied only by differences in auditory properties that are predictable from [loud burst] ([long VOT] and [creak]). The contrast in [loud burst] in (20c) does not violate LARDIST(1v2)-[loud burst] because it is accompanied by a difference in [nasal], which is not predictable from [loud burst]. The intuitive idea behind the constraint is that a difference in [loud burst] is less perceptible in the context of another [loud burst] segment, and that further differences in the predictable features [long VOT] and [creak] does not make for an adequately perceptible contrast. A difference in a non-predictable feature like nasality, for example, does constitute a strong enough contrast.

LARDIST constraints on [loud burst] interact with an IO-faithfulness constraint on [ejective]. Dissimilation in Chol results when only LARDIST(1v2)-[loud burst] outranks faithfulness, but LARDIST(1v0)-[loud burst] is outranked by faithfulness, as shown in the tableau in (21).

(21)   Chol – dissimilation in ejection

{/k'ap', k'ap, kap', kap/}	LARDIST(1v2)-[loud burst]	IDENT	LARDIST(1v0)-[loud-burst]
a. {[k'ap', k'ap, kap', kap]}	** !		****
b. → {[k'ap, kap', kap]}		*	**
c. {[k'ap', kap]}		** !	

The contrasts that incur violations of LARDIST constraints in (21) are summarized in (22).

(22)

	LARDIST(1v2)-[loud burst]	LARDIST(1v0)-[loud-burst]
candidate a	{[k'ap', k'ap]} {[k'ap', kap']}	{[k'ap', k'ap]} {[k'ap', kap']} {[k'ap, kap]} {[kap', kap]}
candidate b		{[k'ap, kap]} {[kap', kap]}

Both candidates b and c satisfy the highest ranked constraint in (21), and so the choice between them is passed down to faithfulness. The violations of LARDIST(1v2) in (21a) can be repaired either by eliminating the output form with two ejectives (dissimilation), or by eliminating both output forms with a single ejective (assimilation). The dissimilatory output in (21b), which neutralizes only one form, wins on faithfulness. In Chol, the less than maximally distinct contrast between one and zero ejectives is maintained in order to allow for three contrasting forms.

5.4 Case study 2 – ejectives and implosives in Hausa

The interaction of ejectives and implosives in Hausa and Tz'utujil was presented and discussed earlier in Chapter 2, in the context of defining laryngeal distinctions in auditory terms. The next two sections present the analysis of laryngeal restrictions in these two languages, repeating some of the data and observations from Chapter 2.

Hausa shows a dissimilatory cooccurrence restriction on the glottalic series of consonants, which is realized as implosive for labial and alveolar stops and as ejective elsewhere. Glottalic consonants contrast with a voiced and voiceless series, as shown in the inventory in (23), adapted from MacEachern (1999). The original source is Kraft and Kraft (1973).

(23)   Hausa consonant inventory

	labial	alveolar	palato alveolar	velar	palatalized velar	labialized velar	glottal
voiced	b	d	dʒ	g	gʲ	gʷ	
voiceless		t	tʃ	k	kʲ	kʷ	
glottalic	ɓ	ɗ ts'		k'	kʲ'	kʷ'	ʔ
fricative	ɸ	s z	ʃ				h
nasal	m	n					
liquid	w	l r ɽ	ɥ ɥ̃				

No two glottalic consonants may cooccur in a Hausa root. The data are repeated in (24). Ejectives and implosives may cooccur with either voiced or voiceless stops, (24a), and voiced and voiceless stops freely cooccur (24b). Pairs of glottalic consonants, however, are unattested, whether two ejectives, two implosives, or one ejective and one implosive (24c).

(24)   Hausa cooccurrence restrictions
    a. k'uta   'displeasure'[15]   ✓ K'-T
        bak'i   'black'   ✓ K'-D
        ɓati   'spoiled'   ✓ ɓ-T
        ɗige: 'filter'[16]   ✓ ɓ-D

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[15] Taken from an online Hausa-English dictionary: http://www.websters-online-dictionary.org/translation/Hausa/.

[16] Taken from an online Hausa-English dictionary: http://www.websters-online-dictionary.org/translation/Hausa/.

120

b. *k̰ʼutʼa　　　　　　*Kʼ-Tʼ
　　*ɓad̰ʼi　　　　　　*ɓ-ɗ
　　*ɓak̰ʼi / *k̰ʼaɓi　　*Kʼ-ɗ

c. ke:tʃè　　'is split, torn'　　✓ K-T
　　bùgu　　'to be drunk'[17]　✓ G-D
　　do:ki　　'horse'　　　　✓ K-D

Ejectives and implosives pattern as a single class in Hausa, and share phonetic cues; both are realized with creaky phonation, indicated with a tilde. The contrast between glottalic and non-glottalic consonants is consistently a difference in creak. There may, however, be other differences as well. The minimal contrast is between an implosive and a voiced stop and between an ejective and a voiceless stop. According to Lindau, implosives differ from their pulmonic counterparts not only in phonation type but also in closure duration and voicing amplitude. The VOT in ejectives is only slightly longer than in the lightly aspirated plain series (Ladefoged 1968).

　　Lindau (1984:152) provides a representative waveform of an implosive bilabial stop in Hausa, shown in (25). Unfortunately, the contrastive voiced plosive is not shown.

(25)　[ɓ]
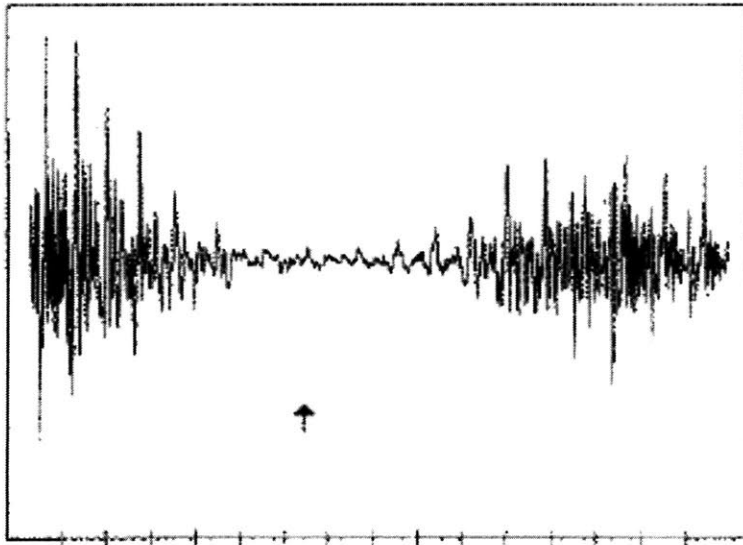
The contrast between ejective and pulmonic voiceless stop is shown in the spectrograms in (26), taken from the UCLA Phonetics Archive database. These examples show a difference in phonation following release. The plain series of stops in Hausa is lightly aspirated.

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[17] Taken from an online Hausa-English dictionary: http://www.websters-online-dictionary.org/translation/Hausa/.

(26) a. [k'a] from [k'aɽa]   b. [ka] from [kaʃi]

The LARDIST constraints on [creak] that drive the cooccurrence restriction in Hausa are defined in (27).

(27) LARDIST(1v2) – [creak]   No minimal contrast in [creak] between roots with another [creak] segment.
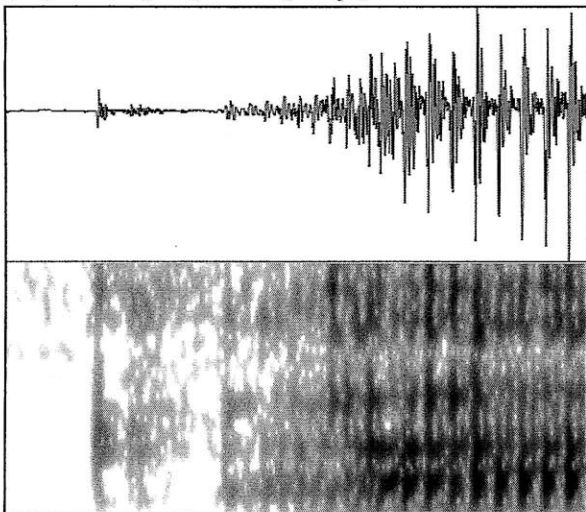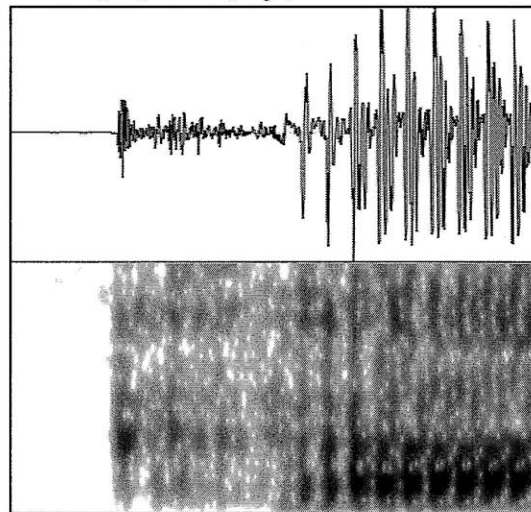
Given two contrasting roots R_1, R_2 such that R_1 and R_2 each contain two segments that minimally contrast for [creak], assign one violation mark if R_1 and R_2 each contain some [creak] segment and are identical except for a minimal contrast in [creak].

LARDIST(1v0) – [creak]   No minimal contrast in [creak] between roots with another segment that minimally contrast for [F].

Given two contrasting roots R_1, R_2 such that R_1 and R_2 each contain two segments that minimally contrast for [creak], assign one violation mark if R_1 and R_2 are identical except for a minimal contrast in [creak].

A minimal contrast in [creak] in Hausa is a contrast in [creak] that may be accompanied by contrasts in voicing amplitude ([v-amp]) and/or closure duration ([duration]). The set of features {[creak], [v-amp], [duration]} is the smallest set of features containing [creak] that distinguishes contrasting segments in Hausa.

The LARDIST-[creak] constraints do not distinguish between creaky ejectives and creaky implosives. This constraint penalizes any contrast between one segment associated with creaky phonation and two, regardless of whether those segments are articulatorily ejective or implosive. The table in (28) shows how LARDIST(1v2)-[creak] evaluates pairs of contrasting forms.

122

(28)		LARDIST(1v2)-[creak]	
a.	{[ɓaɗi, ɓadi]}	*	1. each contain [creak] 2. differ in [creak], [v-amp], [duration]
b.	{[ɓakʼi, ɓaki]}	*	1. each contain [creak] 2. differ in [creak]
c.	{[tsʼakʼi, tsʼaki]}	*	1. each contain [creak] 2. differ in [creak]
d.	{[tsʼakʼi, tsʼagi]}	✓	1. each contain [creak] 2. differ in [creak] as well as [voice]
e.	{[ɓaɗi, ɓati]}	✓	1. each contain [creak] 2. differ in [creak], [v-amp], [duration] as well as [voice]

The table in (28) shows that all contrasts between one and two glottalic consonants violate LARDIST(1v2)-[creak]. While differences in features that are predictable from a contrast in [creak] do not make a contrast non-minimal, as shown in (28a-c), differences in non-predictable features like voicing do constitute a non-minimal contrast (28d,e). The pairs in (28d,e) show a 1 vs. 2 contrast in [creak], but they also show a contrast in [voice] and thus do not violate LARDIST(1v2)-[creak].

The tableaux in (29)-(31) present the analysis of Hausa, showing only sets of forms that minimally contrast for laryngeal specifications.

(29)   Dissimilation in creaky implosives – Hausa

/{ɓaɗi, ɓadi, baɗi, badi}/	LARDIST(1v2) – [creak]	IDENT	LARDIST(1v0) – [creak]
a. [{ɓaɗi, ɓadi, baɗi, badi}]	** !		****
b. → [{ɓadi, baɗi, badi}]		*	**
c. [{ɓaɗi, badi}]		** !	

In (29), the constrasts {ɓaɗi, ɓadi} and {ɓaɗi, baɗi} violate highest ranked LARDIST(1v2)-[creak]. These contrasts are neutralized by eliminating the form with two implosives [ɓaɗi], candidate b, and maintaining three contrasting types of forms. Candidate b wins over candidate c on faithfulness, even though candidate b incurs two violations of lower ranked LARDIST(1v0)-[creak] because of the contrasts {ɓadi, badi} and {baɗi, badi}.

123

(30)   Dissimilation in creaky ejectives – Hausa

/{ts'ak'i, ts'aki, sak'i, saki}/	LARDIST(1v2) – [creak]	IDENT	LARDIST(1v0) – [creak]
a. [{ts'ak'i, ts'aki, sak'i, saki}]	** !		****
b. → [{ts'aki, sak'i, saki}]		*	**
c. [{ts'ak'i, saki}]		** !	

The tableau in (30) shows that the LARDIST constraints in [creak] evaluate ejectives in the same manner as the creaky voiced implosives in (29). The contrasts {ts'ak'i, ts'aki} and {ts'ak'i, sak'i}, which violate high-ranked LARDIST(1v2)-[creak], are neutralized to the forms with one ejective each.

(31)   Dissimilation between creaky ejectives and implosives – Hausa

/{ɓak'i, ɓaki, bak'i, baki}/	LARDIST(1v2) – [creak]	IDENT–[creak]	LARDIST(1v0) – [creak]
a. [{ɓak'i, ɓaki, bak'i, baki}]	** !		****
b. → [{ɓaki, bak'i, baki}]		*	**
c. [{ɓak'i, baki}]		** !	

As in (29) and (30), in (31) roots with two creaky segments are disallowed in favor of roots with a single creaky segment, regardless of whether the given segment is ejective or implosive. The contrasts {ɓak'i, ɓaki} and {ɓak'i, bak'i} are neutralized to [ɓaki] and [bak'i] respectively. All three types of forms with two creaky segments [ɓaɗi, ts'ak'i, ɓak'i] are disallowed in favor of forms with one ejective or implosive.

The tableaux in (29)-(31) show that high ranking LARDIST(1v2)-[creak] accounts for the range of restrictions on glottalic consonants in Hausa. Ejectives and implosives pattern together in dissimilation because they share a single auditory feature. The next section looks at dissimilation in Tz'utujil, a language where ejectives and implosives pattern independently.

5.5   Case study 3 – ejectives and implosives in Tz'utujil

Like Hausa, Tz'utujil has a single contrastive series of glottalic stops that are realized as implosive at some points of articulation and as ejective at others. The inventory of Tz'utujil is repeated in (32), taken from Dayley (1986).

(32)   Tz'utujil consonant inventory

	labial	alveolar	palato alveolar	velar	uvular	glottal
plain	p	t ts	tʃ	k	q	
glottalic	ɓ	ɗ ts'	tʃ'	k'	q'	ʔ
fricative		s	ʃ			h
nasal	m	n				
liquid	w	l r	j			

124

Laryngeal dissimilation in Tz'utujil targets only pairs of ejectives. Pairs of implosives and ejective-implosive pairs are grammatical. The data in (33) represents the Tz'utujil restriction, showing that ejectives may occur in either initial or final position in a root with another plain stop (33a), but may not cooccur in pairs (33b). Roots with pairs of implosives, and pairs of one ejective and one implosive are attested (33c). Pairs of plain stops are also grammatical (33d). Examples are from Pérez Mendoza and Hernández Mendoza (1996).

(33)   Tz'utujil cooccurrence restrictions
    a. **k'at**   e.g. k'aten   'fever'   ✓ K'-T
        pa:tʃ'   'braid'   ✓ K-T'

    b. ***tʃ'a:k'**   *K'-T'

    c. **ɗeɓ**   e.g. ɗeɓeli   'thick (of liquid)'   ✓ ɓ-ɗ
        k'uɓ   e.g. k'uɓuli   'completely full'   ✓ K'-ɗ
        ɓats'   'thread'   ✓ ɓ-T'

    d. **tik**   e.g. tikili   'sewn'   ✓ K-T

The description of the laryngeal restriction in Tz'utujil is complicated by variation in the surface realization of the uvular ejective. The glottalic uvular consonant patterns with the ejectives, even though in prevocalic position there is free variation between an ejective and an implosive (Dayley 1985). Pinkerton (1986) found that the uvular implosive is voiceless, in contrast to the voiced implosives found at the labial and alveolar places. For example, the word *q'iin* 'plot' can be pronounced as [q'iːn] or as [ʛiːn]. Regardless of this variation, combinations of the glottalic uvular and another ejective are unattested in a CVC root (*q'-T', *ʛ-T').

The analysis of the restrictions illustrated in (33) is presented in two parts. First, in §5.5.1, I address the disparate patterning of ejectives and implosives in Tz'utujil, and account for dissimilation in ejection only. In §5.5.2, I address a complications to the analysis in (33) resulting from the realization of implosives in coda position.

5.5.1   The difference between ejectives and implosives

In Tz'utujil, only ejectives are subject to dissimilation. The distribution of implosives is unrestricted, despite the fact that implosives and ejectives form a single contrastive series, just as in Hausa. The difference between Hausa and Tz'utujil lies in the phonetics of glottalic consonants in the two languages, as discussed in Chapter 2. While ejectives and implosives share the auditory property of creaky phonation in Hausa, ejectives and implosives are auditorily distinct in Tz'utujil. Pinkerton's (1986) study finds that the labial and alveolar implosives are modally voiced in Tz'utujil, not creaky voiced as in Hausa. Modally voiced implosives do not form an auditory class with ejectives, regardless of whether the ejectives are primarily associated with creaky phonation or with long VOT and loud burst amplitude, or all three. There is to my knowledge no study of ejectives in Tz'utujil, and thus the primary auditory correlates of these sounds cannot be pinned down. The disparate patterning of ejectives and implosives, however, follows from the realization of the implosives alone.

125

Both ejectives and implosives minimally contrast with the voiceless unaspirated series of stops, as there are no voiced plosive stops in Tz'utujil. While ejectives contrast with plain stops in one or more of [loud burst], [long VOT], [creak], the modally voiced implosives in Tz'utujil contrast with plain stops for none of these. The auditory differences between an implosive and a voiceless unaspirated stop are presumably [voice], as well as any auditory correlates of the rush of air into the mouth in an implosive as opposed to out of the mouth in a plain stop. The precise auditory specifications of implosives is not crucial to the analysis of Tz'utujil; what is relevant is that the implosives are not specified for [creak], and thus do not share any auditory feature with the ejectives.

I assume that the restricted feature in Tz'utujil is [loud burst], as in Chol, though the analysis would work equally well if a restriction on [creak] were supposed instead. Ejectives in Tz'utujil may occur in the same range of environments as in Chol, and thus [long VOT] is not a possible candidate as ejectives in final and pre-consonantal position do not have VOT cues. The LARDIST constraints in Tz'utujil are thus the same as those in Chol, defined in (18) above. LARDIST(1v2)-[loud burst] penalizes a contrast between forms with one and two ejectives, but is silent about the distribution of implosives, which are not specified as [loud burst]. The table in (33) shows how LARDIST(1v2)-[loud burst] evaluates pairs of contrasting Tz'utujil roots.

(34)

		LARDIST(1v2)-[loud burst]	
a.	{[k'ap', kap']}	*	1. each contain [loud burst] 2. differ in [loud burst], [creak], [long VOT]
b.	{[k'aɓ, kaɓ]}	✓	1. no [loud burst] in [tsaɓ] 2. differ in [loud burst], [creak], [long VOT]
c.	{[ɓaɗ, paɗ]}	✓	1. no [loud burst] segment 2. differ in [voice], etc.

The same ranking schema that was seen in the previous two case studies accounts for dissimilation in Tz'utujil. With LARDIST(1v2)-[loud burst] ranked above faithfulness, the contrast between roots with one and two ejectives will be neutralized. The ranking of faithfulness over LARDIST(1v0)-[loud burst] preferes neutralizing the 1 vs. 2 contrast to forms with one ejective. The three tableaux in (35)-(37) show that LarDist constraints on [loud burst] eliminate forms with two ejectives, but allow implosives to cooccur freely with ejectives and other implosives.

(35) Dissimilation in ejection – Tz'utujil

{/k'ap', k'ap, kap', kap/}	LARDIST(1v2) – [loud burst]	IDENT–[cg]	LARDIST(1v0) – [loud burst]
a. {[k'ap', k'ap, kap', kap]}	** !		****
b. → {[k'ap, kap', kap]}		*	**
c. {[k'ap', kap]}		** !	

(36) No restriction on modally voiced implosives – Tz'utujil

{/ɓaɗ, ɓat, paɗ, pat/}	LARDIST(1v2) – [loud burst]	IDENT–[cg]	LARDIST(1v0) – [loud burst]
a. → {[ɓaɗ, ɓat, paɗ, pat]}			
b. {[ɓat, paɗ, pat]}		* !	
c. {[ɓaɗ, pat]}		** !	

(37) No restriction on modally voiced implosives and ejectives – Tz'utujil

{/ɓak', ɓak, pak', pak/}	LARDIST(1v2) – [loud burst]	IDENT–[cg]	LARDIST(1v0) – [loud burst]
a. → {[ɓak', ɓak, pak', pak]}			*
b. {[ɓak, pak', pak]}		* !	*
c. {[ɓak', pak]}		** !	

In (35), high-ranked LARDIST(1v2)-[loud burst] forces neutralization of the contrasts {[k'ap', k'ap]} and {[k'ap', kap']}. LARDIST(1v2)-[loud burst] is not violated, however, by contrasts between implosives and plain stops, as in (37), and thus pairs of implosives and plain-implosive pairs are grammatical. LARDIST(1v2)-[loud burst] is not violated in (37) either. While the pair {[ɓak', ɓak]} shows a contrast in [loud burst], the contrast is in the context of an implosive, rather than another [loud burst] ejective, and thus LARDIST(1v2)-[loud burst] is satisfied. With the analysis of ejective-implosive interaction in Tz'utujil in place, we now turn to the surface realization of consonants in this language.

5.5.2 Tz'utujil consonants in final position

The dissimilatory restriction in Tz'utujil has so far been analyzed as disallowing a contrast between one and two ejectives in a word. This rendering of the pattern is accurate at the level of phonemic analysis, but is complicated by the surface realization of implosives. Dayley reports that implosives in final or pre-consontal position are realized as ejectives. This alternation gives rise to roots with two ejectives surfacing when the final consonant is a labial or alveolar. Roots with phonemic ejectives and implosives freely occur, yet when the implosive is the second consonant in a CVC root, the root will be realized with two ejectives in some contexts. For example, as root like /ts'aɓ/ will be realized as [ts'aɓ] when followed by a vowel initial suffix and as [ts'ap'] when followed by a consonant initial suffix or when unsuffixed. There are a good number of roots of this type in the Pérez Mendoza and Hernández Mendoza dictionary, all of which are given in (38). There are no examples of final alveolar implosives in roots with initial ejectives. This gap is most likely due to the relative rarity of the alveolar implosive in Tz'utujil, particularly in final position.

(38)   ts'aɓ   e.g. ts'aɓe:l   'portion'
         ts'ihɓ   'handwriting'
         ts'uɓ   e.g. ts'uɓu:h   'to suck'
         tʃ'a:ɓ   'reflection'
         tʃ'aɓ   e.g. tʃ'aɓaq   'muddy'
         tʃ'o:ɓ   'pineapple'

tʃ'oɓ   e.g. tʃ'oɓo:h   'think'
tʃ'ohɓ   'soft stick'
tʃ'uɓ   e.g. tʃ'uɓuli   'smoothed with water'
k'i:ɓ   'pacaya de monte'
q'aɓ   e.g. q'aɓa:h   'hand'
q'ohɓ   'earring'

The implosive-ejective alternation means that it is possible to have roots with two ejectives on the surface if one of the ejectives alternates with an implosive. This poses an analytical challenge, as any contrast between roots with one and two ejectives will be neutralized by high-ranking LARDIST(1v2)-[loud burst]. Consider the tableau in (39), which includes the mapping of a final input implosive to an output ejective.

(39)   Wrong result with implosive-ejective alternation

{/k'aɓ, k'ap, kaɓ, kap/}	LARDIST(1v2) – [loud burst]	IDENT–[cg]	LARDIST(1v0) – [loud burst]
a. ★ {[k'ap', k'ap, kap', kap]}	** !		**
b. → {[k'ap, kap', kap]}		*	**
c. {[k'ap', kap]}		** !	

In (39), the mapping of an implosive to an ejective results in the contrast pairs {[k'ap', k'ap]} and {[k'ap', kap']}, which violate LARDIST(1v2)-[loud burst] and cause the intended winner in (39a) to lose to the dissimilatory candidate in (39b).

I do not have a conclusive analysis of the role of the implosive-ejective alternation in Tz'utujil dissimilation, but I offer a largely speculative explanation. Implosives are described as being produced as ejectives in coda position, but no more detail than this descriptive term is given. Thus, it is not clear that a final implosive is truly ejective, with a loud burst or creaky phonation comparable to that in the phonemic ejectives. Pairs like {[k'ap', k'ap]} and {[k'ap', kap']} may avoid a violation of LARDIST(1v2)-[loud burst] because the burst amplitude in [p'] is not sufficient to categorize it as bearing the feature [loud burst].

When considering the idea that implosives are not realized as true ejectives in final position, and thus not specified as [loud burst], it is useful to look at the realization of final consonants generally in Tz'utujil. The implosive/ejective alternation seems to be a specific instance of a general alternation that applies to all final consonants in Tz'utujil. In addition to the variation in implosives, the plain series of stops is aspirated in final position and sonorants surface as voiceless fricatives. A small number of examples of the production of final consonants is available from the Archive of the Indigenous Languages of Latin America (AILLA) and is shown below.[18] An initial and final labial implosive are compared in (40), and (41) shows the difference between an intervocalic and final plain alveolar stop. The two spectrograms in (42) compare an initial and final labial glide.

[18] The citation for the Tz'utujil recordings is as follows: (1998). "Swadesh list". Oxlajuuj Keej Maya' Ajtz'iib' Mayan Languages Collection. The Archive of the Indigenous Languages of Latin America: www.ailla.utexas.org. Media: audio. Access: public. Resource: TZJ004R014.

(40)   a. /ɓ/ from *ɓeey*   b.   /ɓ/ from *kaaɓ*
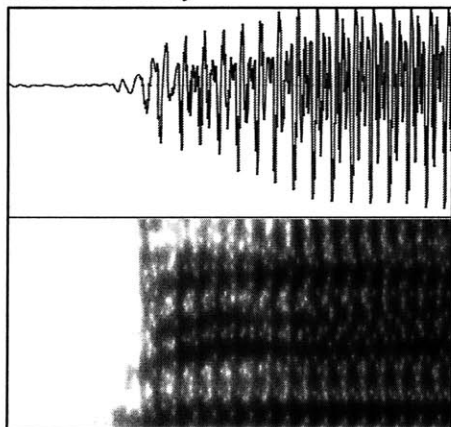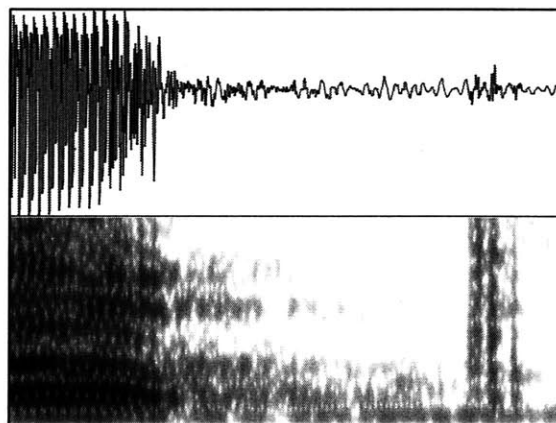
                    no clear burst   release burst

(41)   /t/ from *atet*
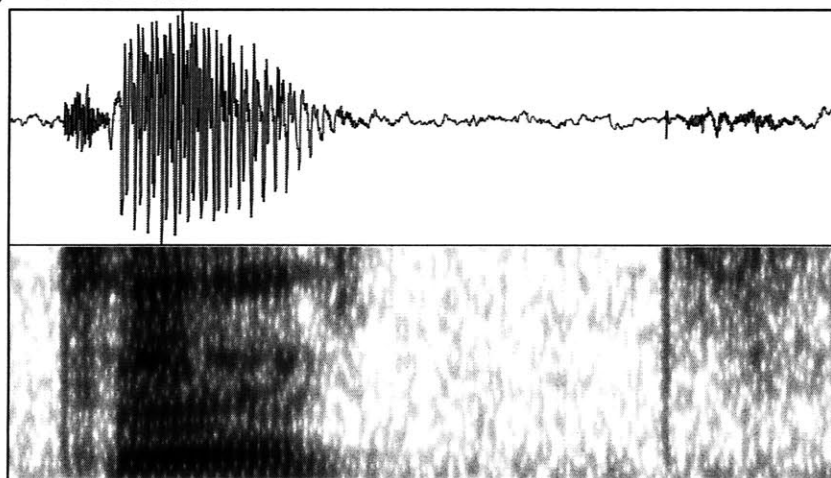
        noisy burst, little aspiration   weak burst, aspiration

(42)   a.   /w/ from *winaq*   b.   /w/ from *teew*
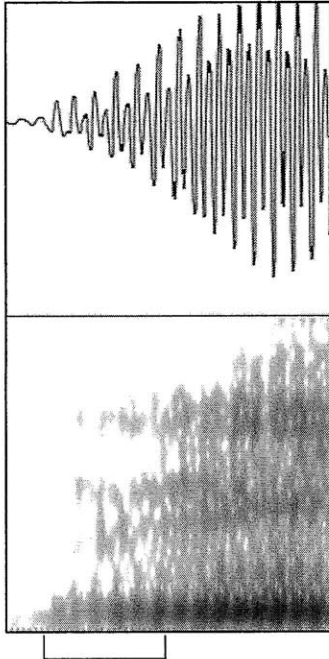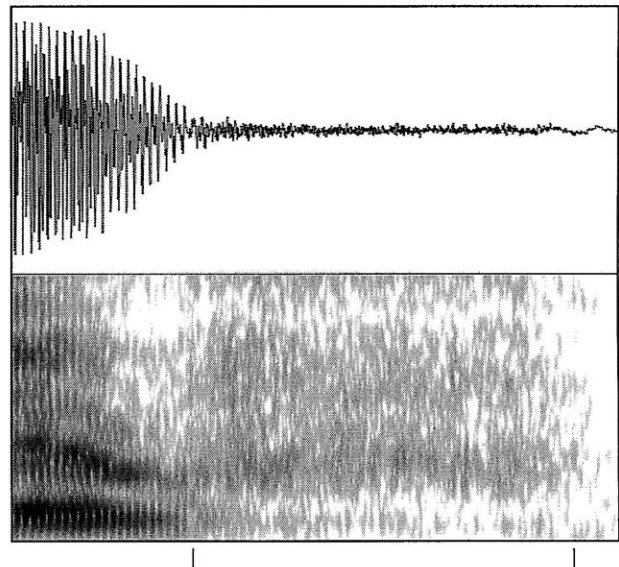
modal voicing   noise

Sonorants, implosives and plain stops all undergo some substantial change in final position, but ejectives seem to be relatively constant. The available recordings show that an ejective in final position is still realized as an ejective, with a large burst amplitude. An example of a final ejective [k'] is given in (43). Unfortunately, there were no examples of pre-vocalic [k'] with which to compare.

(43)   /k'/ from [uk']

loud burst

130
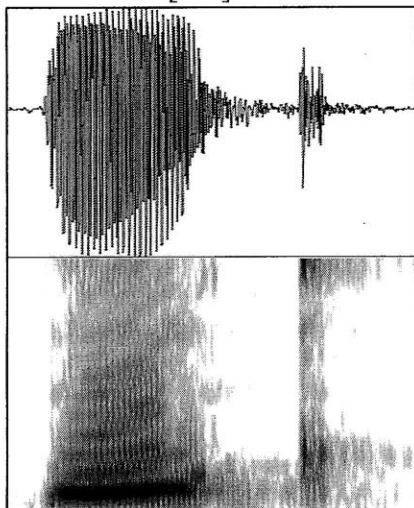
It is not clear what principles govern the realization of consonants in final position in Tz'utujil, though it seems that all final consonants share the properties of being voiceless and somewhat noisy. Plain stops and sonorants are realized with aspiration noise and frication respectively. Ejectives and implosives both have an audible burst.

The analysis of dissimilation argued for here views dissimilation as a restriction on contrasts in a given auditory feature. The main claim with respect to Tz'utujil is that ejectives pattern independently from implosives because these two classes of segments are realized with different auditory properties, and thus cannot be referred to as a class by the LARDIST constraints that drive dissimilation. This line of analysis can be extended to account for why implosives may cooccur with ejectives, despite the variation in the realization of implosives. While implosives in final position may be described as "ejective" due to the presence of a release burst, it may also be that final implosives lack the crucial auditory properties that characterize the other ejectives. Specifically, the amplitude difference between the burst of a final implosive and the burst of a final plain stop may not be sufficient to categorize the implosives as [loud burst]. More detailed research into the phonetics of Tz'utujil consonants is needed to determine whether such an analysis goes through.

5.6   Summary

This chapter introduced two families of perceptually grounded LARDIST constraints and showed how these constraints interact with standard input-output faithfulness constraints to account for dissimilation in laryngeal features. The general ranking schema for dissimilation is given in (44).

(44)   LARDIST(1v2)-[F]   >>   IDENT   >>   LARDIST(1v0)-[F]

Languages with laryngeal dissimilation neutralize the contrast between one and two instances of a laryngeal feature in a root, the weakest contrast on the perceptual hierarchy of long-distance contrasts. Pairs of forms like {[k'ap'i, k'api]} are too confusable with one another, and thus are not allowed to contrast. Given the ranking of IDENT over LARDIST(1v0)-[F], neutralization of the 1 vs. 2 contrast is to forms with one laryngeally marked segment as opposed to two. While neutralization to a form with two laryngeally marked segments allows for a more perceptible contrast {[k'ap'i, kapi]}, neutralization to forms with one laryngeally marked segment allows for more contrasts {[k'api, kap'i, kapi]}. With faithfulness outranking the systemic markedness constraint against the 1 vs. 0 contrast, more, less perceptible contrasts are preferred to fewer, more perceptible contrasts.

The analysis sketched above was applied to three languages, Chol, Hausa and Tz'utujil. Dissimilation in Chol is relatively straightforward, due to the binary contrast between ejectives and voiceless unaspirated stops. The case studies of Hausa and Tz'utujil are somewhat more complex, and show the relevance of phonetic detail in cooccurrence restrictions. Both of these languages have a glottalic series of consonants that is realized as implosive at some places of articulation and as ejective at others. Whether dissimilation targets all glottalic consonants or just a subset is predictable from the phonetics of the glottalic series in the two languages. In Hausa, ejectives and implosives are both realized with creaky phonation, and thus are grouped together with the feature [creak]. Dissimilation in Hausa targets all glottalic consonants uniformly; pairs of ejectives, implosives and ejective-implosive pairs are all disallowed, reflecting a restriction of [creak]. In Tz'utujil, implosives and ejectives are auditorily dissimilar. Implosives are modally

voiced, and thus no auditory feature picks out the class of ejectives and implosives. Only ejectives are subject to dissimilation in Tz'utujil. The phonological distinction between ejectives and implosives follows from the disparity in the auditory cues to the two types of consonants.

Chapter 6   Ordering restrictions and laryngeal dissimilation

This chapter addresses the analysis both of ordering restrictions on laryngeal features, and of the analysis of dissimilation in a language with ordering restrictions. The languages analyzed in this chapter, Souletin Basque, Quechua and Bolivian Aymara, have the cooccurrence pattern schematized in (1).

(1) Laryngeal dissimilation and ordering restriction: *K'-T'   ✓K'-T   *K-T'   ✓K-T

This pattern requires expanding on the constraint set in the previous chapter in two ways. First, some constraint must penalize forms like K-T', where a laryngeally marked stop follows a plain stop in the root. Second, the preference for dissimilation over assimilation was analyzed in the previous chapter as an effect of faithfulness; dissimilation is prefered because it allows more contrasting forms than assimilation. In a language with both dissimilation and ordering restrictions, however, there are only two contrasting output forms {K'-T, K-T} as opposed to the three in a language with simple dissimilation {K'-T, K-T', K-T}. When dissimilation and assimilation both result in a contrast between two output forms, some additional constraint is needed to favor the dissimilatory candidate {K'-T, K-T} over the stronger contrast in the assimilatory candidate {K'-T', K-T}.

To account for the prohibition on forms with a laryngeally marked stop following a plain stop, I propose an additional systemic markedness constraint penalizing a minimal contrast in the position of a given laryngeal feature {K'-T, K-T'}. This constraint is not directly tested in the experiments in Chapter 4, and thus its perceptual basis is a conjecture. The hypothesis is that a positional contrast falls between the 1 vs. 2 and 1 vs. 0 contrast in the perceptual hierarchy. In a languages with ordering restrictions and dissimilation, both the positional contrast and the 1 vs. 2 contrast in laryngeal features are neutralized.

The preference for dissimilation over assimilation results from the relative ranking of articulatory markedness constraints with the systemic markedness constraint against the 1 vs. 0 contrast. A language with dissimilation {K'-T, K-T} is preferred over a language with assimilation {K'-T', K-T} on articulatory grounds, as plain stops involve fewer and simpler articulatory gestures that ejective, aspirate or implosive stops. When articulatory markedness outranks constraints preferring maximally strong contrasts, dissimilation is selected over assimilation.

The case studies in this section show restrictions on [long VOT] and [loud burst]. In Souletin Basque, aspirates contrast with voiced and voiceless stops and may not cooccur in pairs. Aspirates in Souletin Basque may not follow a voiceless stop in a root, but may follow a voiced stop, showing the importance of the concept of a minimal contrast in ordering restrictions. Both Quechua and Bolivian Aymara have a ternary contrast between ejectives, aspirates and plain stops. In Quechua, the restrictions on ejectives and aspirates are completely parallel, while in Bolivian Aymara only ejectives are subject to dissimilation while both ejectives and aspirates are subject to ordering restrictions. The two patterns are summarized in (2).

(2) a. Quechua – dissimilation: *K'-T'   *K^h-T^h *K'-T^h
        Quechua – ordering restriction: ✓K'-T   *K-T'   ✓K^h-T   *K-T^h

b. Bolivian Aymara – dissimilation: *K'-T'   ✓ K^h-T^h ✓ K'-T^h
    Bolivian Aymara – ordering restriction: ✓ K'-T   *K-T'   ✓ K^h-T   *K-T^h

The comparison in (2) is somewhat similar to the comparison between Hausa and Tz'utujil in the previous chapter. Here, however, the different patterns do not correlate with any known difference in the realization of laryngeal features. Rather, it will be shown that the difference between Quechua and Bolivian Aymara is in the ranking of systemic markedness constraints on [loud burst] and [long VOT]. While the 1 vs. 2 contrast is neutralized in Quechua for both of these features, in Bolivian Aymara only the 1 vs. 2 contrast in [loud burst] is neutralized. Dissimilation in Quechua thus targets both ejectives and aspirates, while only ejectives are subject to dissimilation in Bolivian Aymara. The analysis of Quechua makes crucial reference to the feature [long VOT], as argued for in Chapter 2.

This chapter begins in §6.1 by introducing the new constraints at play in the analysis of languages with both dissimilation and ordering restrictions, and then outlining the schematic analysis of this pattern in §6.2. The case study of Souletin Basque in §6.3 shows dissimilation and an ordering restriction on [long VOT], which picks out aspirates. The analysis of ejective and aspirate interactions is presented in §6.3 for Quechua and in §6.4 for Bolivian Aymara.

6.1   *Constraints*

The analysis of ordering restrictions relies on a third family of systemic markedness constraints on laryngeal contrasts. It is argued that the absence of roots with a laryngeally marked stop preceded by an initial plain stop is the result of a systemic constraint penalizing a minimal contrast in the position of a laryngeal feature in a root. For example, forms like [kap^{h}a] may be disallowed because they are too similar to forms like [k^{h}apa]. The constraint schema is defined in (3).

(3)   LARDIST(pos)-[F]   No minimal contrast between roots for the position of [F].

                                      Given two contrasting roots R_1, R_2, assign one violation mark if R_1 and R_2 are identical except for a minimal contrast in the position of [F].

Unlike LARDIST(1v2)-[F] and LARDIST(1v0)-[F], the constraint in (3) has not been explicitly tested. The hypothesis underlying the analysis developed throughout the next two chapters is that a positional contrast in laryngeal features is perceptually stronger than the 1 vs. 0 contrast and weaker than the 1 vs. 2 contrast. As with the LARDIST constraints in Chapter 5, the constraint in (3) may refer to a variety of features [F]. Crucially, however, the group of features that LARDIST(pos) may refer to is predicted to be limited. As with the other LARDIST constraints, LARDIST(pos) is projected from perceptual facts (albeit hypothesized perceptual facts) and thus LARDIST(pos) constraints are only predicted to refer to those features for which the positional contrast is relatively weak. I assume that the all three LARDIST constraints may refer to the four auditory features [loud burst], [long VOT], [creak] and [v-amp], and leave it to further research to verify and expand this set.

The analysis in this chapter introduces two types of constraints that are not in the LARDIST family. The first is a more standard systemic markedness constraint that is sensitive to the

strength of the auditory cues to a given laryngeal contrast, and the second is articulatory markednss constraints, which are not contrast sensitive.

The outcome of neutralizing the positional contrast {K'-T, K-T'} is resolved by a markedness constraint that evaluates the relative perceptual strength of the resulting contrasts. The idea is that in the three languages in question, the positional contrast is neutralized to a form with an initial laryngeally marked segment because contrasts in initial position {K'-T, K-T'} are generally more perceptible than contrasts in medial or final position {K-T', K-T}. The constraint is defined in (4).

(4)   INITIALCONTRAST-[F]   A contrast in [F] is initial: *([K'-K] / ¬ #__)

Given two contrasting roots R_1, R_2, assign one violation mark if R_1 and R_2 are identical except for a minimal contrast in [F] in non-initial position.

The constraint in (4) reflects the fact, documented for Quechua in Chapter 3, that the acoustic cues to laryngeal contrasts are stronger in initial position than in final position, see also Pierrehumbert and Talkin (1991). It was found that VOT in Quechua is longer for both aspirates and ejectives in initial position than in medial position, and for ejectives burst amplitude is also greater in initial position. The perceptual studies in Chapter 4 similarly showed that the 1 vs. 0 contrast for ejectives and aspirates is weaker in medial position than in initial position (the same asymmetry was found for the 1 vs. 2 contrast in aspirates and ejectives). These results support the hierarchy in (5), which is reflected in the constraint in (4).

(5) $\Delta([K'-K] / ¬ \#\_\_)$ < $\Delta([K'-K] / \#\_\_)$
           non-initial contrast   initial contrast

The hierarchy in (5) states that contrasts in laryngeal features are weaker in non-initial position than in initial position. This asymmetry projects the constraint in (4), which neutralizes non-initial laryngeal contrasts. The activity of a constraint like that in (4) is limited in the languages in question to roots with two stops. Non-initial laryngeal contrasts are generally allowed, but when neutralization of the positional contrast is forced by a higher ranked constraint, the effect of the preference for initial contrasts can be seen. Neutralization of non-initial laryngeal contrasts occurs as a general pattern in languages like Navajo (Athabaskan) (McDonough 2003) where the laryngeally marked aspirates and ejectives only occur in root initial position.

The constraint in (4) specifically references *initial* position. The data, however, tend to support a preference for laryngeal contrasts *earlier* in the root, even if the first stop is non-initial. As was mentioned in Chapter 2, if a laryngeally marked stop occurs in a tri-syllabic Quechua root with two non-initial stops, the laryngeally marked stop will be first, e.g. [huk'utʃa] 'mouse', *[hukutʃ'a]. The constraint in (4) does not account for this preference for laryngeal features to occur earlier in the root as opposed to in absolute initial position. The hypothesis is that this preference reflects a perceptual asymmetry in the strength of contrasts earlier vs. later in the root, e.g. {huk'utʃa, hukutʃa} is predicted to be a stronger contrast than {hukutʃ'a, hukutʃa}. One possible explanation for this perceptual asymmetry in Quechua is that the penultimate syllable bears stress, but further research is needed into this issue.

135

The second type of constraint introduced in this chapter is contrast insensitive articulatory markedness. Up until now, the choice between dissimilation and assimilation has rested on faithfulness. Without an ordering contrast in roots with one laryngeally marked stop, however, dissimilation is not more faithful than assimilation. Articulatory markedness constraints evaluate the effort involved in producing a given set of forms, regardless of the perceptual strength of the contrast between forms. In the absence of a positional contrast in laryngeal features, dissimilation may be preferred over assimilation by articulatory markedness constraints. A contrast in 1 vs. 0 laryngeally marked stops is articulatorily simpler than a contrast in 2 vs. 0 laryngeally marked stops. The general schema for an articulatory markedness constraint is relatively simple, and is given in (6).

(6)   *[F]   Output forms do not have the feature [F]

I will assume that articulatory markedness constraints with the form in (6) refer to standard articulatory features like [spread glottis] and [constricted glottis], though this is not crucial. The constraint in (6) penalizes all instances of a given feature in an entire set of forms. For example, the output sets of forms {[k'ap'i, kapi]} and {[k'api, kap'i, kapi]} violate *[constricted glottis] equally because both sets have two [cg] segments; the fact that in one set of forms both [cg] segments are in a single root and in the other they are in two roots is irrelevant to articulatory markedness constraints.

6.2   Schematic analysis of ordering restrictions and dissimilation

The schematic analysis in this section demonstrates how the constraints introduced in the previous section interact with one another as well as the constraints employed in Chapter 5 to account for languages with both ordering restrictions and dissimilation. The analysis of ordering restrictions will be presented first, followed by an explanation of why ordering restrictions pose a problem for the analysis of dissimilation presented in Chapter 6. The role of articulatory markedness constraints in the analyzing both dissimilation and ordering restrictions will then be shown.

Consider a language that contrasts aspirates and plain stops. The relevant auditory feature distinguishing these two types of segments is [long VOT]. In this language, aspirates must be initial in a root with two stops, ✓[kʰapa] *[kapʰa]. The two constraints that interact with faithulness to drive this pattern are defined in (7).

(7)   LARDIST(pos)-[long VOT]   No minimal contrast between roots for the position of [long VOT].

Given two contrasting roots R_1, R_2, assign one violation mark if R_1 and R_2 are identical except for a minimal contrast in the position of [long VOT].

INITIALCONTRAST-[long VOT]   A contrast in [long VOT] is initial: *([K'-K] / ¬ #__)

Given two contrasting roots R_1, R_2, assign one violation mark if R_1 and R_2 are identical except for a minimal contrast in [long VOT] in non-initial position.

The two constraints in (7) refer to a minimal contrast in [long VOT]. In a language with aspirates and plain stops, a minimal contrast in [long VOT] is always accompanied by a contrast in [aspiration]; the minimal contrast referred to by the constraints in (7) is the contrast between an aspirate and a plain stop, which differ in [long VOT] and [aspiration]. The chart in (8) shows how LARDIST(pos)-[long VOT] evaluates pairs of contrasting roots.

(8)	contrasting pair	LARDIST(pos)-[long VOT]	comments
a.	{kʰapi, kapʰi}	*	contrast for the position of [long VOT] and [aspiration]
b.	{kʰabi, gapʰi}	✓	contrast for the position of [long VOT], [aspiration] contrast for the position of [voice]
c.	{tʰami, napʰi}	✓	contrast for the position of [long VOT] and [aspiration] contrast for the position of [nasal]
d.	{kʰapi, kapi}	✓	don't contrast for the position of [long VOT]

The chart in (9) shows how INITIALCONTRAST-[long VOT] evaluates contrasting pairs of forms. The contrasting segments are marked in bold.

(9)	contrasting pair	INITIALCONTRAST-[long VOT]	comments
a.	{kʰa**pʰ**i, kʰa**p**i}	*	[long VOT] and [aspiration] contrast on non-initial stop.
b.	{ka**pʰ**i, ka**p**i}	*	[long VOT] and [aspiration] contrast on non-initial stop.
c.	{**kʰ**api, **k**api}	✓	[long VOT] and [aspiration] contrast on initial stop.
d.	{**kʰ**a**pʰ**i, **k**a**p**i}	✓	Non-minimal contrast.

These two constraints interact with faithfulness to drive an ordering restriction on aspiration, as shown in the tableaux in (10). The tableau in (10a) shows aspirates surfacing only in initial

137

position in roots with two voiceless stops, while the tableau in (10b) shows that aspirates may surface non-initially in roots with another voiced stop. The tableau in (10b) would look the same for an aspirate cooccurring with any segment other than a voiceless stop, e.g. a nasal or sonorant). In the tableaux in (10), forms with two aspirates are not considered. The analysis of the absence of forms with two aspirates is dealt with below.

(10) a. Ordering restriction – aspirates do not follow a voiceless unaspirated stop

{/kʰati, katʰi, kati/}	LARDIST(pos)-[long VOT]	IDENT[sg]	INICON-[long VOT]
i. {[kʰati, katʰi, kati]}	*!		*
ii. → {[kʰati, kati]}		*	
iii. {[katʰi, kati]}		*	*!

b. no ordering restriction on aspirates and voiced stops or non-stops

{/kʰadi, gatʰi, gati, kadi/}	LARDIST(pos)-[long VOT]	IDENT[sg]	INICON-[long VOT]
i. → {[kʰadi, gatʰi, gati, kadi]}			*
ii. {[kʰadi, gati, kadi]}		*!	
iii. {[gatʰi, gati, kadi]}		*!	*

In (10a), the fully faithful set of three contrasting forms violates the highest ranked markedness constraint. To satisfy markedness, either [kʰati] or [katʰi] needs to be eliminated. Lower ranked INICON-[long VOT] favors elimination of [katʰi] because the contrast {[kʰati, kati]} is stronger than {[katʰi, kati]}. In (10b), forms with aspirates and voiced stops surface faithfully because LARDIST(pos) is not violated. In the absence of neutralization, the ranking of INICON below faithfulness ensures that this constraint has no effect.

Integrating the analysis of ordering restrictions with the analysis of dissimilation in the previous chapter leads to the wrong result. The tableau in (11) shows that the assimilatory candidate is incorrectly preferred over the dissimilatory candidate in an analysis with only systemic markedness constraints and faithfulness.

(11) Dissimilation and ordering restrictions – wrong winner

{/kʰatʰi, kʰati, katʰi, kati/}	LD(1v2) – [VOT]	LD(pos) – [VOT]	IDENT – [VOT]	INITIAL CONTRAST	LD(1v0) – [VOT]
a. {[kʰatʰi, kʰati, katʰi, kati]}	**!	*		**	****
b. {[kʰati, katʰi, kati]}		*!	*	*	**
c. ★ {[kʰati, kati]}			**		*!
d. {[katʰi, kati]}			**	*!	*
e. → {[kʰatʰi, kati]}			**		

In (11), high-ranked LARDIST(1v2) and LARDIST(pos) force neutralization to one of the three binary oppositions in candidates c-e. Candidates c-e satisfy high-ranked markedness, and perform equally well on faithfulness. The dissimilatory candidate in (11c) and the assimilatory candidate in (11e) also tie on INITIALCONTRAST. The decision is then passed to low ranked LARDIST(1v0), which prefers the assimilatory candidate in (11e) over the intended winner in (11c). The candidates in (11) are represented schematically in (12). Violations of LARDIST(1v2)

138

are in bold, violations of LARDIST(pos) are in solid, violations of LARDIST(1v0) are indicated with dashed lines and violations of INICON with dotted lines.

(12) a.

b.

c.

d.

e.
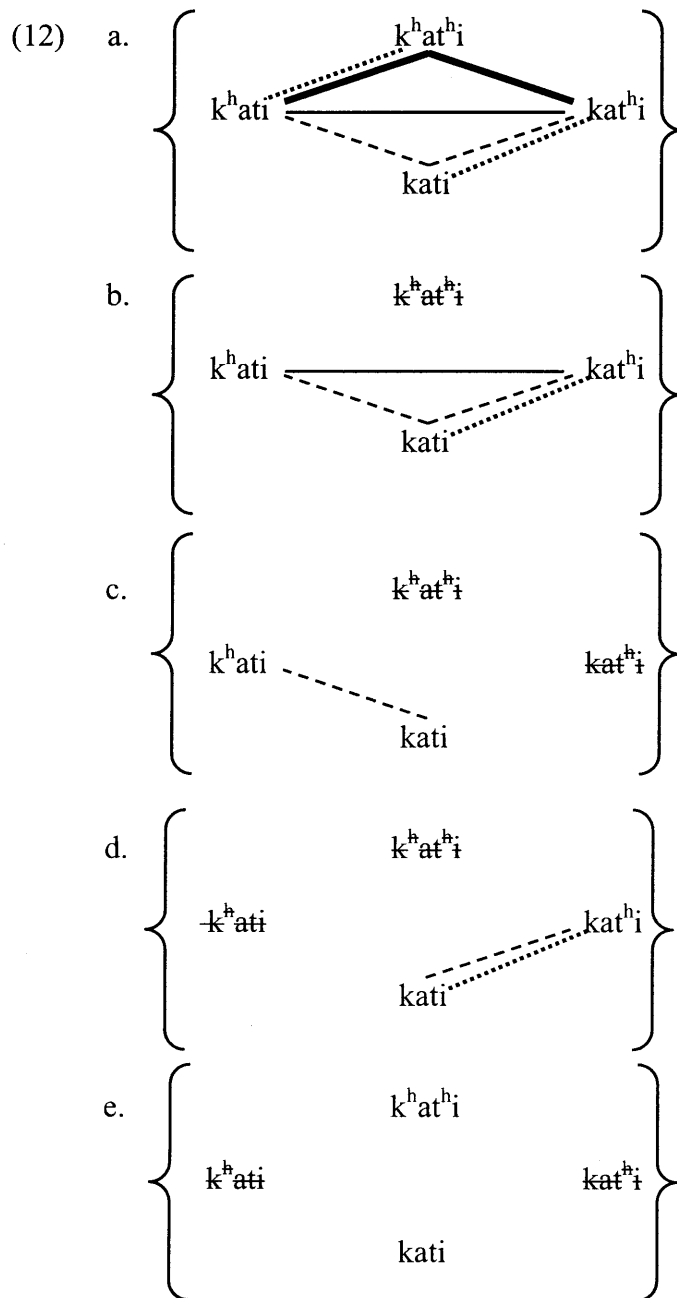
To account for dissimilation in a language with an ordering restriction, some additional constraint must prefer dissimilation to assimilation. Articulatory markedness does just this. The constraint in (13) favors fewer aspirates.

(13) *[spread glottis]   Do not have [spread glottis] segments.

139

If *[spread glottis] outranks LARDIST(1v0), dissimilation is preferred over assimilation, as shown in (14).

(14) Dissimilation and ordering restrictions – right winner

{/kʰatʰi, kʰati, katʰi, kati/}	LD(1v2)	LD(pos)	IDENT	INICONT	*[sg]	LD(1v0)
a. {[kʰatʰi, kʰati, katʰi, kati]}	**!	*		**	****	****
b. {[kʰati, katʰi, kati]}		*!	*	*	**	**
c. → {[kʰati, kati]}			**		*	*
d. {[katʰi, kati]}			**	*!	*	*
e. {[kʰatʰi, kati]}			**		**!	

In (14), *[spread glottis] prefers the dissimilatory candidate with only a single aspirate to the assimilatory candidate with two aspirates.

The next three sections present three case studies of languages with dissimilation and an ordering restriction. The most basic pattern is the restriction on aspirates in Souletin Basque. The case studies of Quechua and Bolivian Aymara show the interaction of ejectives and aspirates.

6.3 Case study 1 – aspirates in Souletin Basque

The cooccurrence pattern in Souletin Basque is virtually identical to the language analyzed schematically above. Souletin Basque contrasts voiced, voiceless unaspirated and aspirated stops, and the aspirated stops are subject to two long-distance restrictions: 1. Pairs of aspirates may not cooccur in a root and 2. An aspirate may not follow a voiceless unaspirated stop in a root. The consonantal inventory of Souletin Basque is given in (15), adopted from MacEachern (1999) whose original source is Hualde (1993).

(15) Souletin Basque consonant inventory

	labial	alveolar	retroflex	palato alveolar	palatal	velar	glottal
plain	p	t ts	ʈʂ	tʃ	c	k	
aspirate	pʰ	tʰ				kʰ	
voiced	b	d	(ɖʐ)		ɟ	g	
fricative	f	s z	ʂ ʐ	ʃ ʒ			h ɦ
nasal	m	n			ɲ		
liquid		l r			ʎ		

MacEachern reports, citing an original observation by Lafon (1958), that pairs of aspirates do not cooccur in roots. Aspirates may cooccur with voiced and voiceless stops, as shown in (16a,b). Voiced and voiceless unaspirated stops also freely cooccur, both in pairs and with one another (16c,d). Examples are from Hualde (1993) and MacEachern (1999).

(16) Souletin Basque dissimilatory restrictions

    a. kʰalka   'to stuff'   ✓ Kʰ-T

        tʰorpe   'heavy'

140

b. kʰo'gan 'beehive'   ✓ Kʰ-D
tʰabela 'wooden collar for pigs'

c. báke   'peace'   ✓ K-D
kobya   'to persevere'

d. pártü   'to cross'   ✓ K-T
bíldotś 'lamb'   ✓ G-D

d. *tʰorpʰe   *Kʰ-Tʰ

In addition to the dissimilatory restriction illustrated in (16), aspirates are also subject to an ordering restriction. Aspirates do not follow voiceless unaspirated stops. Aspirates may appear preceding or following a voiced or non-stop consonant, as shown in (17a,b), but may only precede a voiceless unaspirated stop (17c). Voiced and voiceless unaspirated stops may appear in either order (17d).

(17)   Souletin Basque ordering restriction
      a. tʰabela 'wooden collar for pigs'
         górtʰa   'to soften'

      b. pʰala   'shovel'
         mántʰar 'shirt'

      c. tʰipil   'nude'
         *tipʰil

      d. báke   'peace'
         kobya   'to persevere'

The data in (17) show that the ordering restriction in Souletin Basque only applies between stops that minimally differ in aspiration. Non-initial aspirates are grammatical in roots with voiced or non-stops, but not in roots with the minimally contrastive voiceless unaspirated stops. Another interesting aspect of the ordering restriction in Souletin Basque is that the affricates, which contrast for voicing but not aspiration, do not seem to be active in the ordering restriction. While there are few forms with both an affricate and an aspirate, the dictionary of Larrasquet (1939) gives two loanwords where an aspirate follows a voiceless unaspirated affricate.

(18) tʃerkʰa 'to search' (orthog. *txerkha*) < French [ʃɛʁʃe] *chercher*
      tʃinkʰor 'a slice of fat' (orthog. *txinkhor*) < Béarnais *chingarre*

The data in (18) support the idea that the position of aspirates is only restricted with respect to other segments that minimally contrast for aspiration.

The ordering restriction in Souletin Basque is accounted for with two systemic markedness constraints on [long VOT], LARDIST(pos)-[long VOT] and INICON-[long VOT], both defined in the previous section. As in the schematic example above, a minimal contrast in [long VOT] in

Souletin Basque is a contrast in [long VOT] and [aspiration]. The contrast between an aspirate in a plain stop is thus minimal, while the contrast between an aspirate and a voiced stop (differing in [long VOT], [aspiration] and [voice]) or any other non-stop in the language is non-minimal. The tableaux in (19) show that aspirated stops may not follow voiceless unaspirated stops in Souletin Basque, but may follow voiced stops (or other non-stops).

(19)   a. Souletin Basque – aspirates do not follow a voiceless unaspirated stop

{/kʰati, katʰi, kati/}	LARDIST(pos)-[long VOT]	IDENT[sg]	INICON-[long VOT]
i. {[kʰati, katʰi, kati]}	* !		*
ii. → {[kʰati, kati]}		*	
iii. {[katʰi, kati]}		*	* !

b. Souletin Basque – aspirates may follow a voiced stop or non-stop

{/kʰadi, gatʰi, gati, kadi/}	LARDIST(pos)-[long VOT]	IDENT[sg]	INICON-[long VOT]
i. → {[kʰadi, gatʰi, gati, kadi]}			*
ii. {[kʰadi, gati, kadi]}		* !	
iii. {[gatʰi, gati, kadi]}		* !	*

The basic idea behind the analysis in (19), as discussed earlier, is that ordering restrictions arise from a pressure to neutralize a minimal contrast in the position of a given laryngeal feature, penalizing pairs of forms like {pʰati, patʰi}. Roots with two voiceless stops have the potential to minimally contrast for the position of aspiration, while roots with stops that disagree in voicing or have only one stop cannot. The tableau in (19b) shows that the effect of INICON-[long VOT] is limited to roots with two voiceless stops. The ranking of this constraint below faithfulness means that it cannot force neutralization of medial contrasts on its own; rather, it can only choose between sets of forms that violate faithfulness equally.

Dissimilation in Souletin Basque results from the high-ranking of LARDIST(1v2)-[long VOT], and the ranking of an articulatory markedness constraint against aspirates over LARDIST(1v0)-[long VOT], as shown in the tableau in (20), which is the same as the tableau in (14).

(20)   Souletin Basque – dissimilation and ordering restriction

{/kʰatʰi, kʰati, katʰi, kati/}	LD(1v2)	LD(pos)	IDENT	INICONT	*[sg]	LD(1v0)
a. {[kʰatʰi, kʰati, katʰi, kati]}	** !	*		**	****	****
b. {[kʰati, katʰi, kati]}		* !	*	*	**	**
c. → {[kʰati, kati]}			**		*	*
d. {[katʰi, kati]}			**	* !	*	*
e. {[kʰatʰi, kati]}			**		** !	

The analysis in the tableau in (20) illustrates the systemic, contrast-markedness based analysis of the ordering restriction and dissimilation in Souletin Basque. The constraint against a positional contrast in laryngeal features is formalized as a LARDIST constraint, reflecting the hypothesis that ordering restrictions stand in a systematic relation to dissimilatory and assimilatory cooccurrence restrictions. The three phenomena of dissimilation, ordering restrictions and assimilation reflect

142

different cut-off points along the hierarchy of perceptual distinctness in laryngeal contrasts between roots. Souletin Basque, and other languages with a similar pattern, thus have a somewhat more stringent restriction on the cooccurrence of laryngeally marked stops than the languages with only dissimilation analyzed in the previous chapter. In Souletin Basque, both the contrast between 1 vs. 2 instances of a laryngeal feature and the contrast between the position of a laryngeal feature are neutralized.

The analysis of Souletin Basque relies on three new constraints introduced in this section. LARDIST(pos) penalizes contrasts based solely on the position of a laryngeal feature, accounting for the existence of ordering restrictions. Neutralization of the positional contrast to initial position is achieved by INICON, another systemic constraint which favors contrasts in initial position, where they are more perceptible. Finally, articulatory markedness favors dissimilation.

In languages like Chol, Hausa and Tzutujil, which allow a positional contrast in forms with a single laryngeally marked segment, dissimilation results in three contrasting forms. In this type of language, the ranking of faithfulness over LARDIST(1v0) is sufficient to render dissimilation optimal. In languages like Souletin Basque (as well as Quechua and Bolivian Aymara, analyzed below), however, dissimilation and assimilation both result in a contrast between two types of forms, and thus tie on faithfulness. In this scenario, articulatory markedness must outrank LARDIST(1v0) in order for the dissimilatory candidate to be optimal.

6.4   Case study 2 – ejectives and aspirates in Quechua

Quechua shows dissimilation and an ordering restriction on both ejectives and aspirates. Quechua has a ternary contrast between ejectives, aspirates and plain stops; ejectives and aspirates pattern as a single class with respect to cooccurrence restrictions. This section extends the analysis of dissimilation and ordering restrictions to account for the uniform patterning of ejectives and aspirates in Quechua. The analysis makes crucial reference to the auditory features [long VOT], which groups both ejectives and aspirates, and [loud burst], which uniquely picks out ejectives. The inventory of Quechua is given in (21) below, repeated from (53) in Chapter 2.

(21)   Quechua consonant inventory

	labial	alveolar	postalveolar	velar	uvular	glottal
plain	p	t	$t\int$	k	q	$\textipa{P}$
aspirate	p^h	t^h	$t\int^h$	k^h	q^h	
ejective	p'	t'	$t\int$'	k'	q'	
fricative		s	$\int$			h
nasal	m	n	$\textipa{\textltailn}$			
liquid		l ɾ	ʎ			
glide	w		j			

In Quechua, pairs of ejectives, pairs of aspirates and pairs of one ejective and one aspirate are all disallowed (MacEachern 1999). Examples of dissimilation are given in (22), taken from Ajacopa et al.'s (2007) dictionary. Pairs of plain stops are unrestricted.

(22) Quechua dissimilatory restriction
a.	t'impuy	'to boil'	✓ K'-T
	p'atʃa	'clothes'	
	qʰatiy	'to follow'	✓ Kʰ-T
	pʰaskay	'to tie up'	
	tinkuy	'to meet'	✓ K-T
	puka	'red'	
b.	*t'imp'uy		*K'-T'
	*qʰatʰiy		*Kʰ-Tʰ
	*t'impʰu / *qʰat'i		*K'-Tʰ

Ejectives and aspirates in Quechua are also subject to an ordering restriction with respect to plain stops. Ejectives and aspirates may appear in medial position in roots with other non-stops, but not in roots with an initial plain stop. Some examples are given from Ajacopa et al. (2007) in (23).

(23) Quechua ordering restriction
a.	kʰapa	'step'	✓ Kʰ-T
	pʰuti	'pain'	
	*kapʰa		*K-Tʰ
b.	kʰuru	'small animal'	✓ Kʰ-M
	qʰasa	'ice'	
	rukʰu	'decrepit'	✓ M-Kʰ
	mapʰa	'wax'	
c.	k'apa	'cartilage'	✓ K'-T
	p'atʃa	'clothing'	
	*kap'a		*K-T'
d.	k'iri	'injury'	✓ K'-M
	q'aʎa	'slice'	
	ruk'iy	'to pack tightly'	✓ M-K'
	sut'i	'clear, visible'	

The ordering restriction in Quechua disallows a minimal contrast in the position of [long VOT] in the root, just as in Souletin Basque. While in Souletin Basque aspirates are the only [long VOT] segments, in Quechua both aspirates and ejectives are [long VOT] and thus both are subject to the ordering restriction. The structure of the inventory of Quechua is different from that of Souletin Basque, however, and thus what consitutes a minimal contrast in [long VOT] also differs. In Quechua, all three laryngeal categories minimally contrast with one another. A minimal contrast in [long VOT] may be accompanied by a contrast in [loud burst] or [aspiration]. Similarly, a minimal contrast in [loud burst] may be accompanied by a contrast in [long VOT] or [aspiration]. The auditory features that define the laryngeal contrasts of Quechua are shown in (24a).

144

(24)   contrast   difference
          K' vs. K^h [loud burst]   [aspiration]
          K' vs. K   [long VOT]   [loud burst]
          K^h vs. K   [long VOT]   [aspiration]

Each laryngeal category in Quechua is separated by the other two categories by two laryngeal features. Crucially, no sub-set relation holds between any two contrasts. The contrasts between these three series of stops are thus entirely symmetrical. The ternary laryngeal contrast in Quechua differs from that in Souletin Basque, where the contrasts between the three series of stops are not symmetrical. The features that differ between an aspirate and a plain stop in Souletin Basque are a sub-set of the features that differ between an aspirate and a voiced stop, and thus aspirates and voiced stops do not minimally contrast. The contrasts in Souletin Basque are shown in (25).

(25)   contrast   difference
          K^h vs. K   [long VOT]   [aspiration]
          K vs. G   [voice]
          K^h vs. G   [long VOT]   [aspiration]   [voice]

While aspirates and plain stops differ in [long VOT] and [aspiration], aspirates differ from voiced stops in both these features as well as closure voicing, [voice]. The comparison between Quechua and Souletin Basque shows that the idea of a minimal contrast is inventory dependent. Moreover, Quechua shows that a given segment may minimally contrast with more than one other segment in the inventory.

Due to the relative complexity of the Quechua data, the analysis is divided into two sections. The ordering restriction is discussed first in §6.4.1 and then integrated with the analysis of dissimilation in §6.4.2.

6.4.1 Ordering restrictions in Quechua

The ordering restrictions in Quechua are analyzed as a single restriction on a minimal contrast in [long VOT]. There are two arguments for viewing the ordering restrictions as a single restriction, as opposed to two cooccurring but independent restrictions. First, ejectives and aspirates pattern together in both the ordering and dissimilatory restrictions in Quechua. It will be shown in the next sub-section that the dissimilatory pattern in Quechua can only be accounted for as a restriction on [long VOT], and thus the unity of ejectives and aspirates in Quechua is a general property of the language. Second, ejectives and aspirates also pattern together in the ordering restrictions in Bolivian Aymara, even though they pattern separately with respect to the dissimilatory cooccurrence restriction in the language. The three known patterns of ordering restrictions, in Souletin Basque, Quechua and Bolivian Aymara, all refer to [long VOT].

The comparison between the ordering restrictions in Souletin Basque and Quechua show the benefit of the auditory feature [long VOT] over the laryngeal node. In Souletin Basque, the two laryngeally marked series of stops pattern separately. While aspirates and voiced stops both contrast with the voiceless unaspirated series, only aspirates are restricted. In Quechua, both laryngeally marked series of stops are subject to ordering restrictions. Under the laryngeal node hypothesis, aspirated stops are expected to pattern with voiced stops as often as they pattern with

145

ejective stops, as all three types of stops are specified under the laryngeal node. Given the auditory feature [long VOT], however, the propensity of aspirates to pattern together with ejectives but not with voiced stops has an explanation.

The analysis of the ordering restriction in Quechua is the same as in Souletin Basque. For clarity, the tableaux in (26) and (27) show the analysis of ejective and aspirate contrasts separately. The analyses are integrated in (28).

(26)   Ordering restriction on ejectives

{/k'api, kap'i, kapi/}	LARDIST(pos) – [long VOT]	IDENT – [long VOT]	INICONT – [long VOT]
a. {[k'api, kap'i, kapi]}	* !		*
b.→ {[k'api, kapi]		*	
c. {[kap'i, kapi]}		*	* !

(27)   Ordering restriction on aspirates

{/kʰapi, kapʰi, kapi/}	LARDIST(pos) – [long VOT]	IDENT – [long VOT]	INICONT – [long VOT]
a. {[kʰapi, kapʰi, kapi]}	* !		*
b.→ {[kʰapi, kapi]		*	
c. {[kapʰi, kapi]}		*	* !

(28)   Ordering restriction on ejectives and aspirates - integrated

{/k'api, kʰapi, kap'i, kapʰi, kapi/}	LARDIST(pos) – [long VOT]	IDENT – [long VOT]	INICONT – [long VOT]
a. {[k'api, kʰapi, kap'i, kapʰi, kapi]}	** !		**
b.→ {[k'api, kʰapi,kapi]		**	
c. {[kap'i, kapʰi, kapi]}		**	** !

LARDIST(pos)-[long VOT] penalizes contrasts in the position of [long VOT], regardless of whether the [long VOT] segment is an ejective or an aspirate. The offending contrasts can be seem schematically in (29).

(29)   candidate (28a)

$$
\left\{
\begin{array}{cc}
\text{k'api} & \text{kʰapi} \\
| & | \\
\text{kapʰi} & \text{kap'i} \\
& \text{kapi}
\end{array}
\right\}
$$
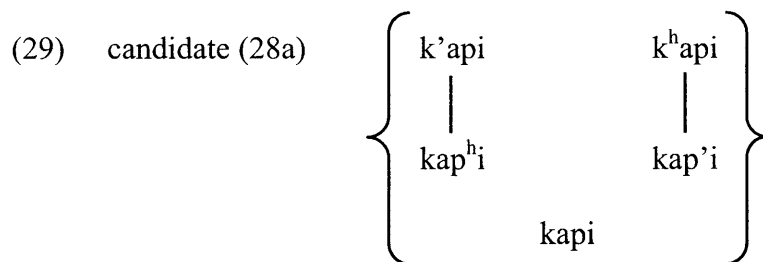
With LARDIST(pos)-[long VOT] high ranked, the position of a [long VOT] segment in a root will be predictable. Low-ranked INICONT-[long VOT] favors initial contrasts over medial contrasts. We now turn to the analysis of ejective and aspirate dissimilation in Quechua.

146

6.4.2 Dissimilation and ordering restrictions in Quechua

Dissimilation in Quechua targets ejectives and aspirates as a class. Pairs of ejectives, pairs of aspirates and pairs of one ejective and one aspirate are all ungrammatical: *K'-T', *K^h-T^h, *K'-T^h. This dissimilatory pattern results from LARDIST(1v2) constraints referring to the auditory dimensions of both [loud burst] and [long VOT]. The uniform patterning of ejectives and aspirates necessitates a restriction on a single feature that picks out both categories, [long VOT]. While the absence of pairs of ejectives and pairs of aspirates can be accounted for with individual restrictions on ejection and aspiration, the inability of aspirates and ejectives to cooccur with one another cannot be accounted for in this way. A root with one aspirate and one ejective does not violate a constraint referring only to aspirates or only to ejectives. This point will be illustrated with tableaux later in this section.

The constraint that motivates dissimilation in both aspiration and ejection is defined in (30).

(30) LARDIST(1v2)-[long VOT]   No minimal contrast in [long VOT] between roots with another [long VOT] segment.

Given two contrasting roots R_1, R_2 such that R_1 and R_2 each contain two segments that minimally contrast for [long VOT], assign one violation mark if R_1 and R_2 each contain some [long VOT] segment and are identical except for a minimal contrast in [long VOT].

The constraint LARDIST(1v2)-[long VOT] penalizes the contrast between an ejective or aspirate and a plain stop in the context of another ejective or aspirate. The constraint in (30) penalizes contrasts in [long VOT] and the features that predictably accompany [long VOT], [aspiration] and [loud burst], but not contrasts in [long VOT] that are accompanied by independent contrasts, e.g. place contrasts or nasality contrasts. The evaluation of this constraint is illustrated by considering the sample contrasts in (31). The contrasting segments in each pair are marked in bold.

(31)

	contrasting pair	LARDIST(1v2)-[long VOT]	
a.	{k'ap'i, k'api}	*	1. [long VOT] segment in each 2. contrast for [long VOT] and [loud burst]
b.	{kʰapʰi, kʰapi}	*	1. [long VOT] segment in each 2. contrast for [long VOT] and [aspiration]
c.	{k'apʰi, k'api}	*	1. [long VOT] segment in each 2. contrast in [long VOT] and [aspiration]
d.	{k'apʰi, kapʰi}	*	1. [long VOT] segment in each 2. contrast in [long VOT] and [loud burst]
e.	{k'ap'i, k'apʰi}	✓	1. [long VOT] segment in each 2. contrast in [loud burst] and [aspiration]
f.	{kʰapʰi, k'apʰi}	✓	1. [long VOT] segment in each 2. contrast in [loud burst] and [aspiration]

The restriction in Quechua falls out from the combined effects of LARDIST(1v2)-[long VOT] and a LARDIST(1v2) constraint on [loud burst] segments. The constraint on [loud burst] is defined in (32).

(32) LARDIST(1v2)-[loud burst]   No minimal contrast in [loud burst] between roots with another [loud burst] segment.

Given two contrasting roots R_1, R_2 such that R_1 and R_2 each contain two segments that minimally contrast for [loud burst], assign one violation mark if R_1 and R_2 each contain some [loud burst] segment and are identical except for a minimal contrast in [loud burst].

The constraint LARDIST(1v2)-[loud burst] penalizes contrasts in [loud burst] that are accompanied either by a contrast in [long VOT], as is the case for the ejective-plain contrast, or by a contrast in [aspiration], as is the case for the ejective-aspirate contrast. While LARDIST(1v2)-[long VOT] penalizes any contrast between an ejective or aspirate and a plain stop in the context of another ejective or aspirate, LARDIST(1v2)-[loud burst] only penalizes contrasts between ejectives and other laryngeal categories in the context of an ejective. The evaluation of this constraint is demonstrated with the sample contrasts in (33), which are the same as those in (31) above.

(33)

	contrasting pair	LARDIST(1v2)-[loud burst]	
a.	{k'apʹi, k'api}	*	1. [loud burst] segment in each 2. contrast for [loud burst] and [long VOT]
b.	{kʰapʰi, kʰapi}	✓	1. no [loud burst] segment in either 2. contrast for [long VOT] and [aspiration]
c.	{k'apʰi, k'api}	✓	1. [loud burst] segment in each 2. contrast in [long VOT] and [aspiration]
d.	{k'apʰi, kapʰi}	✓	1. no [loud burst] segment in [kapʰi] 2. contrast in [loud burst] and [long VOT]
e.	{k'apʹi, k'apʰi}	*	1. [loud burst] segment in each 2. contrast in [loud burst] and [aspiration]
f.	{kʰapʰi, k'apʰi}	✓	1. no [loud burst] segment in [kʰapʰi] 2. contrast in [loud burst] and [aspiration]

The two constraints LARDIST(1v2)-[long VOT] and LARDIST(1v2)-[loud burst] drive the dissimilatory restriction in Quechua. Given the large number of contrasting forms that need to be considered in Quechua, the analysis will be shown in two stages. First, the analysis of dissimilation will be established, and then integrated with the analysis of ordering restrictions. The tableau in (34) shows the analysis of dissimilation, considering only forms that obey the ordering restriction. As in Souletin Basque, dissimilation in the absence of a positional contrast arises when articulatory markedness constraints outrank LARDIST(1v0).

(34)   Quechua – dissimilation in ejection and aspiration

{/k'apʹi, kʰapʰi, k'apʰi, kʰapʹi, k'api, kʰapi, kapi/}	LD(1v2) - [loud burst]	LD(1v2) - [long VOT]	IDENT	*[sg] / *[cg]	LD(1v0) – [long VOT]
a. {[k'apʹi, kʰapʰi, k'apʰi, kʰapʹi, k'api, kʰapi, kapi]}	*** !	****		*(10)	*(12)
b. [{ k'apʰi, kʰapʹi, k'api, kʰapi, kapi}]		** !	**	*(6)	*(6)
c. [{k'apʹi, kʰapʰi, k'apʰi, kʰapʹi, kapi}]	** !		**	*(8)	
d. [{k'apʹi, kʰapʰi, kapi}]			****	**** !	
→ e. [{ k'api, kʰapi, kapi}]			****	**	**

Candidates a-c are eliminated by the high ranking LARDIST constraints on [loud burst] and [long VOT]. Candidate a, which allows the full set of possible contrasts, violates both constraints numerous times, as shown in (35). Contrasts that violate LARDIST(1v2)-[loud burst] are marked

149

with solid lines, contrasts that violate LARDIST(1v2)-[long VOT] with dashed lines, and violations of low-ranked LARDIST(1v0)-[long VOT] with dotted lines.

(35)   Candidate (34a)

$$\left\{ \begin{array}{c} \text{k'ap'i} \qquad\qquad \text{k}^h\text{ap}^h\text{i} \\[2em] \text{k'ap}^h\text{i} \qquad\qquad \text{k}^h\text{ap'i} \\[2em] \text{k'api} \qquad \text{k}^h\text{api} \\[1em] \text{kapi} \end{array} \right\}$$
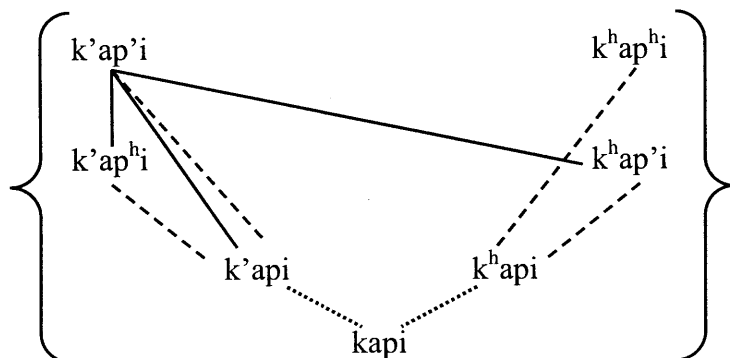
Candidate b and c each violate only one of the two top ranked LARDIST(1v2) constraints. Candidate b incurs two violations of LARDIST(1v2)-[long VOT] because of the contrast between forms with two laryngeally marked consonants and forms with one laryngeally consonant, as shown in (36).

(36)   Candidate (34b)

$$\left\{ \begin{array}{c} \text{k'ap'i} \qquad\qquad \text{k}^h\text{ap}^h\text{i} \\[2em] \text{k'ap}^h\text{i} \qquad\qquad \text{k}^h\text{ap'i} \\[2em] \text{k'api} \qquad \text{k}^h\text{api} \\[1em] \text{kapi} \end{array} \right\}$$
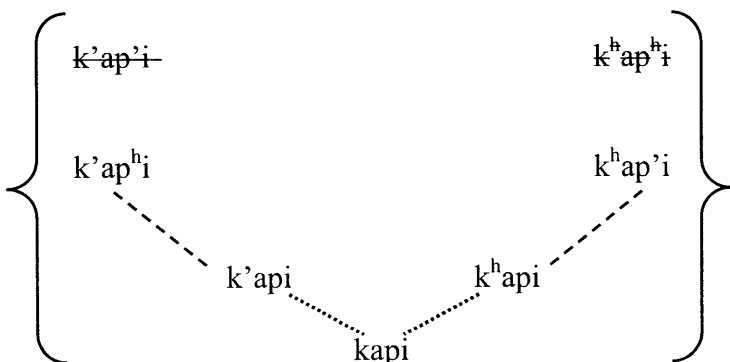
Candidate c violates LARDIST(1v2)-[loud burst] because of the contrasts between a form with two ejectives and forms with one ejective.

(37)   Candidate (34c)

$$\left\{ \begin{array}{c} \text{k'ap'i} \qquad\qquad \text{k}^h\text{ap}^h\text{i} \\[2em] \text{k'ap}^h\text{i} \qquad\qquad \text{k}^h\text{ap'i} \\[2em] \text{k'api} \qquad \text{k}^h\text{api} \\[1em] \text{kapi} \end{array} \right\}$$
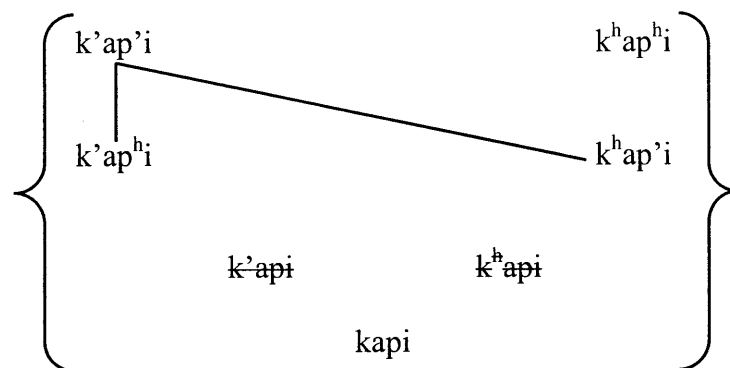
The table in (38) summarizes the violations of high ranked LarDist constraints.

(38)	LarDist(1v2)-[loud burst]	LarDist(1v2)-[long VOT]
cand. a	{[k'ap'i, k'api]} {[k'ap'i, k'apʰi]} {[k'ap'i, kʰap'i]}	{[k'ap'i, k'api]} {[kʰapʰi, kʰapi]} {[k'apʰi, k'api]} {[kʰap'i, kʰapi]}
cand. b		{[k'apʰi, k'api]} {[kʰap'i, kʰapi]}
cand. c	{[k'ap'i, k'apʰi]} {[k'ap'i, kʰap'i]}	

With candidates a-c eliminated by highest ranked systemic markedness, the choice between candidate d ({[k'ap'i, kʰapʰi, kapi]}) and candidate e ({[k'api, kʰapi, kapi]}) is passed down to lower ranked articulatory markedness. Both of the remaining candidates fare equally well on faithfulness, neutralizing only those contrasts that are required by higher ranked LarDist(1v2), and allow three contrasting forms. The dissimilatory candidate in (34e) is preferred over the assimilatory candidate in (34d) by articulatory markedness, which favors sets of forms with fewer ejectives and aspirates. LarDist(1v0) favors the (34d), but is outranked by articulatory markedness.

The tableau in (39) shows the full analysis of both laryngeal dissimilation and ordering restrictions in Quechua. For reasons of space, violations of LarDist(1v2)-[long VOT] and LarDist(1v2)-[loud burst] are collapsed, and low ranked LarDist(1v0) is left out of the tableau.

(39)   Quechua – dissimilation and ordering restrictions on ejectives and aspirates

{/k'ap'i, kʰapʰi, k'apʰi, kʰap'i, k'api, kʰapi, kap'i, kapʰi, kapi/}	LD(1v2)	LD(pos)	IDENT	*[sg] / *[cg]	INICONT
a. {[k'ap'i, kʰapʰi, k'apʰi, kʰap'i, k'api, kʰapi, kap'i, kapʰi, kapi]}	*(7) !	****		*(10)	*(6)
b. {[k'apʰi, kʰap'i, k'api, kʰapi, kapi]}	** !		****	*(6)	**
c. {[k'api, kʰapi, kap'i, kapʰi, kapi]}		**** !	****		**
d. {[k'ap'i, kʰapʰi, k'apʰi, kʰap'i, kapi]}	** !		****	*(8)	
e. {[k'ap'i, kʰapʰi, kapi]}			*(6)	**** !	
f. {[kap'i, kapʰi, kapi]}			*(6)	**	** !
→ g. {[k'api, kʰapi, kapi]}			*(6)	**	

Integrating the analysis of dissimilation and ordering restrictions does not pose any special challenge. The LarDist(1v2) constraints require an output set of forms with either forms with only a single laryngeal feature (as in candidates b, f, g) or forms with two segments marked for

the same laryngeal feature (as in candidate e). LARDIST(pos) eliminates the candidate in (39c), which satisfies LARDIST(1v2) by only have forms with a single laryngeal feature, but allows a positional contrast. The choice between assimilation, as in (39e) and dissimilation (39f,g) is made by articulatory markedness, which prefers dissimilation. Finally, INICONT prefers laryngeally marked segments in initial as opposed to medial position, rendering (39g) optimal. The next section builds on the analysis of Quechua to analyze similar patterns in Bolivian Aymara.

6.5 Case study 3 – ejectives and aspirates in Bolivian Aymara

The cooccurrence restrictions in Bolivian Aymara are similar to those in Quechua, but also different in an interesting way. The consonant inventory and root structure in Bolivian Aymara is the same as that of Quechua in all ways relevant to cooccurrence restrictions. The dissimilatory restriction in Bolivian Aymara applies only to pairs of ejectives; pairs of aspirates and ejective-aspirate pairs are grammatical. As in Quechua, ejectives and aspirates may both also cooccur with plain stops, and plain stops may cooccur in pairs with one another.

(40)   Bolivian Aymara dissimilatory restriction

    a. **k'astu**   'pole'   ✓ K'-T

        t'uku   'lethargy'

        kʰiti   'who'   ✓ Kʰ-T

        tʰaski   'stride'

        kuʎta   'button'   ✓ K-T

        tunka   'ten'

    b. ***k'ast'u**   *K'-T'

    c. **kʰitʰa**   'messenger'   ✓ Kʰ-Tʰ

        pʰutʰu   'hueco'

        t'inkʰa   'tip'   ✓ K'-Tʰ

        qʰatʃ'a   'incest'

Dissimilation in Bolivian Aymara targets ejectives exclusively. While pairs of ejectives are disallowed (as in Quechua), pairs of aspirates and pairs of one ejective and one aspirate are grammatical (unlike Quechua): *K'-T', ✓ Kʰ-Tʰ, ✓ K'-Tʰ. The comparison between the dissimilatory restrictions in Bolivian Aymara and Quechua is schematized in (41).

(41)

Quechua	Bolivian Aymara
*K'-T'	*K'-T'
*Kʰ-Tʰ	✓ Kʰ-Tʰ
*K'-Tʰ	✓ K'-Tʰ
✓ K'-T	✓ K'-T
✓ Kʰ-T	✓ Kʰ-T
✓ K-T	✓ K-T

While Quechua and Bolivian Aymara differ as to whether both ejectives and aspirates are subject to dissimilation, the ordering restrictions between plain stops and ejectives or aspirates in the two languages are the same. In both languages, neither an ejective nor an aspirate may follow a plain stop. Some examples are given from de Lucca (1987) in (42).

(42) Bolivian Aymara ordering restriction

a.	tʃ^{h}aχta	'fear'	✓ K^h-T
	k^{h}itʃu	'sorrow'	
	*tʃat^{h}a		*K-T^h
b.	k^{h}aru	'moth'	✓ K^h-M
	p^{h}isa	'loose'	
	mik^{h}i	'incapable'	✓ M-K^h
	sap^{h}i	'root'	
c.	tʃ'ata	'complaint'	✓ K'-T
	p'utu	'bud, sprout'	
	*kap'a		*K-T'
d.	k'umu	'load'	✓ K'-M
	q'asa	'deficient'	
	mik'i	'moisture	✓ M-K'
	sanq'a	'harelipped'	

The examples in (42a,c) show that while ejectives and aspirates may precede plain stops, they may not follow a plain stop in a root. Ejectives and aspirates may both precede or follow non-stop consonants in a root, as shown in (42b,d). The data in (42) show that ejectives and aspirates are subject to ordering restrictions with respect to plain stops. The ordering restriction is represented schematically in (43) for both Quechua and Bolivian Aymara.

(43)

Quechua	Bolivian Aymara
✓ K'-T	✓ K'-T
✓ K^h-T	✓ K^h-T
*K-T'	*K-T'
*K-T^h	*K-T^h

Bolivian Aymara exhibits an additional ordering restriction, not seen in Quechua, due to the grammaticality of roots with both ejectives and aspirates in Bolivian Aymara but not Quechua. In roots with both ejectives and aspirates, the order of ejection and aspiration is predictable from the place of articulation of the consonants (MacEachern 1999). While both ejective-aspirate and aspirate-ejective sequences occur in the language, there is no minimal contrast for the ordering of laryngeal features. If the initial consonant is an alveolar, palatoalveolar, or velar, then the initial consonant is ejective and the medial consonant is aspirate. Some examples from de Lucca (1987) are given in (44).

(44)   Ejectives precede aspirates – Bolivian Aymara

    a. Initial alveolar: ✓ t'-T^h *t^h-T'

t'alp^{h}a	'wide'		*t^{h}alp'a
t'aq^{h}e	'sorrow'		*t^{h}aq'e
t'ink^{h}a	'tip'		*t^{h}ink'a

    b. Initial palatoalveolar: ✓ tʃ'-T^h *tʃ^h-T'

tʃ'ump^{h}i	'brown'		*tʃ^{h}ump'i
tʃ'ank^{h}a	'thread of wool'		*tʃ^{h}ank'a
tʃ'oʎq^{h}e	'firmness'		*tʃ^{h}oʎq'e

    c. Initial velar: ✓ k'-T^h *k^h-T'

| k'it^{h}a | 'fugitive' | | *k^{h}it'a |
| k'iʎp^{h}a | 'ceremony of marking animals' | | *k^{h}iʎp'a |

The data in (44) show that if the initial consonant is an alveolar, palatoalveolar or velar, the ordering of laryngeal features is ejective-aspirate, regardless of the place of articulation of the medial consonant. The examples in (44) do not include any forms with both an alveolar and a palatoalveolar, or a form with both a velar and a uvular, combinations that are generally absent in the language. De Lucca's dictionary also does not contain any forms with an initial velar ejective and a medial palatoalveolar aspirate (e.g. [k'itʃ^{h}a]), which I assume is an accidental gap.

When the initial consonant is a labial or uvular, aspiration precedes ejection, as shown in (45a,b). In uvular-labial pairs, ejection precedes aspiration (45c). There are no labial-uvular pairs in de Lucca's dictionary, which I take to be an accidental gap.

(45)   Aspirates precede ejectives – Bolivian Aymara

    a. Initial labial: ✓ p^h-T'   *p'-T^h

p^{h}ank'a	'rubble'		*p'ank^{h}a
p^{h}ant'a	'a black shawl'		*p'ant^{h}a
p^{h}intʃ'a	'ditch'		*p'intʃ^{h}a

    b. Initial uvular (non-labial medial): ✓ q^h-T'   *q'-T^h

| q^{h}atʃ'u | 'fodder' | | *q'atʃ^{h}u |
| q^{h}ot'i | 'waterfall' | | q^{h}ot'i |

    c. Initial uvular (labial medial):   ✓ q'-p^h *q^h-p'

| q'ap^{h}a | 'active' |
| q'ap^{h}i | 'fragrance' |

The data in (44) show that Bolivian Aymara does not allow contrasts in the position of [long VOT], hence the predictable order of ejectives and aspirates with respect to plain stops. The data in (45) show further that minimal contrasts in the position of [loud burst] are disallowed, and

thus the order of ejectives and aspirates is also predictable.[19] With minimal contrasts in both [long VOT] and [loud burst] disallowed, the position of ejection and aspiration in a root is always predictable. The analysis of ordering restrictions is presented in §6.5.1 and integrated with the analysis of dissimilation in §6.5.2.

6.5.1 Ordering restrictions in Bolivian Aymara

Ordering restrictions in Bolivian Aymara are driven by the two LARDIST(pos) constraints in (46).

(46) LARDIST(pos)-[long VOT] No minimal contrast between roots for the position of [long VOT].

Given two contrasting roots R_1, R_2, assign one violation mark if R_1 and R_2 are identical except for a minimal contrast in the position of [long VOT].

LARDIST(pos)-[loud burst] No minimal contrast between roots for the position of [loud burst].

Given two contrasting roots R_1, R_2, assign one violation mark if R_1 and R_2 are identical except for a minimal contrast in the position of [loud burst].

LARDIST(pos)-[long VOT] penalizes contrasts in the position of [long VOT] segments, which will always be accompanied by a contrast in the position of [loud burst] or [aspiration], as is the case in Quechua. Similarly, a minimal contrast in [loud burst] is accompanied by either [long VOT] or [aspiration]. The two constraints in (46) have an overlapping domain; both penalize contrasts in the order of ejectives and plain stops. Only LARDIST(pos)-[long VOT] penalizes positional contrasts between aspirates and plain stops and only LARDIST(pos)-[loud burst] penalizes positional contrasts between ejectives and aspirates. The evaluation of these two constraints is shown in the chart in (47).

(47)		LARDIST(pos)-[loud burst]	LARDIST(pos)-[long VOT]
a.	{[k'api, kap'i]}	*	*
b.	{[kʰapi, kapʰi]}	✓	*
c.	{[k'api, kapʰi]}	✓	✓
d.	{[k'apʰi, kʰap'i]}	*	✓

The constraints in (46) motivate neutralization of positional contrasts. Additional constraints on the position of contrasts account for the outcome of neutralization. Contrasts in [long VOT] are favored in initial position, an effect of INICONT-[long VOT], as can be seen from the ordering of ejectives and aspirates with respect to plain stops. Additionally, contrasts in [loud burst] are also

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[19] The ordering restriction on ejective-aspirate pairs can be accounted for as either a restriction on minimal contrasts in the position of [loud burst] or [aspiration]. I choose an analysis based on [loud burst] so that both the analysis of ordering restrictions and dissimilatory restrictions results from constraints referring to [long VOT] and [loud burst].

favored in initial position, over contrasts in [aspiration], as can be seen from the general preference for ejective-aspirate ordering in roots with both ejectives and aspirates. This preference is a result of the relative ranking of the two constraints in (48).

(48) INITIAL-[loud burst]   [loud burst] contrasts are initial: *([K'-K] / ¬ #__)

Given two contrasting roots R_1, R_2, assign one violation mark if R_1 and R_2 are identical except for a minimal contrast in [loud burst] in non-initial position.

accompanying feature: [long VOT] or [aspiration]

INITIAL-[aspiration]   [aspiration] contrasts are initial: *([K'-K] / ¬ #__)

Given two contrasting roots R_1, R_2, assign one violation mark if R_1 and R_2 are identical except for a minimal contrast in [aspiration] in non-initial position.

The tableaux in (49) shows the analysis of ordering restrictions in Bolivian Aymara. In this tableau, I consider all types of forms except those with two ejectives, which are absent due to the dissimilatory restriction analyzed below.

(49)   Ordering restrictions in Bolivian Aymara

{/kʰapʰi, kʰap'i, k'apʰi, k'api, kʰapi, kap'i, kapʰi, kapi/}	LD(pos) [burst]	LD(pos) [VOT]	IDENT	INICON [burst]	INICON [VOT]	INICON [asp]
a. {[kʰapʰi, kʰap'i, k'apʰi, k'api, kʰapi, kap'i, kapʰi, kapi]}	** !	**		****	*(5)	*(5)
b. {[kʰapʰi, kʰap'i, k'api, kʰapi, kapi]}			***	** !	**	**
c. {[kʰapʰi, kʰap'i, kap'i, kapʰi, kapi]}			***	*** !	**	***
d. {[kʰapʰi, k'apʰi, kap'i, kapʰi, kapi]}			***	** !	**	**
e. → {[kʰapʰi, k'apʰi, k'api, kʰapi, kapi]}			***		**	**

The violations incurred by candidate a are summarized in (50). Contrasts in the position of [loud burst] are indicated with bold solid lines and contrasts in the position of [long VOT] are indicated with dashed lines. Non-initial contrasts in [burst], [VOT] and [aspiration] are indicated with solid, dotted and double lines respectively.

156
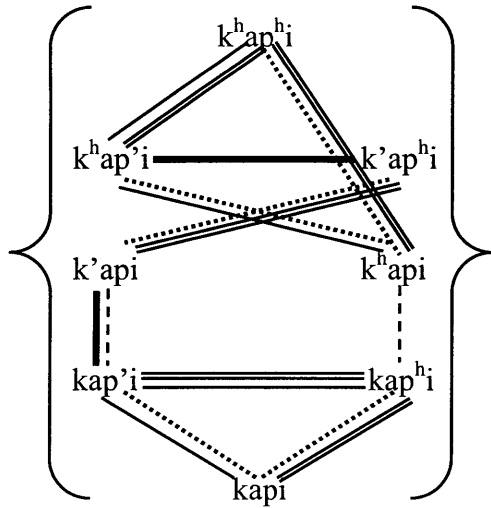
(50) Candidate a

Candidates b-e all satisfy both high-ranking LARDIST(pos) constraints by eliminating three forms. Candidates b,c neutralize the {/kʰap'i, k'apʰi/} contrast to [kʰap'i] while candidate d,e neutralize to [k'apʰi]. Candidates b,e neutralize the [long VOT] contrast to forms with initial ejectives and aspirates, and candidates c,d neutralize to forms with medial ejectives and aspirates. The ranking of INICONT-[loud burst] over INICONT-[aspiration] selects candidate e as the winner. INICONT-[long VOT] has no effect on the output in Bolivian Aymara, as this constraint duplicates the effects of INICONT-[loud burst] and INICONT-[aspiration] which are crucially ranked. These four candidates are shown schematicaly in (51).

(51) candidate b: candidate c:

157

candidate d: candidate e:

$$
\left\{
\begin{array}{cc}
 & k^h ap^h i \\
k^h ap'i & k'ap^h i \\
k'api & k^h api \\
kap'i ======= kap^h i \\
 & kapi
\end{array}
\right\}
\qquad
\left\{
\begin{array}{cc}
 & k^h ap^h i \\
k^h ap'i & k'ap^h i \\
k'api & k^h api \\
kap'i & kap^h i \\
 & kapi
\end{array}
\right\}
$$
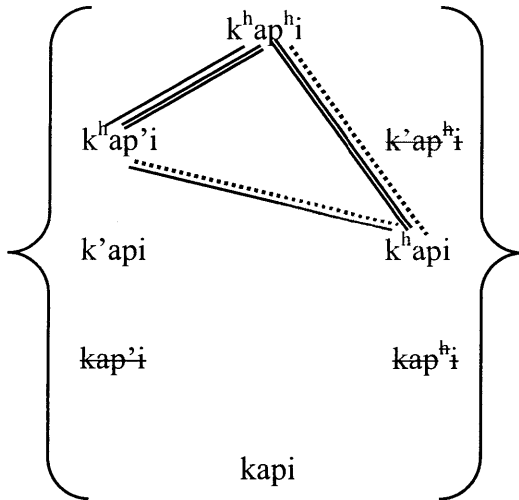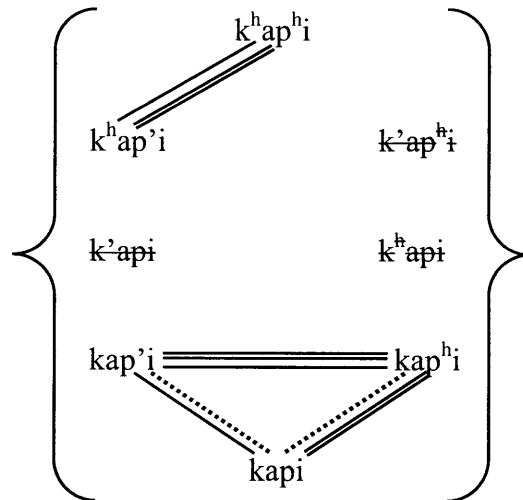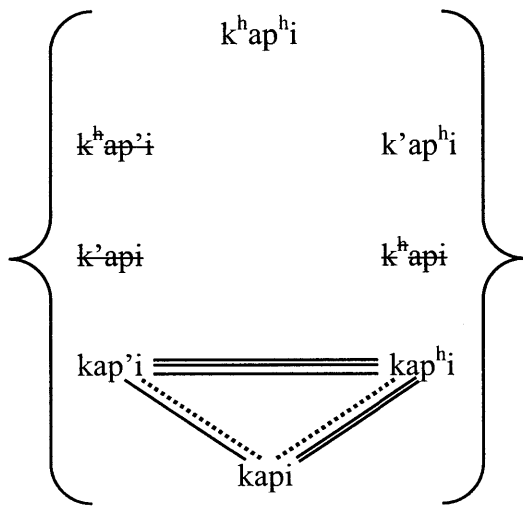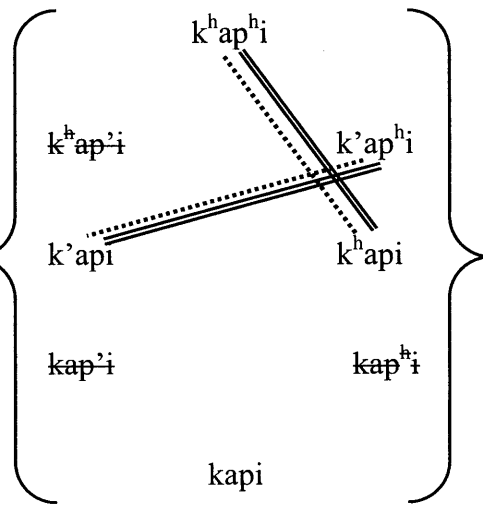
In Bolivian Aymara, INITIAL-[loud burst] is responsible for the ordering of ejectives and aspirates with respect to plain stops as well as one another. Given five contrasting forms, including forms with two aspirate and an ejective-aspirate pair, it is not possible to eliminate non-initial contrasts in [long VOT]. In Quechua, ordering aspirates and ejective before plain stops results in perfect satisfaction of INITIAL-[long VOT]. In Bolivian Aymara, however, there are two violations of INITIAL-[long VOT] regardless of the ordering of ejectives and aspirates with plain stops. Ordering aspirates and ejectives before plain stops still results in non-initial [long VOT] contrasts, due to the presence of forms with two laryngeally marked segments, as in candidates b and e. It is, however, possible to ensure that non-initial [long VOT] contrasts are contrasts in [aspiration] and not [loud burst], as in candidate e. The difference between Bolivian Aymara and Quechua, then, is that in Quechua all [long VOT] segments are initial, whereas in Bolivian Aymara all [loud burst] segments are initial. The asymmetry between [loud burst] and [long VOT] in Bolivian Aymara is mirrored in the analysis of dissimilation. While Quechua disallows all 1 vs. 2 contrasts among [long VOT] segments, Bolivian Aymara only disallows a 1 vs. 2 contrast in [loud burst].

There is one element of the ordering restriction in Bolivian Aymara that has yet to be accounted for. The tableau in (49) derives the more common ejective-aspirate ordering in roots with both ejectives and aspirates. In a smaller number of roots, however, the aspirate-ejective order surfaces. Roots with initial labials or uvulars (with the exception of uvular-labial pairs), show the order aspirate-ejective. I do not have an analysis of this opposite ordering. While the current analysis does not fully account for the attested orderings of ejectives and aspirates, it correctly accounts for the fact that there is never a *contrast* in the ordering of laryngeal features.

To account for the exceptional or independent behavior of roots with initial labial or uvular stops, MacEachern appeals to markedness constraints against labial and uvular ejectives, *p' and *q'. These markedness constrainst are motivated by the observation that languages with ejectives may lack ejectives at the labial or uvular places, and that ejectives at these places imply ejectives at intermediate places (Greenberg 1970; Maddieson 1984). The ejective-aspirate order does not surface when it would result in an ejective labial or uvular. While this is an elegant analysis of the pattern, it cannot be imported into the present system. Consider the tableau in (52), which is a

streamlined version of the tableau in (50). For a constraint like *p' to have any effect, it has to outrank INICON[burst], which is responsible for the general preference for the ejective-aspirate ordering. In (52), the high-ranking of *p' correctly prefers sets of contrasting forms with [p^hak'i] instead of [p'ak^{h}i]. However, this constraint also prefers [pak'i] over [p'aki], and incorrectly selected candidate b is optimal instead of the attested candidate a.

(52) Ordering restrictions with *p'

{/p^hak^hi, p^hak'i, p'ak^{h}i, p'aki, p^haki, pak'i, pak^{h}i, paki/}	*p'	INICON [burst]	INICON [asp]
a. ★ {[p^hak^hi, p^hak'i, p'aki, p^haki, paki]}	* !	** !	**
b. → {[p^hak^hi, p^hak'i, pak'i, pak^{h}i, paki]}		*** !	***
c. {[p^hak^hi, p'ak^{h}i, pak'i, pak^{h}i, paki]}	* !	** !	**
d. {[p^hak^hi, p'ak^{h}i, p'aki, p^haki, paki]}	** !		**

The dispreference for ejective labials and uvulars is only seen in the ordering of ejectives and aspirates, but a constraints like *p' and *q' predict that this effect should be more general, and show up in the ordering restrictions between ejectives and plain stops as well. The correct analysis of aspirate-ejective forms with initial labials and uvulars is left open.

6.5.2 Dissimilation and ordering restrictions in Bolivian Aymara

The dissimilatory restriction in Bolivian Aymara targets only ejectives. Pairs of ejectives are absent from the language, but pairs of aspirates and ejective-aspirate pairs are attested. This restriction emerges if only LARDIST(1v2)-[loud burst] outranks faithfulness, and LARDIST(1v2)-[long VOT] is low-ranked. The tableau in (53) shows dissimilation in ejectives but not aspirates. This tableau considers only forms that obey the ordering restrictions established in the previous section. The full set of forms is considered later in this section.

(53) Bolivian Aymara – Dissimilation in ejectives

{/k'ap'i, k^hap^hi, k'ap^{h}i, k'api, k^hapi, kapi/}	LD(1v2) - [loud burst]	IDENT	*[sg] / *[cg]	LD(1v2) - [long VOT]	LD(1v0) – [long VOT]
a. {[k'ap'i, k^hap^hi, k'ap^{h}i, k'api, k^hapi, kapi]}	*** !		*(8)	***	*(5)
b. {[k'ap'i, k^hap^hi, k'api, k^hapi, kapi]}	* !	*	*(6)	**	****
c. {[k'ap'i, k^hap^hi, k'ap^{h}i, k^hapi, kapi]}	* !	*	*(8)	*	**
d. {[k'ap'i, k^hap^hi, k^hapi, kapi]}		** !	*(5)	*	**
e. → {[k^hap^hi, k'ap^{h}i, k'api, k^hapi, kapi]}		*	*(6)	**	****

159

The set of possible contrasts in Bolivian Aymara is determined by the ranking of LARDIST(1v2)-[loud burst] over IDENT, which outranks all other relevant markedness constraints. The two pairs {[k'ap'i, k'api]} and {[k'ap'i, k'apʰi]} violate LARDIST(1v2)-[loud burst]. These violations can be resolved be eliminating a single form [k'ap'i], as in candidate e, or by eliminating two forms, [k'api] and [k'apʰi], as in candidate d. Candidate e is preferred by IDENT, and emerges as the winner. Lower ranked constraints do not effect the outcome of neutralization.

Integrating the analysis of dissimilation with the analysis of ordering restrictions is straightforward. The full set of contrasting input forms is considered in (54).

(54)   Ordering restrictions and dissimilation in Bolivian Aymara

{/k'ap'i, kʰapʰi, k'apʰi, kʰap'i, k'api, kʰapi, kap'i, kapʰi, kapi/}	LD(1v2) [burst]	LD(pos) [burst]/[VOT]	IDENT	INITIAL [burst]	LD(1v2) [VOT]
a. {[k'ap'i, kʰapʰi, k'apʰi, kʰap'i, k'api, kʰapi, kap'i, kapʰi, kapi]}	****!	*(5)		*(5)	*(8)
b. {[k'ap'i, kʰapʰi, kapʰi, kapi]}			*(5)!		**
c. {[kʰapʰi, k'apʰi, kap'i, kapʰi, kapi]}			****	**!	**
d. → {[kʰapʰi, k'apʰi, k'api, kʰapi, kapi]}			****		**

The tableau in (54) shows that the optimal set of contrasting forms has no forms with two ejectives, no forms with an aspirate-ejective sequence, and no forms with aspirates or ejectives following plain stops. Candidate (54a) is fully faithful, and does not neutralize the 1 vs. 2 contrast in [loud burst] or the positional contrasts in [loud burst] and [long VOT]. Candidate b satisfies the highest ranked markedness constraints, but resolves the violations of LARDIST(1v2)-[loud burst] by assimilation, and is thus less faithful than the two dissimilatory candidates in (54c,d). Both dissimilatory candidates have non-initial laryngeal contrasts. In candidate d, however, all contrasts in [loud burst] are initial, and thus this candidate is preferred by the highest ranking of the INICONT constraints.

The ranking of LARDIST constraints in Bolivian Aymara contradicts the proposed fixed hierarchy of LARDIST constraints, specifically the ranking of LARDIST(1v2)-[F] >> LARDIST(pos)-[F]. Aspirates in Bolivian Aymara are subject to an ordering restriction, but not dissimilation, and thus LARDIST(pos)-[long VOT] must outrank LARDIST(1v2)-[long VOT]. The ranking of LARDIST constraints, then, is not entirely fixed. It will be shown in the next chapter that there is no evidence that LARDIST(1v0)-[F] ever outranks LARDIST(pos)-[F] or LARDIST(1v2)-[F]. It is thus the relative ranking of LARDIST(1v2)-[F] and LARDIST(pos)-[F] that is variable, at least for the feature [long VOT]. It is an empirical question whether other features show the same degree of variation. It should be noted that the relative perceptual strength of 1 vs. 2 and positional contrast has not been empirically tested, and it may be the case that these two contrasts are more or less of equal strength. While the patterning of [long VOT] segments in Bolivian Aymara does not conform to the hierarchy of LARDIST constraints, this abnormality does not contradict the more general hypothesis that more confusable contrasts are more likely to be neutralized than less confusable contrasts.

160

6.6 Summary

This section has shown how ordering restrictions can be accounted for with systemic markedness constraints, and how the systemic analysis of ordering restrictions is integrated with the analysis of dissimilation. In Souletin Basque and Quechua, dissimilation and ordering restrictions apply to the same set of features. Ordering restrictions reflect a systemic markedness constraint against a minimal positional contrast in the position of a given laryngeal feature. Neutralization of this contrast is resolved by further systemic constraints favoring contrasts in initial position (or wherever they are strongest in the language in question). Dissimilation in a language with an ordering restriction arises from the high-ranking of LARDIST(1v2)-[F], and the ranking of articulatory markedness over LARDIST(1v0)-[F]. The ranking schema for the restrictions in Souletin Basque and Quechua is given in (55).

(55)   LD(1v2)-[F] >> LD(pos)-[F] >> IDENT >> *[F], INICONT[F] >> LD(1v0)-[F]

The ranking for Bolivian Aymara is essentially the same, except that articulatory markedness is not crucially ranked with respect to INICONT[F] and LARDIST(1v0)-[F]. Because [loud burst] and [long VOT] are subject to different restrictions in Bolivian Aymara, the ranking of INICONT[F] constraints on laryngeal features alone determines the outcome of neutralization.

The similar restrictions in Quechua and Bolivian Aymara were also analyzed in this section. The major difference between the laryngeal restrictions in Quechua and Bolivian Aymara is in the ranking of LARDIST(1v2)-[long VOT] and IDENT. The rankings are compared in (56).

(56)   Quechua: LD(1v2)-[loud burst], **LD(1v2)-[long VOT] >> IDENT**
        Bolivian Aymara: LD(1v2)-[loud burst] >> **IDENT >> LD(1v2)-[long VOT]**

In Quechua, the general restriction on all combinations of laryngeal features in a single root results from the combined effects of LARDIST(1v2)-[loud burst] and LARDIST(1v2)-[long VOT] outranking IDENT. In Bolivian Aymara, LARDIST(1v2)-[long VOT] ranks below IDENT, and thus only LARDIST(1v2)-[loud burst] has an effect on the output and only pairs of ejectives are disallowed.

The differences in the positional restrictions seen in the two languages follow from the difference in the ranking of LARDIST(1v2)-[long VOT]. Both languages show the same restriction on the ordering of ejectives and aspirates with plain stops, showing that LARDIST(pos)-[long VOT] outranks IDENT in both languages. It can also be assumed that LARDIST(pos)-[loud burst] is high-ranked in both languages, but its effects can only be seen in Bolivian Aymara. Bolivian Aymara allows pairs of ejectives and aspirates, and thus ordering restrictions on these segments can be seen. The high-ranking of LARDIST(1v2)-[long VOT] in Quechua results in no roots with both ejectives and aspirates, thus obscuring any effect of LARDIST(pos)-[loud burst].

The general ranking of LARDIST constraints on [loud burst] over LARDIST constraints on [long VOT] is supported by the data in Bolivian Aymara, and assumed for both languages. Similarly, while the ranking of INITIAL-[loud burst] over INITIAL-[long VOT] is only evidenced in Bolivian Aymara, the same ranking can be assumed in Quechua. Finally, while articulatory markedness constraints only have an effect in Quechua, it is assumed that their position in the

hierarchy is the same in Bolivian Aymara. The full constraint hierarchies for the two languages are given in (57).

(57)   a.   <u>Quechua – constraint ranking</u>

LARDIST(1v2)-[loud burst]   LARDIST(pos)-[loud burst]

↓   ↓

LARDIST(1v2)-[long VOT]   LARDIST(pos)-[long VOT]

IDENT

INITIAL-[loud burst]   *ejective, *aspirate

↓   ↓

INITIAL-[long VOT]   LARDIST(1v0)-[long VOT]
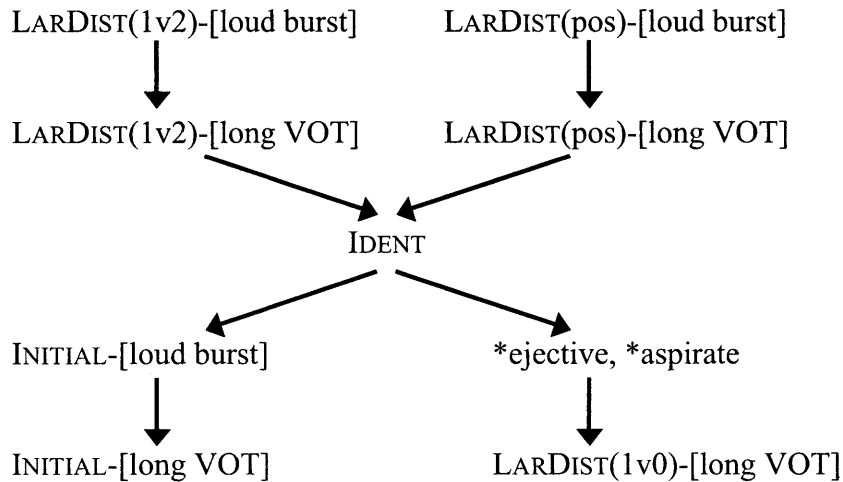
b.   <u>Bolivian Aymara – constraint ranking</u>

LARDIST(1v2)-[loud burst]

↓

LARDIST(pos)-[loud burst]

↓

LARDIST(pos)-[long VOT]

↓

IDENT

INITIAL-[loud burst]   *ejective, *aspirate

↓   ↓

INITIAL-[long VOT]   LARDIST(1v2)-[long VOT]

↓

LARDIST(1v0)-[long VOT]
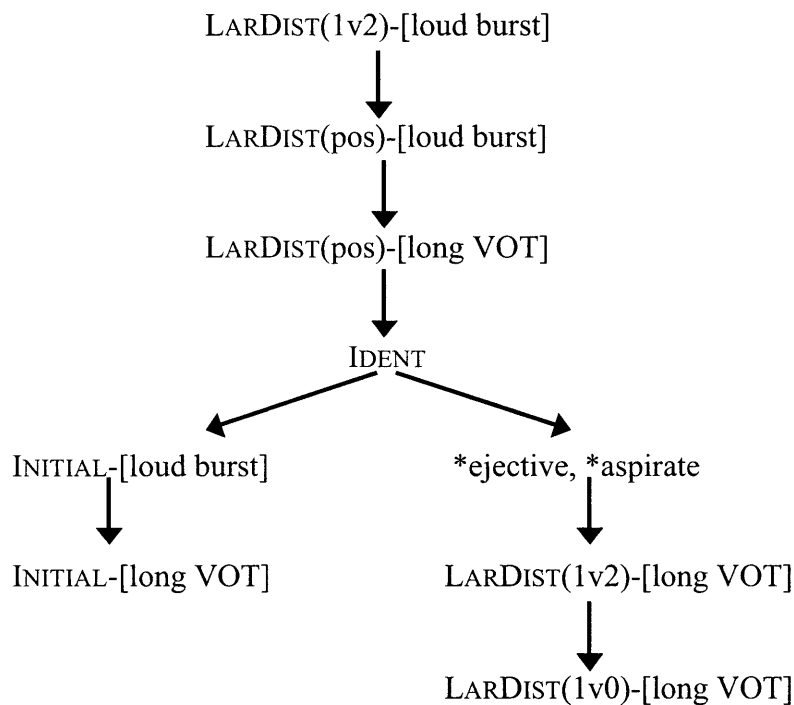
The systematic ranking of constraints referring to [loud burst] over constraints referring to [long VOT] is not entirely surprising. The feature [loud burst] picks out a sub-set of the segments referred to by [long VOT], and is thus more specific. There is thus a parallel in the feature system, where [loud burst] implies [long VOT], and in the cooccurrence restrictions, where a restriction on [long VOT] implies a restriction on [loud burst].

Chapter 7   Laryngeal assimilation

This section looks at languages with the strictest requirements on the distinctness of contrasting roots. In languages with laryngeal assimilation, only the strongest 2 vs. 0 contrast in laryneally marked segments is allowed. The pattern is shown schematically in (1).

(1) Laryngeal assimilation: ✓ K'-T'   *K'-T   *K-T'   ✓ K-T

In a language with assimilation, the 1 vs. 2 and positional contrasts are both neutralized. The outcome of neutralization favors neutralizing the 1 vs. 0 contrast as well, showing that LARDIST(1v0)-[F] outranks articulatory markedness constraints in this type of language.

The case studies of assimilation in this chapter show variation in the domain of assimilation. In no language is assimilation required between all consonants; that is, all languages with assimilation allow words with a single laryngeally marked stop. The restriction is on the cooccurrence of a laryngeally marked stop with another stop. In Kalabari Ijo and Amharic, assimilation only holds between the most similar pairs of stops; implosives and voiced stops assimilate, and ejectives and voiceless stops assimilate. In Chaha, however, ejectives assimilate with both voiced and voiceless stops. The two types of attested patterns, and the unattested pattern of complete assimilation, are shown schematically in (2).

(2) Laryngeal assimilation 1:   ✓ K'-T'   *K'-T   ✓ K'-D   ✓ K'-N
    Laryngeal assimilation 2:   ✓ K'-T'   *K'-T   *K'-D   ✓ K'-N

    Unattested assimilation: ✓ K'-T'   *K'-T   *K'-D   *K'-N

The typology of assimilation shows that the grammaticality of the 1 vs. 0 contrast in laryngeal features is sensitive to the similarity of the consonants in a root. Assimilation may be required in roots with the most similar stops, or all stops, but never in all roots. This chapter analyzes three case studies of assimilation, and discusses the formal properties of LARDIST(1v0)-[F].

7.1   Schematic analysis of assimilation

Assimilation in laryngeal features arises when LARDIST(1v2)-[F] and LARDIST(pos)-[F] outrank faithfulness, and LARDIST(1v0)-[F] outranks articulatory markedness. Given this ranking schema, the 1 vs. 2 and positional contrasts in laryngeal features will be neutralized, and the outcome of neutralization will be determined in favor of further neutralizing the 1 vs. 0 contrast, resulting in assimilation. The basic analysis is shown in (3) for roots minimally contrasting [loud burst] ejectives and plain stops.

163

(3) Laryngeal assimilation

{/k'ap'i, k'api, kap'i, kapi/}	LD(1v2) [loud burst]	LD(pos) [loud burst]	IDENT	LD(1v0) [loud burst]	*[cg]
a. {[k'ap'i, k'api, kap'i, kapi]}	**!	*		****	****
b. {[k'api, kap'i, kapi]}		*!	*	**	**
c. {[k'api, kapi]}			**	*!	*
d. {[k'api, kap'i]}		*!	**		**
e. → {[k'ap'i, kapi]}			**		**

In (3), the fully faithful candidate a violates both high-ranked markedness constraints. Candidate b satisfied LARDIST(1v2)-[loud burst] by eliminating the form with two ejectives, but still maintains a positional contrast in ejection. The candidates in (3c-e) all eliminate two forms, incurring the same violations of faithfulness. The two forms in candidate d contrast for the position of ejection, and consequently this candidate is ruled out by LARDIST(pos)-[loud burst]. The choice between candidates d and e is passed down to lower ranked constraints. LARDIST(1v0)-[loud burst] outranks *[cg], a ranking that renders the stronger contrast in (3e) optimal over the few ejectives in (3c).

The tableau in (3) shows that a positional contrast in laryngeal features is disallowed in languages with assimilation, eliminating candidates like (3c) which satisfy LARDIST(1v0). Assimilatory languages can be seen as enforcing the most general condition on contrast strength, disallowing all but the strongest contrast. Some dissimilatory languages neutralize only the weakest 1 vs. 2 contrast in laryngeal features, while others additionally neutralize the positional contrast in laryngeal features. Assimilatory languages neutralize both the 1 vs. 2 and the positional contrast in laryngeal features, and additionally disallow the 1 vs. 0 contrast. The fixed ranking of LARDIST constraints is appealing because it accounts for two relationships in the typology of laryngeal restriction. First, ordering restrictions on laryngeal features tend to imply dissimilation; there are no known languages that have *only* an ordering restriction (✓ K'-P' ✓ K'-P *K-P' ✓ K-P), though [long VOT] in Bolivian Aymara is subject to an ordering restriction but not dissimilation. Second, assimilation implies a positional restriction as well as a restriction on the 1 vs. 2 contrast, as seen in (3).

The ranking of LARDIST(1v0)-[loud burst] and IDENT is not fixed. In languages with assimilation, 1 vs. 0 contrasts in the restricted laryngeal feature are generally allowed; they are neutralized only in roots with another minimally contrastive segment. Considering contrasts in [loud burst], LARDIST(1v0)-[loud burst] penalizes contrasts in [loud burst] in roots with another plain stop, which minimally contrasts for [loud burst], but not in roots with anoteher voiced stop or non-stop. The tableau in (4) shows that LARDIST(1v0)-[loud burst] has no effect on the output when roots with only one stop are considered.

(4) No assimilation in roots with one stop

{/t'ap'i, t'ami, nap'i, tami, napi, nami/}	LD(1v2) [loud burst]	LD(pos) [loud burst]	IDENT	LD(1v0) [loud burst]	*[cg]
a. → {[t'ap'i, t'ami, nap'i, tami, napi, nami]}					****
b. {[t'ap'i, tami, napi, nami]}			**!		**

164

The simple tableau in (4) shows that pairs like {[t'ami, tami]} and {[nap'i, napi]} do not violate LARDIST(1v0)-[loud burst], and thus surface faithfully. Neutralizing the 1 vs. 0 contrast between all roots, as in (4b), results in excessive violations of faithfulness. The formulation of LARDIST(1v0) ensures that the preference for a 2 vs. 0 contrast in laryngeal features will only be seen in roots with two stops that minimally contrast for the restricted feature. Since LARDIST(1v2) and LARDIST(pos) can, by definition, only be violated in roots with two segments that minimally contrast for the restricted feature, the ranking of LARDIST(1v0) and IDENT is moot. LARDIST(1v0) decides on the outcome of neutralization, but is never in a position to force neutralization itself.

The analysis of assimilation presented here shows that the same set of conditions on contrast strength account for both dissimilation and assimilation in laryngeal features. In assimilatory languages, both a minimal contrast in 1 vs. 2 instances of a given auditory feature and a minimal contrast in the position of a feature are disallowed. These ungrammatical contrasts are neutralized to an assimilatory pair like {[k'ap'i, kapi]} instead of a dissimilatory pair {[k'api, kapi]} because of the relative ranking of LARDIST(1v0)-[F] over articulatory markedness. The added articulatory effort involved in producing multiple implosives is overridden by the preference for the strongest possible contrast.

7.2   Case study 1 – implosives in Kalabari Ijo

Kalabari Ijo exhibits an assimilatory restriction on modally voiced implosives and the minimally contrastive modally voiced plosives. The consonantal inventory is given in (5), showing the contrast between voiced, voiceless and implosive stops (Jenewari 1989).

(5) Kalabari Ijo consonant inventory

	labial	alveolar	velar	labio-velar	glottal
voiceless	p	t	k	kp	
voiced	b	d	g	gb	
implosive	ɓ	ɗ			
fricative	f v	s			h
nasal	m	n	ŋ	ŋm	
liquid	w	r l j			

The labial and alveolar implosives and voiced stops do not cooccur in a Kalabari Ijo root (Jenewari 1989; Hansson 2001). Pairs of implosives and pairs of voiced plosives are well attested, but implosive-plosive pairs are absent from the language. Jenewari describes the restriction as follows (page 109):

> Kalaḅarị has a form of consonant harmony, which may be termed 'implosive harmony'.
> Within a morpheme, either the implosive set /ɓ, ɗ/ or the plosive set /b, d/ may occur,
> but implosives and plosives never cooccur...

He provides the supporting examples in (6a,b). Forms with labial or alveolar plosives cooccurring with implosives, as in (6c), are reportedly absent.

165

(6)   Kalabari Ijo assimilation
       a. ɓiɓɪ   'mouth'   ✓ ɓ-ɗ
           ɗáɓá   'lake'
           ɓaɓa   'calabash'
           ɗóɓárí 'stone'

       b. ébébé   'talk while sleeping'   ✓ B-D
           badara 'be(come) very wide'
           bábā   'cut'
           bébé   'whole'

       c. *ɓɪdɪ   *ɗábá   *ɓ-D

Jenewari does not give examples of implosives cooccuring with voiceless stops, but there is one example of an implosive cooccurring with a non-stop (ɗáwó 'kola nut'). Jenewari also does not give any examples of implosives cooccuring with the voiced plosive velar and labio-velar [g, gb]. Despite the lack of examples to substantiate the domain of the restriction, I interpret Jenewari's statement in the most restrictive sense and assume that implosive assimilation holds only between voiced labial and alveolar stops. This is the same assumption made in previous work on the Kalabari Ijo restriction (Hansson 2001; Mackenzie 2009). The only ungrammatical combination of consonants in Kalabari Ijo, then, is the combination of an implosive and labial or alveolar voiced plosive, implosives may cooccur with labial and labio-velar voiced plosives (✓ ɓ-g, ✓ ɓ-gb), all voiceless plosives (✓ ɓ-T), and all non-stops (✓ ɓ-N). A similar effect will be seen in Amharic in §7.3, where ejectives are restricted from cooccurring only with the most similar voiceless stops, but may cooccur freely with voiced stops.

Implosives in Kalabari Ijo are modally voiced and are truly implosive. Voicing amplitude increases throughout the duration of the closure, and at release of the closure air rushes into the mouth (Lindau 1984). These implosives are thus like the labial and alveolar implosives in Tz'utujil, and not like the creaky voiced implosives in Hausa. While I was not able to find examples of spectrograms from Kalabari Ijo, Ladefoged and Maddieson (1996) show the contrast between an implosive and plosive voiced stop in Degema, a language that is reported by Lindau (1984) to have similar implosives to Kalabari Ijo. The Degema contrast is shown in (7), taken from Ladefoged and Maddieson (1996:84).

166

(7)　　Implosive-plosive contrast in Degema
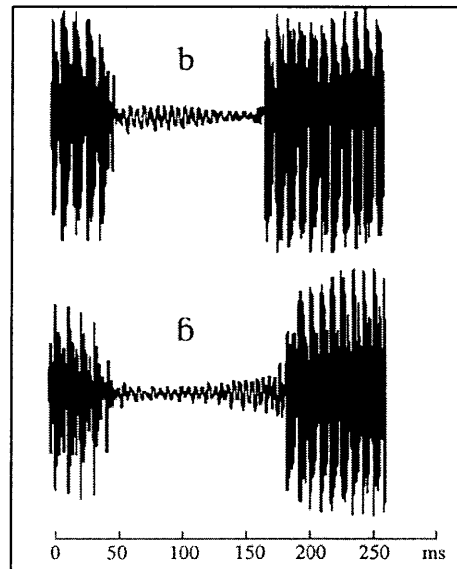
The image in (7) shows that plosives and implosives differ in the amplitude of voicing during closure. In a voiced plosive, voicing amplitude decreases throughout the closure period, while in an implosive stop voicing amplitude increases. I hypothesize that this distinction in voicing amplitude is the auditory property that is subject to a long-distance perceptual interaction, as is found for [long VOT] (see experiment 3 in Chapter 4), and thus a long-distance phonological restriction. It is left to future work to verify if this hypothesis is correct, or if it is some other auditory difference between plosive and implosive stops that is relevant to long-distance assimilation. The three LARDIST constraints referring to [v-amp] are defined in (8).

(8)　LARDIST(1v2)-[v-amp]　　No minimal contrast in [v-amp] between roots with another [v-amp] segment.

Given two contrasting roots R_i, R_2 such that R_1 and R_2 each contain two segments that minimally contrast for [v-amp], assign one violation mark if R_1 and R_2 each contain some [v-amp] segment and are identical except for a minimal contrast in [v-amp].

LARDIST(pos)-[v-amp]　　No minimal contrast between roots for the position of [v-amp].

Given two contrasting roots R_1, R_2, assign one violation mark if R_1 and R_2 are identical except for a minimal contrast in [v-amp].

LARDIST(1v0)-[v-amp]   No minimal contrast in [v-amp] between roots with another segment that minimally contrasts for [v-amp].
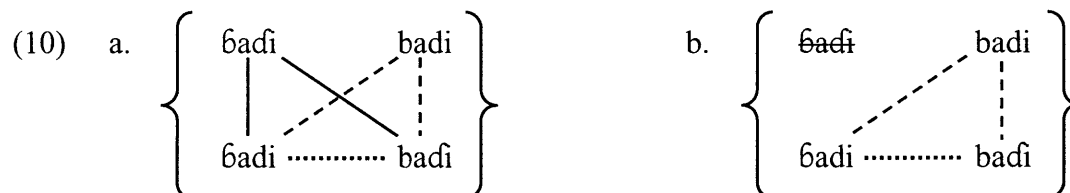
Given two contrasting roots R_1, R_2 such that R_1 and R_2 each contain two segments that minimally contrast for [v-amp], assign one violation mark if R_1 and R_2 are identical except for a minimal contrast in the position of [v-amp].

For assimilation to obtain, LARDIST(1v2) and LARDIST(pos) must outrank IDENT, and LARDIST(1v0) must outrank *[implosive]. The tableau in (9) shows the mapping of roots with voiced plosives and implosives.

(9) Kalabari Ijo – assimilation between voiced plosives and implosives

{/ɓaɗi, ɓadi, baɗi, badi/}	LD(1v2) [v-amp]	LD(pos) [v-amp]	IDENT	LD(1v0) [v-amp]	*[imp]
a. {[ɓaɗi, ɓadi, baɗi, badi]}	** !	*		****	***
b. {[ɓadi, baɗi, badi]}		* !	*	**	**
c. {[ɓadi, baɗi]}		* !	**		**
d. {[ɓadi, badi]}			**	* !	*
e. → {[ɓaɗi, badi]}			**		**

Neutralization to three contrasting forms, as in (9b), violates both other high-ranking LARDIST constraints, due to a contrast in the position of the [v-amp] segment, and the contrast between one and zero [v-amp] segments. Neutralization to two contrasting forms results in one of three contrasts. In (9c), the form with zero implosives is neutralized and the remaining forms contrast for the position of implosive. While deleting the form with no implosives satisfies LARDIST(1v0), this candidate still incurs a fatal violation of LARDIST(pos). The candidate in (9d) takes the opposite strategy, eliminating the positional contrast in implosion and satisfying LARDIST(pos), but allowing a contrast between one and zero implosives, thereby violating LARDIST(1v0). Candidate e perfectly satisfies all three high-ranked LARDIST constraints by allowing only the maximally perceptible contrast between two implosives and two plosives. The ranking of LARDIST(1v0) over *[implosive] favors assimilation in (9e) to dissimilation in (9d). The candidates and the contrasts they involve are represented schematically in (10). Violations of LARDIST(1v2) are represented with solid lines, violations of LARDIST(pos) with dotted lines, and violations of LARDIST(1v0) with dashed lines.

(10) a.   { ɓaɗi ⎯ badi ; ɓadi ⎯ badi }   b.   { ɓaɗi̶ ⎯ badi ; ɓadi ⎯ badi }

168

c.
$$\left\{\begin{array}{ll} \text{~~~~} \sout{\text{ɓadɪ}} & \sout{\text{badi}} \\[2ex] \text{ɓadi} \cdots\cdots \text{badɪ} \end{array}\right\}$$

d.
$$\left\{\begin{array}{ll} \sout{\text{ɓadɪ}} & \text{badi} \\[2ex] \text{ɓadi} & \sout{\text{badɪ}} \end{array}\right\}$$

e.
$$\left\{\begin{array}{ll} \text{ɓadɪ} & \text{badi} \\[2ex] \sout{\text{ɓadi}} & \sout{\text{badɪ}} \end{array}\right\}$$
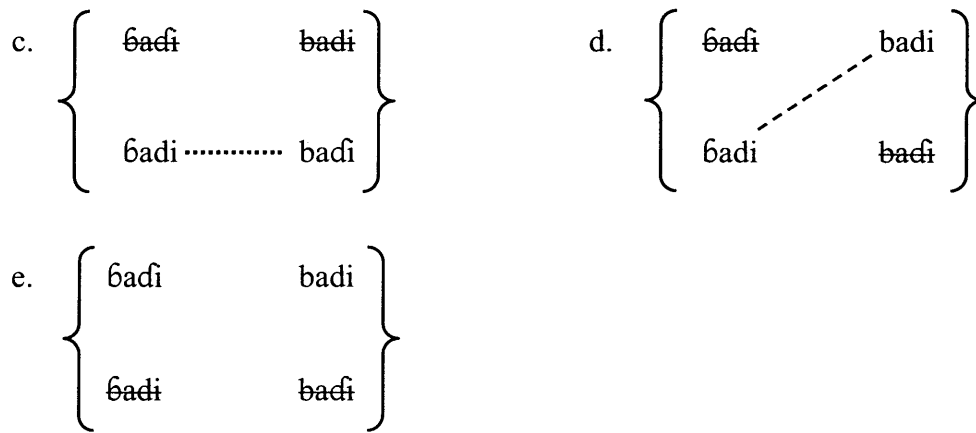
Assimilation in Kalabari Ijo only applies between labial and alveolar stops, which show a contrast between plosives and implosives. While forms with plosive-implosive pairs like [ɓadi] are unattested, forms like [ɓagi] are grammatical. This asymmetry falls out from the formulation of LARDIST(1v0) to penalize 1 vs. 0 contrasts only in roots with two stops that minimally contrast for the restricted feature. The fact that velar and labiovelar stops do not minimally contrast for [v-amp] is determined in the Inventory, and thus the distinction between the Inventory and ESC components of the grammar is particularly useful here. As discussed in Chapter 2, the Inventory component selects a set of contrasting sounds in a language. Roots are then constructed based on all possible combinations of these sounds, and these roots are evaluated by contextual systemic markedness constraints like LARDIST constraints.

In Kalabari Ijo, the Inventory component selects a contrast between voiced plosives and implosives at the labial and alveolar places of articulation, but not the velar or labiovelar places. Assume that the contrast between an implosive and an implosive is more perceptable further front in the vocal tract, as is consistent with the implicational universal that languages with velar implosives also have alveolar and labial implosives (Greenberg 1970). In Kalabari, the ranking of MINDIST constraints requires contrasting segments to be as perceptually distinct as labial and alveolar plosive-implosive pairs. The plosive-implosive contrast at the velar and labiovelar places is smaller than this, and is thus penalized by a higher ranking MINDIST constraint, written schematically as MINDIST(g-ɠ), as shown in (11). Articulatory markedness favors a plain voiced plosive in the absence of a contrast.

(11)   Inventory – Kalabari Ijo

	MINDIST (g-ɠ)	MAXCONT	MINDIST (d-ɗ)	MINDIST (b-ɓ)	*[imp]
a. {[ɓ, b, ɗ, d, ɠ, g, ɠb, gb]}	*!	✓✓✓✓ ✓✓✓	*	*	****
b. → {[ɓ, b, ɗ, d, g, gb]}		✓✓✓✓ ✓✓	*	*	**
c. {[ɓ, b, ɗ, d, ɠ, ɠb]}		✓✓✓✓ ✓✓	*	*	****!
d. {[b, d, g, gb]}		✓✓✓✓!			

169

Given that the implosives [] are not part of the inventory of Kalabari Ijo, the voiced plosives [] do not minimally contrast for [v-amp]. Contrasts like {[ɓagi, bagi]} do not violate LARDIST(1v0)-[v-amp]. While this pair of roots contrasts minimally for [v-amp] ([ɓ] vs. [b]), LARDIST(1v0)-[v-amp] only penalizes minimal contrasts in [v-amp] in the context of another segment that minimally contrasts for [v-amp], which [g] does not. The tableau in (12) shows that implosives may contrast in roots with other non-contrastive voiced stops.

(12)   Kalabari Ijo – no assimilation with velars (or labiovelars)

{/ɓagi, bagi/}	LD(1v2)-[v-amp]	LD(pos)-[v-amp]	IDENT	LD(1v0)-[v-amp]	*[implosive]
a. → {[ɓagi, bagi]}					*
b. {[ɓagi]}			*!		*
c. {[bagi]}			*!		

The full set of possible combinations of voiced labials and velars does not violate either of the LARDIST constraints that outrank IDENT, and thus this set surfaces as is.

The formulation of LARDIST(1v0)-[F] also accounts for why assimilation only targets pairs of roots with two voiced stops, as opposed to all roots, e.g. *{ɓadi, badi}, ✓ {ɓati, bati}, ✓ {ɓani, bani}. The tableau in (13) considers all combinations of voiced, voiceless and implosive stops, showing that voiceless stops freely cooccur with implosives.

(13) Kalabari Ijo – no assimilation between implosives and voiceless plosives

{/ɓaɗi, badi, pati, ɓadi, baɗi, ɓati, paɗi, bati, padi/}	LD(1v2) [v-amp]	LD(pos) [v-amp]	IDENT	LD(1v0) [v-amp]	*[imp]
a. {[ɓaɗi, badi, pati, ɓadi, baɗi, ɓati, paɗi, bati, padi]}	**	*		****	*(6)
b. {[badi, pati, ɓadi, baɗi, ɓati, paɗi, bati, padi]}		*!	*	**	****
c. {[badi, pati, ɓadi, ɓati, paɗi, bati, padi]}			**	*!	
d. → {[ɓaɗi, badi, pati, ɓati, paɗi, bati, padi]}			**		****
e. {[ɓaɗi, badi, pati, bati, padi]}			****!		**

In (13), LARDIST(1v0) chooses between candidates c and d, which each neutralize two forms. In candidate c, [ɓaɗi] and [baɗi] are merged, while in candidate d [ɓaɗi] and [baɗi] are merged. Candidate d wins on LARDIST(1v0) because the contrast {[ɓadi, badi]} has been neutralized, but the contrasts {[ɓati, bati]} and {[paɗi, padi]} have been maintained. In candidate e, there are no 1 vs. 0 contrasts in [v-amp], incurring excessive violations of faithfulness.

170

7.3 Case study 2 – ejectives in Amharic

The laryngeal restriction in Amharic is extremely similar to that in Kalabari Ijo. In Amharic, assimilation targets ejectives, which contrast with voiceless unaspirated and voiced stops. The consonantal inventory is given in (14), adapted from Rose and King (2007).

(14) Amharic consonant inventory

	labial	alveolar	palatoalveolar	velar	labialized velar	glottal
voiced	b	d	dʒ	g	g^w	
voiceless		t	tʃ	k	k^w	
ejective		t'	tʃʼ	k'	$k^{wʼ}$	
fricative	f	s s' z	ʃ ʒ			h
nasal	m	n	ɲ			
liquid	w	l r	j			

In order to document cooccurrence restrictions in Amharic, Rose and King (2007) computed the O/E (Observed/Expected) ratio for pairs of the 14 most common and evenly distributed consonants in their databases of verbal roots. Alveolar and velar stops were analyzed for any laryngeal cooccurrence restriction; the other series of stops were excluded either because they were too infrequent in the database or their distribution was skewed towards a particular position or environment.

In Amharic, pairs of adjacent (C_1C_2 or C_2C_3 in a tri-consonantal root) voiceless stops must agree in laryngeal features. Voiceless unaspirated and ejective stops do not cooccur. Ejectives may cooccur with voiced stops, and voiced and voiceless stops also freely cooccur. Non-adjacent pairs do not show any restrictions. The analysis of Amharic presented here does not address the locality conditions on cooccurrence restrictions in this language. The O/E for adjacent and non-adjacent alveolar and velar consonant pairs are given in (15), glossing over order and position.

(15)

	K'-T	K'-D	K-D
adjacent	.29	1.02	1.2
non-adjacent	.98	1.15	1.11
overall	.52	1.06	1.17

The examples in (16) show that roots in Amharic may have two ejective stops (16a), two voiceless stops (16b), or two voiced stops (16c). Ejective and voiceless stops both freely cooccur with voiced stops and non-stops (16d). Examples are from Leslau (1976).
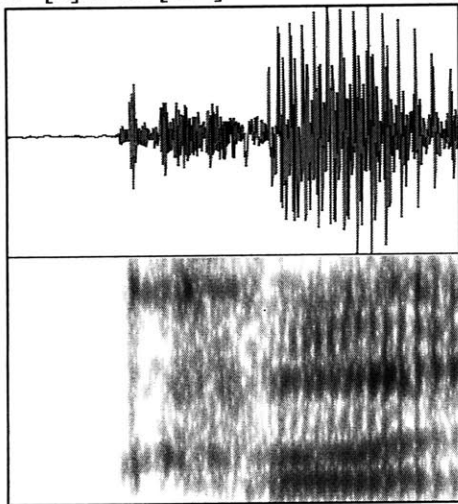
(16) Amharic assimilation

a. t'ik':a   'to beat, knock'   ✓ K'-T'
   t'ək'ʃa   'wink, hint'

b. tɨk:a   'to replace'   ✓ K-T
   tɨk:izɨ   'to be sad'

c. dɨg:imɨ   'to repeat'   ✓ G-D
   dɨg:isɨ   'to give a feast'

d.	**t'ɨg:a**	'to approach'	✓ K'-D
	tɨg:a	'be diligent'	

e.	**t'ɨl:a**	'to hate'	✓ K-N
	tɨl:a	'be rotten'	

f.	***t'ɨk:a**		*K'-T
	*tɨk':a		

The restriction on ejectives in Amharic mirrors the restriction on implosives in Kalabari Ijo. In Kalabari Ijo, implosives are restricted from cooccurring with the most similar voiced stops, but freely cooccur with voiceless stops and non-stops. In Amharic, ejectives are restricted from cooccurring with the most similar voiceless stops, but may freely cooccur with voiced stops and non-stops.

The available evidence points towards ejectives in Amharic being short lag, creaky voiced ejectives, as in Hausa. Tigrinya, a closely related language, is reported by Kingston (1985) to have creaky voiced ejectives. Examination of the recordings of ejectives in Amharic from the UCLA language database reveals a substantial period of creaky phonation following the release of an ejective, as well as increased burst amplitude, as can be seen in the examples in (17).

(17) a. [k] from [kus] 'chicken manure'

172

b. [k'] from [k'um] 'get up! stop!'
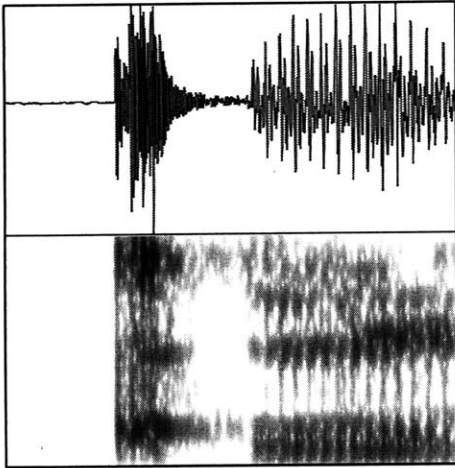
I will assume that the restricted feature in Amharic [creak]. The three LARDIST constraints relevant to the analysis of assimilation in Amharic are defined in (18).

(18)   LARDIST(1v2)-[creak]   No minimal contrast in [creak] between roots with another [creak] segment.

                                     Given two contrasting roots R_1, R_2 such that R_1 and R_2 each contain two segments that minimally contrast for [creak], assign one violation mark if R_1 and R_2 each contain some [creak] segment and are identical except for a minimal contrast in [creak].

          LARDIST(pos)-[creak]   No minimal contrast between roots for the position of [creak].

                                       Given two contrasting roots R_1, R_2, assign one violation mark if R_1 and R_2 are identical except for a minimal contrast in the position of [creak].

          LARDIST(1v0)-[creak]   No minimal contrast in [creak] between roots with two segments that minimally contrast for [creak].

                                       Given two contrasting roots R_1, R_2 such that R_1 and R_2 each contain two segments that minimally contrast for [creak], assign one violation mark if R_1 and R_2 are identical except for a minimal contrast in [creak].

In Amharic, a minimal contrast in [creak] may be accompanied by a contrast in [loud burst], but no other feature. Contrasts between an ejective and a voiced stop or non-stop are non-minimal because they require a difference in [creak] and [loud burst] as well as other features. The

173

analysis of Amharic is shown in the tableau in (19). The ranking schema is the same as in Kalabari Ijo, and results in assimilation between ejectives and voiceless stops, but not between ejectives and voiced stops or between voiced and voiceless stops.

(19)   Amharic – assimilation between ejectives and voiceless stops

{/k'at'i, kati, gadi, k'ati, kat'i, k'adi, gat'i, gati, kadi/}	LD(1v2) [creak]	LD(pos) [creak]	IDENT	LD(1v0) [creak]	*[cg]
a. {[k'at'i, kati, gadi, k'ati, kat'i, k'adi, gat'i, gati, kadi]}	**	*		****	*(6)
b. {[kati, gadi, k'ati, kat'i, k'adi, gat'i, gati, kadi]}		* !	*	**	****
c. {[kati, gadi, k'ati, k'adi, gat'i, gati, kadi]}			**	* !	
d. → {[k'at'i kati, gadi, k'adi, gat'i, gati, kadi]}			**		****
e. {[k'at'i kati, gadi, gati, kadi]}			**** !		**

In (19), LARDIST(1v2) is violated by the contrasting pairs {[k'at'i, k'ati]} and {[k'at'i, kat'i]} in candidate a, and LARDIST(pos) is violated by the pair {[k'ati, kat'i]} in candidates a and b. The pairs {[k'at'i, k'adi]} and {[k'at'i, gat'i]} do not violate LARDIST(1v2) because they differ in voicing as well as in [creak]. Similarly, the pair {[k'adi, gat'i]} does not violate LARDIST(pos) because these two roots contrast both the position of [creak] and the position of voicing. The ranking of LARDIST(1v0) over *ejective selects candidate d, with assimilation between ejectives and voiceless stops, over candidate c, with dissimilation. While candidate e also perfectly satisfies LARDIST(1v0), by disallowing all contrasts in a single ejective, it incurs excessive violations of faithfulness. As in Kalabari Ijo, in Amharic, LARDIST(1v0) only favors neutralization of the 1 vs. 0 contrast in roots with two segments that minimally contrast for the restricted feature.

7.4   Case study 3 – ejectives, aspirates and slack voiced stops in Zulu

Zulu exhibits an assimilatory cooccurrence restriction on combinations of stops from three laryngeal categories: aspirated, slack voiced and ejective (Khumalo 1987; Hansson 2001). The consonantal inventory of Zulu is given in (20), taken from Doke et al. (1990). The prenasalized consonants and clicks are not included.

(20) Zulu consonant inventory

	labial	alveolar	postalveolar/ palatal	velar	glottal
implosive	ɓ				
voiced	b	d	dʒ	g	
aspirate	pʰ	tʰ		kʰ	
ejective	p'	t'	tʃ	k'	
plain				k	
fricative	f v	s z ɬ lʒ	ʃ		h ɦ
nasal	m	n	ɲ	ŋ	
liquid	w	l	j		

The root level cooccurrence restrction in Zulu disallows combinations of voiced, aspirate and ejective stops. Zulu roots may have two voiced stops [b, d, g], two aspirates [pʰ, tʰ, kʰ] or two ejectives [p', t', k'], but combinations of these three series of stops are rare.

(21) Zulu laryngeal assimilation
   a. k'ap'   'spit'   b. *K'-Pʰ
       kʰapʰ   'push violently'   *K'-B
       gub   'celebrate'   *Kʰ-B

Voiced, aspirated and ejective stops in Zulu may generally occur in either initial or final position of a CVC root, as shown by the examples in (22) from the Doke et al. dictionary (1990).

(22)   a. bal   'yard'   lub   'desire'
       b. pʰal   'roof'   ɬupʰ   'annoy'
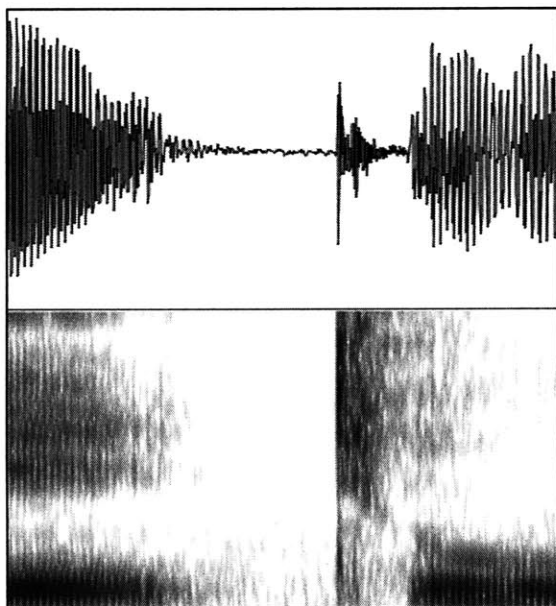   c. p'atʃ 'to work into a conical shape'   tʃap' 'to spray out'

Velar aspirates generally do not occur in C₂ outside of assimilatory environments, i.e. outside of roots like CʰVkʰ (Khumalo 1987; Hansson 2001). Similar laryngeal restrictions are also found in the closely related languages Ndebele, Xhosa and Swati (comprising the Nguni sub-group of the Bantu family).

Laryngeal assimilation in Zulu restricts the cooccurrence of stops that minimally contrast for the auditory features that define voiced, aspirate and ejective stops. Segments outside of this symmetrical system do not participate in the cooccurrence restriction. The cooccurrence restriction in Zulu is fully symmetrical, in that all three laryngeal categories show the same restriction. In Amharic, Kalabari Ijo and Chaha, only a single laryngeal feature is restricted. In Zulu, the data show grammatical restrictions on more than one laryngeal category. To see what auditory features and contrasts are restricted in Zulu, we must look at the phonetics of the laryngeal contrasts in this language.

The studies of Giannini et al. (1988) found an increased burst amplitude and moderate VOT (about 50 ms) in ejectives. Doke (1969) claims that in normal speech ejection is barely audible, and only becomes pronounced in very careful speech. The production of ejectives and consequently the auditory cues to ejection may be quite variable. Aspirates in Zulu have a much longer VOT than ejectives, but are otherwise unremarkable. The series of stops transcribed as voiced is the most interesting. Giannini et al. and Traill (1987) found no closure voicing in this

series, but did find a lowered F0 in the following vowel. Roux describes the voiced series in Xhosa, a language that shows a similar restriction to Zulu, as slack-voiced, produced with lowering of the larynx and slacking of the vocal folds. I adopt this terminology for Zulu as well. Spectrograms of a each of the three series of stops are given in (23), from recordings I took of a middle aged female Zulu speaker.

(23) a. [t'] from [ukup'et'ula]   b. [tʰ] from [ukutʰatʰa]
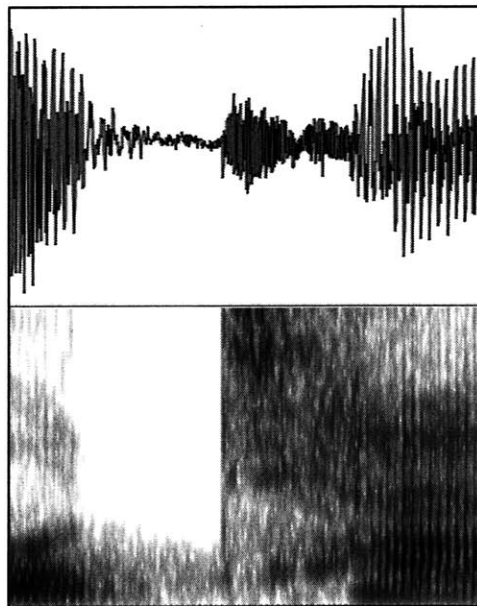
  c. [d] from [ukudak'a]

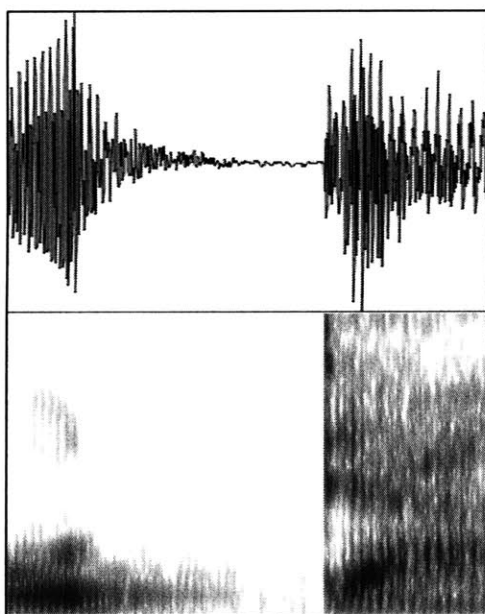The phonetics of Zulu stops, as represented in the spectrograms in (23), support the following auditory specifications in (24). I include the feature [slack voice] to stand in for whatever auditory properties define the phonation quality associated with this series of stops in Zulu.

(24)   K'   [loud burst]
         K^h [long VOT]   [aspiration]
         G   [slack voice]   [low f0]

I do not specify ejectives as [long VOT], because the average VOT length in an ejective is so much shorter than in an aspirate. Moreover, the realization of ejectives is variable and VOT may offer be even shorter than what is depicted in (23). The relevant factor is that VOT in Zulu defines aspirates as distinct from both ejectives and slack voiced stops, rather than grouping aspirates and ejectives together as it does in Quechua and Bolivian Aymara.

Laryngeal assimilation in Zulu results from LARDIST constraints referring to [long VOT] and [slack voice], discussed below. The LARDIST(1v2) constraints are defined in (25).

(25) LARDIST(1v2)-[long VOT]   No minimal contrast in [long VOT] between roots with another [long VOT] segment.

                                    Given two contrasting roots R_1, R_2 such that R_1 and R_2 each contain two segments that minimally contrast for [long VOT], assign one violation mark if R_1 and R_2 each contain a [long VOT] segment and are identical except for a minimal difference in [long VOT].

      LARDIST(1v2)-[slack voice]   No minimal contrast in [slack voice] between roots with another [slack voice] segment.

                                    Given two contrasting roots R_1, R_2 such that R_1 and R_2 each contain two segments that minimally contrast for [slack voice], assign one violation mark if R_1 and R_2 each contain a [slack voice] segment and are identical except for a minimal difference in [slack voice].

The constraints in (25) penalize minimal 1 vs. 2 contrasts in [long VOT] and [slack voice]. Each of the three laryngeal categories minimally contrast with each of the other laryngeal categories, as there is no subset relation in the features that differ between categories. The differences in auditory features between the contrasting series are shown in (26).

(26)   contrast   difference
         K^h vs. K'   [loud burst]   [long VOT]   [aspiration]
         K' vs. G   [slack voice]   [loud burst]
         K^h vs. G   [slack voice]   [long VOT]   [aspiration]

177

A minimal contrast in [long VOT] is thus a contrast in [long VOT] accompanied by a contrast in either [aspiration] and [loud burst] or [aspiration] and [slack voice]. A minimal contrast in [slack voice] is a contrast in [slack voice] accompanied by a contrast in [loud burst] or [long VOT] and [aspiration]. Contrasting pairs that violate the two constraints in (26) are shown in (27).

(27)

		LARDIST(1v2)-	contrast
a.	{[gabi, gap'i]}	[slack voice]	1. [slack voice] in each 2. contrast in [slack voice], [loud burst]
	{[gabi, gapʰi]}	[slack voice]	1. [slack voice] in each 2. contrast in [slack voice], [long VOT], [aspiration]
b.	{[kʰapʰi, kʰap'i]}	[long VOT]	1. [long VOT] in each 2. contrast in [long VOT], [aspiration], [loud burst]
	{[kʰapʰi, kʰabi]}	[long VOT]	1. [long VOT] in each 2. contrast in [long VOT], [aspiration], [slack voice]
c.	{[k'ap'i, k'apʰi]}	✓	1. [long VOT] segment only in [k'apʰi]
	{[k'ap'i, k'abi]}	✓	1. [slack voice] segment only in [k'abi]

The examples in (27) show that slack voiced stops minimally contrast for [slack voice] both with aspirates and ejectives. There are no two sounds in Zulu that differ only in [slack voice]. A difference in [slack voice] is either accompanied by a difference in [long VOT] and [aspiration], as in the slack voice-aspirate contrast, or a difference in [loud burst], as in the slack voice-ejective contrast. LARDIST(pos) constraints on [slack voice] and [long VOT] are defined in (28).

(28) LARDIST(pos)-[long VOT]   No minimal contrast between roots for the position of [long VOT].

Given two contrasting roots R_1, R_2, assign one violation mark if R_1 and R_2 are identical except for a minimal contrast in the position of [long VOT].

LARDIST(pos)-[slack voice]   No minimal contrast between roots for the position of [slack voice].

Given two contrasting roots R_1, R_2, assign one violation mark if R_1 and R_2 are identical except for a minimal contrast in the position of [slack voice].

178

Violations of these two constraints are shown in (29). Since there is no truly minimal contrast in the position of either [slack voice] or [long VOT], pairs of roots that contrast the order of slack voicing and ejection (29a), slack voicing and aspiration (29b) or aspiration and ejection (29c) all violate one of the LARDIST(pos) constraints in (28).

(29)   LARDIST(pos)-   contrast

a.   {[gap'i, k'abi]}   [slack voice]   position of [slack voice] and [loud burst]

b.   {[gap^{h}i, k^{h}abi]}   [slack voice]   position of [slack voice], [aspiration], [long VOT]   [long VOT]

c.   {[k^{h}ap'i, k'ap^{h}i]}   [long VOT]   position of [long VOT], [aspiration], [loud burst]

With LARDIST(1v2) and LARDIST(pos) constraints on [long VOT] and [slack voice] outranking IDENT, the laryngeal assimilation between ejectives, aspirates and slack voiced stops in Zulu can be accounted for. The Zulu pattern of assimilation is thus slightly different from the examples seen so far, in that the relative ranking of constraints below IDENT does not affect the output. The analysis is shown in (30).

(30)   Zulu laryngeal assimilation

{/k'ap'i, gabi, k^{h}ap^{h}i, k'abi, k'ap^{h}i, k^{h}abi k^{h}ap'i, gap'i, gap^{h}i/}	LD(1v2) [sl voi]	LD(1v2) [long VOT]	LD(pos) [sl voi]	LD(pos) [long VOT]	IDENT
a. {[k'ap'i, gabi, k^{h}ap^{h}i, k'abi, k'ap^{h}i, k^{h}abi k^{h}ap'i, gap'i, gap^{h}i]}	**** !	**** !	**	**	
b. {[k'ap'i, k'abi, k'ap^{h}i, k^{h}abi k^{h}ap'i, gap'i, gap^{h}i]}			** !	**	**
c. → {[k'ap'i, gabi, k^{h}ap^{h}i]}					*(6)

The tableau in (30) is relatively simple. The fully faithful candidate in (30a) has multiple 1 vs. 2 and positional contrasts in both [slack voice] and [long VOT]. The 1 vs. 2 contrasts can be remedied either by eliminating the two forms with two slack voiced and two aspirate stops {gabi, k^{h}ap^{h}i}, as in candidate b, or by eliminating the six forms with a single slack voiced or aspirated stop {k'abi, k'ap^{h}i, k^{h}abi, k^{h}ap'i, gap'i, gap^{h}i}, as in candidate c. While eliminating only two forms is more faithful, merger of all six forms is necessary in order to avoid a positional contrast in either [slack voice] or [long VOT], and thus candidate c is preferred. The three candidates are represented visually in (31). Violations of LARDIST(1v2)-[long VOT] are bold, LARDIST(1v2)-[slack voice] solid, LARDIST(pos)-[long VOT] dashed and LARDIST(pos)-[slack voice] dotted.

(31) a.
$$\left\{ \begin{array}{ccc} \text{k'ap'i} & \text{gabi} & \text{k}^h\text{ap}^h\text{i} \\ & & \\ \text{k'abi} & \text{k'ap}^h\text{i} & \text{k}^h\text{abi} \\ & & \\ \text{k}^h\text{ap'i} & \text{gap'i} & \text{gap}^h\text{i} \end{array} \right\}$$

b.
$$\left\{ \begin{array}{ccc} \text{k'ap'i} & \sout{\text{gabi}} & \sout{\text{k}^h\text{ap}^h\text{i}} \\ & & \\ \text{k'abi} & \text{k'ap}^h\text{i} & \text{k}^h\text{abi} \\ & & \\ \text{k}^h\text{ap'i} & \text{gap'i} & \text{gap}^h\text{i} \end{array} \right\}$$

c.
$$\left\{ \begin{array}{ccc} \text{k'ap'i} & \text{gabi} & \text{k}^h\text{ap}^h\text{i} \\ & & \\ \sout{\text{k'abi}} & \sout{\text{k'ap}^h\text{i}} & \sout{\text{k}^h\text{abi}} \\ & & \\ \sout{\text{k}^h\text{ap'i}} & \sout{\text{gap'i}} & \sout{\text{gap}^h\text{i}} \end{array} \right\}$$
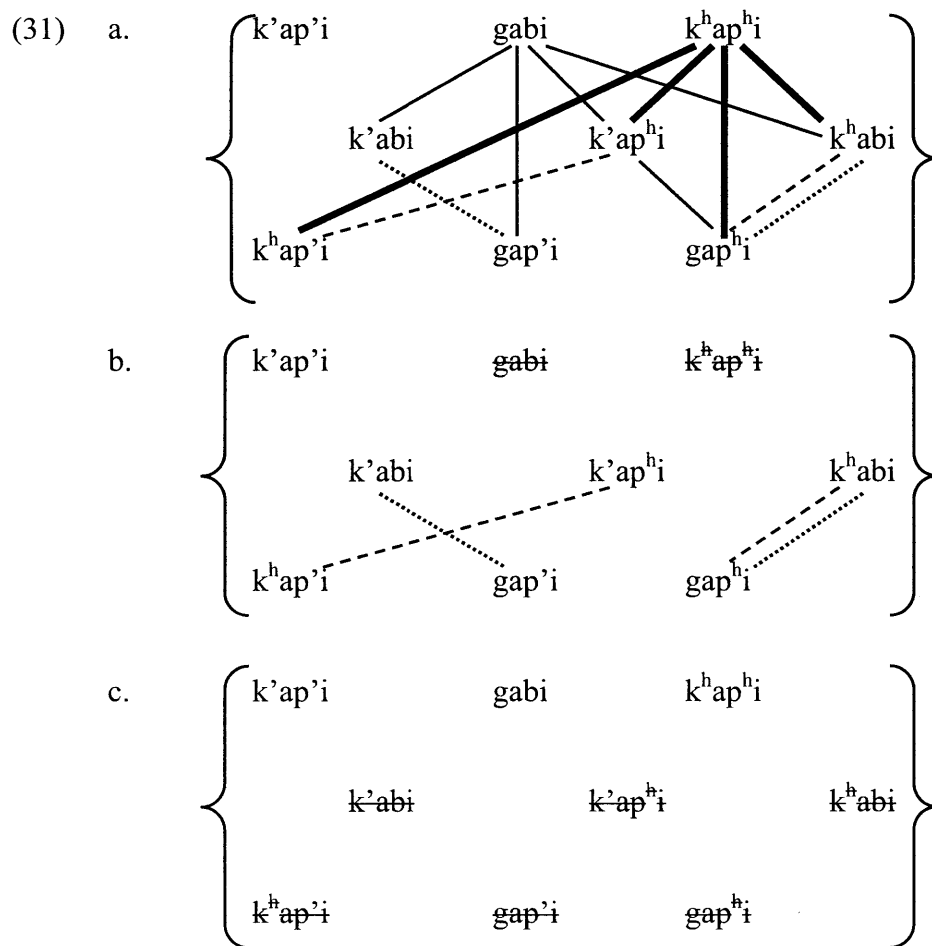
The fully symmetric system of laryngeal assimilation between ejectives, aspirates and slack voiced stops in Zulu is the result of high ranked constraints against the 1 vs. 2 and positional contrasts in [long VOT] and [slack voice].

7.6 Summary

This chapter has analyzed three cases of assimilation, which show two analytical patterns. The difference between Kalabari Ijo and Amharic on one hand and Zulu on the other is that assimilation has to be explicitly required by the ranking of LARDIST(1v0) and articulatory markedness in Kalabari Ijo and Amharic, but not in Zulu. In Zulu, high-ranking LARDIST(1v2) and LARDIST(pos) constraints on [long VOT] and [slack voice] result in roots with two stops having either two ejectives, two aspirates, or two slack voiced stops. The ranking schema for assimilation as in Kalabari Ijo and Amharic is shown in (32).

(32)   Assimilation - Amharic, Kalabari Ijo
        LARDIST(1v2)-[F] >> LARDIST(pos)-[F] >> IDENT, LARDIST(1v0)-[F] >> *[F]

The assimilatory pattern in Chaha, a language closely related to Amharic, has not been analyzed in this chapter, and shows a variation on the pattern seen in Amharic. In Amharic, ejectives are

restricted from cooccurring with other voiceless unaspirated stops but may cooccur with other voiced stops. In Chaha, ejectives *may* cooccur with voiced stops, but combinations of ejectives and voiced stops are underrepresented. As for Amharic, Rose and King calculated the O/E of pairs of alveolar and velar stops to document any laryngeal restrictions. The analysis shows that ejectives in Chaha are underattested in roots with other voiceless or voiced stops, regardless of order or position. Their results, glossing over order and position in the root, are reported in (33).[20]

(33)   K'-T = 0   K'-D = .32   K-D = 1.08

The dispreference for roots with ejective-voiced stop pairs cannot be accounted for with LARDIST(1v0), as this constraint only penalizes a 1 vs. 0 contrast in roots with two stops that minimally contrast for ejection, which voiced stops do not. The Chaha data thus show that the restriction on the 1 vs. 0 contrast may be somewhat more general. While in Amharic and Kalabari Ijo, laryngeally marked stops are only restricted from cooccurring with their minimally contrastive counterpart, in Chaha, laryngeally marked stops are restricted from cooccurring with any other stop. In no language, however, do all consonants interact. In Chaha as well as Amharic, the 1 vs. 0 contrast in ejection is licensed in words with fricatives or sonorants ✓ {[K'-N, K-N]}, (cf. Chaha *fək'am* 'split wood with an ax' (Leslau 1979)).[21] In both languages, then, there is some effect of similarity on the interacting set of consonants. I do not offer a formal analysis of the dispreference for ejective-voiced stops pairs in Chaha. The role of similarity on the grammaticality of a 1 vs. 0 contrast is a topic for future research.

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[20] Rose and Walker (2007) describe the Chaha laryngeal restriction as disallowing any disagreement in laryngeal features between stops, including voiced-voiceless pairs. Such a restriction is not supported by the statistical analysis in Rose and King (2007).

[21] Thanks to Sharon Rose for sharing her database of Chaha roots.

Chapter 8   Conclusion

There are two main results presented in this dissertation. The first is that the typology of laryngeal cooccurrence restrictions reflects a fixed hierarchy of systemic markedness constraints, which penalize indistinct contrasts between roots. This approach departs from previous analyses that rely on syntagmatic constraints and analyze the range of cooccurrence patterns as unrelated phenomena. The second major result is that segments that share auditory features interact over long-distances. The perceptual strength of a given laryngeal contrast is affected by the presence of another segment with the same *auditory* feature elsewhere in the word. Thus, not only do ejectives interact with ejectives and aspirates with aspirates, but aspirates and ejectives that share a long VOT interact with one another. This perceptual interaction underlies the striking phonological parallel between the patterning of ejectives and aspirates in Quechua.

    To conclude, the analysis is summarized in §8.1 and the factorial typology of the proposed constraint set is lain out in §8.2. The summary of the arguments for auditory features, both in the perceptual and phonological domain, is discussed in §8.3 along with an outline of some predictions to be tested in future work. Finally, §8.4 sketches some possible extensions of the proposed analysis to account for the identity effect seen in many languages with laryngeal dissimilation.

8.1   *Summary of constraint rankings*

This dissertation has developed an analysis of a range of laryngeal cooccurrence restrictions, based on a fixed hierarchy of systemic markedness constraints and auditory representations of laryngeal contrasts. The analysis of the three main types of cooccurrence patterns is summarized in (1).

(1) <u>Dissimilation</u>
    LARDIST(1v2)   >>   IDENT   >>   LARDIST(pos)   >>   LARDIST(1v0), *F, INICON

    <u>Dissimilation and ordering restriction</u>
    LARDIST(1v2)   >>   LARDIST(pos)   >>   IDENT   >>   *F   >>   LARDIST(1v0), INICON

    <u>Assimilation</u>
    LARDIST(1v2)   >>   LARDIST(pos)   >>   IDENT, LARDIST(1v0), INICON   >>   *F

A dissimilatory restriction imposes the weakest requirement on the perceptual strength of contrasting forms. In this type of language, LARDIST(1v2) outranks IDENT, requiring neutralization of the 1 vs. 2 contrast in laryngeal features. All other contrasts in laryngeal configurations are allowed. The outcome of the neutralization of the 1 vs. 2 contrast is determined by faithfulness; neutralization to forms with one laryngeally marked stop allows for more contrasting forms than neutralization to forms with two laryngeally marked stops, and thus the output is the set of forms with either one or zero laryneally marked stops {K'-T, K-T', K-T}.

    In the other two types of cooccurrence patterns, both LARDIST(1v2) and LARDIST(pos) outrank faithfulness, requiring neutralization of both the 1 vs. 2 contrast in laryngeal features and the positional restriction in laryngeal features. Neutralization of these two contrasts results in a

binary contrast, either between forms with a 1 vs. 0 contrast in laryngeal features or a 2 vs. 0 contrast. The choice between these two outcomes falls to constraints that rank below faithfulness.

In a language with dissimilation and an ordering restriction, neutralization to the 1 vs. 0 contrast is preferred by articulatory markedness, which outranks LARDIST(1v0). Articulatory markedness favors fewer articulatory gestures, while LARDIST(1v0) favors the strongest 2 vs. 0 contrast in laryngeal features. When articulatory markedness outranks LARDIST(1v0), the preferred outcome of neutralization will be to a binary 1 vs. 0 contrast, either {K'-T, K-T} with an initial contrast, or {K-T', K-T} with a medial or final contrast. The choice between these two falls to INICONT, which prefers contrasts in initial position, where they are more perceptible. The result is {K'-T, K-T} as the contrasting set of forms in a language with dissimilation and an ordering restriction.

In a language with assimilation, the opposite ranking of articulatory markedness and LARDIST(1v0) holds. LARDIST(1v0) outranks articulatory markedness and prefers the strongest possible contrast in laryngeal features, that between two and zero larygneally marked stops. In assimilatory languages, the attested set of contrasts is {K'-T', K-T}. The ranking of INICONT with respect to articulatory markedness and LARDIST(1v0) has no effect on the output.

8.2 Factorial typology

The variation in cooccurrence restrictions results from variation in the ranking of IDENT and articulatory markedness in the fixed hierarchy of the systemic LARDIST constraints. Some other permutations of the proposed constraints also yield attested languages.

If articulatory markedness outranks IDENT, the language in question will simply lack the relevant laryngeal contrast, regardless of the ranking of LARDIST constraints with respect to IDENT or articulatory markedness. Consider the tableau in (2), with constraints referring to aspiration.

(2) *F >> IDENT – no contrast for [F]

{/kʰapʰi, kʰapi, kapʰi, kapi/}	*[sg]	IDENT	LARDIST(1v2)-[long VOT]	LARDIST(pos)-[long VOT]
a. {[kʰapʰi, kʰapi, kapʰi, kapi]}	****!		****	*
b. {[kʰapi, kapʰi, kapi]}	**!	*		*
c. {[kʰapi, kapi]}	*!	**		
d. {[kʰapʰi, kapi]}	**!	**		
e. → {[kapi]}		***		

With *[spread glottis] outranking IDENT, a language will lack aspirates entirely. The ranking of constraints that evaluate contrasts in aspiration is then irrelevant. Languages without aspiration contrasts are well attested (e.g. Romance languages), as are languages without ejectives or implosives (e.g. English).

If IDENT outranks both articulatory markedness and all LARDIST constraints, a language will emerge with no cooccurrence restrictions on laryngeal features. Given this ranking, a language may have roots with either one, two or zero laryngeally marked stops, as shown in (3).

183

(3) IDENT >> LARDIST(1v2)

{/kʰapʰi, kʰapi, kapʰi, kapi/}	IDENT	LARDIST(1v2)- [long VOT]	LARDIST(pos)- [long VOT]	*[sg]
a. → {[kʰapʰi, kʰapi, kapʰi, kapi]}		****	*	****
b. {[kʰapi, kapʰi, kapi]}	* !		*	**
c. {[kʰapi, kapi]}	** !			*
d. {[kʰapʰi, kapi]}	** !			**
e. {[kapi]}	*** !			

Languages with laryngeal contrasts but no cooccurrence restrictions are attested. An example is Acoma (Keres) (Miller 1965), where a root may have zero (4a), one (4b) or two (4c) ejectives.

(4) a. **péeʈa**   'jack rabbit'   b. **k'úutʃin'i** 'yellow'   c. **ts'ík'úm'i** 'string'
       kúuku   'winter'   **spa'at'i** 'mockingbird'   **k'âakaat'i** 'plaza'

If INICONT outranks IDENT, two types of languages can emerge, one attested and one unattested. First, if articulatory markedness outranks LARDIST(1v0), a language with only initial contrasts in a given laryngeal feature is predicted. This seems to be an attested pattern. In Athabaskan languages, like Navajo, the full range of laryngeal contrasts is only attested on the initial root root consonant (McDonough 2003). Consider the two tableaux in (5), showing only initial contrasts in root eith either two stops or only one stop.

(5) INICONT-[F] >> IDENT >> *F >> LARDIST(1v0)-[F] – only initial contrasts for [F]

a.	{/kʰapʰi, kʰapi, kapʰi, kapi/}	INICONT [long VOT]	IDENT	*[sg]	LD(1v0) [long VOT]
	i. {[kʰapʰi, kʰapi, kapʰi, kapi]}	** !		****	****
	ii. {[kʰapi, kapʰi, kapi]}	* !	*	**	*
	iii. → {[kʰapi, kapi]}		**	*	*
	iv. {[kʰapʰi, kapi]}		**	** !	
	v. {[kapi]}		*** !		

b.	{/napʰi, tʰani, napi, tani/}	INICONT [long VOT]	IDENT	*[sg]	LD(1v0) [long VOT]
	i. {[napʰi, tʰani, napi, tani]}	* !		**	**
	ii. → {[tʰani, napi, tani]}		*	*	*
	iii. {[napʰi, napi, tani]}	* !	*	*	*
	iv. {[napi, tani]}		** !		

In (5a), INICONT only penalizes minimal non-initial contrasts in [long VOT]. The contrast {[kʰapʰi, kapi]}, while containing a non-initial [long VOT] contrast, does not violate this constraint because there is also an initial contrast. The choice between candidates iii and iv falls to *[sg], which prefers candidate iii. Given the reverse ranking of *[sg] and LARDIST(1v0), however, an stranger pattern emerges. Consider the two tableaux in (6).

184

(6) INICONT-[F] >> IDENT >> LARDIST(1v0)-[F] >> *F – non-initial [F] in assimilatory roots

a.

{/kʰapʰi, kʰapi, kapʰi, kapi/}	INICONT [long VOT]	IDENT	LD(1v0) [long VOT]	*[sg]
i. {[kʰapʰi, kʰapi, kapʰi, kapi]}	**!		****	****
ii. {[kʰapi, kapʰi, kapi]}	*!	*	*	**
iii. {[kʰapi, kapi]}		**	*!	*
iv. → {[kʰapʰi, kapi]}		**		**
v. {[kapi]}		***!		

b.

{/napʰi, tʰani, napi, tani/}	INICONT [long VOT]	IDENT	LD(1v0) [long VOT]	*[sg]
i. {[napʰi, tʰani, napi, tani]}	*!		**	**
ii. → {[tʰani, napi, tani]}		*	*	*
iii. {[napʰi, napi, tani]}	*!	*	*	*
iv. {[napi, tani]}		**!		

The tableau in (6a) shows how INICONT-[long VOT] and LARDIST(1v0)-[long VOT] can select a candidate with seeming assimilation. In roots with two stops, as in (6a), this ranking allows only the 2 vs. 0 contrast in laryngeal features. In (6b), however, we see that medial contrasts are disallowed in roots with a single stop. The ranking in (6) derives a language with medial aspirates only in roots with an initial aspirate. I know of no languages with such a pattern in a general sense, though Hansson (2001) provides some data on a somewhat similar pattern in Ndebele. Ndebele is a Bantu language closely related to Zulu, and like Zulu it exhibits laryngeal assimilation. Velar aspirates generally do not occur in medial position in Ndebele, except in roots with an initial velar aspirate. This pattern is similar to that in (6) in that a given laryngeal contrast only surfaces in medial position as the result of laryngeal harmony. The representative data are given in (7), taken from Hansson (2001) who cites the Pelling (1971) Ndebele dictionary available through the CBOLD database.

(7) a.   generally, no non-initial velar aspirates
    ✓ kʰ-m, ✓ kʰ-l, etc.
    *m-kʰ, *l-kʰ, etc.

   b.   medial velar aspirates transparent to laryngeal harmony with non-velars
    pʰek-a   'cook, brew'   *pʰekʰa
    tʰuk-a   'abuse, curse'   *tʰukʰa

   c.   medial velar aspirates surface with initial velar aspirate
    kʰokʰ-a   'pull, draw out'   *kʰoka
    kʰukʰ-ul-a   'to sweep away'   *kʰukula

Thus, it is possible for a harmony or assimilatory restriction to result in a laryngeal feature surfacing in an otherwise unattested position.

The variable ranking of IDENT, INITIALCONTRAST and articulatory markedness constraints in the fixed hierarchy of LARDIST constraints results in only attested patterns.

8.3 Auditory features, perception and predictions

The support for auditory representations comes from the phonological and perceptual evidence for the feature [long VOT].

On the phonological side, the cooccurrence restrictions in Quechua require this feature, due to the uniform patterning of ejectives and aspirates. The crucial data point is that ejectives and aspirates may not cooccur in a root, $*K'-T^h$, a restriction that cannot be accounted for with individual constraints referring to ejection and aspiration. The ungrammaticality of this type of form requires reference to a feature that groups ejectives and aspirates to the exclusion of plain stops. Ejectives and aspirates, however, do not share any articulatory property and thus there is no feature in the standard articulator based feature set that groups these two types of segments. The shared property between ejectives and aspirates in Quechua is the auditory feature [long VOT]. The feature [long VOT] allows for an account of the ungrammaticality of ejective-aspirate pairs in Quechua, as well as the otherwise parallel restrictions on these two types of segments. The cooccurrence restrictions in Quechua are summarized schematically in (9).

(9) Schematic representation of Quechua cooccurrence restrictions
   a. $*K'-T'$ b. $*K-T'$
        $*Kh-T^h$ $*K-T^h$
        $*K'-T^h$
        $*K^h-T'$

Experimental results also support the independent status of [long VOT]. Ejectives and aspirates share [long VOT], but the period of VOT is silent in ejectives and filled with aspiration noise in aspirates. The perception experiments in Chapter 4 documented long-distance interference between laryngeally marked stops. It was found that ejectives diminish the accurate perception of an ejective contrast elsewhere in the root, and that aspirates diminish the accurate perception of an aspirate contrast elsewhere in the root. It was also found that ejectives and aspirates interact with one another – an aspirate degrades the perception of an ejective contrast and an ejective degrades the perception of an aspirate contrast. These perceptual asymmetries are shown schematically in (10).

(10)   a.   ejectives interact with ejectives
          $\{K'-T', K'-T\}$ $<$ $\{K-T', K-T\}$ e.g. $\{k'ap'i, k'api\}$ $<$ $\{kap'i\text{-}kapi\}$

        b.   aspirates interact with aspirates
          $\{K^h-T^h, K^h-T\}$ $<$ $\{K-T^h, K-T\}$ e.g. $\{k^hap^hi, k^hapi\}$ $<$ $\{kap^hi\text{-}kapi\}$

        c.   ejectives interact with aspirates
          $\{K'-T^h, K'-T\}$ $<$ $\{K-T^h, K-T\}$ e.g. $\{k'ap^hi, k'api\}$ $<$ $\{kap^hi, kapi\}$

        d.   aspirates interact with ejectives
          $\{K^h-T', K^h-T\}$ $<$ $\{K-T', K-T\}$ e.g. $\{k^hap'i, k^hapi\}$ $<$ $\{kap'i, kapi\}$

The interaction of ejectives and aspirates in perception, as shown in (10c,d), parallels the interaction of ejectives and aspirates in cooccurrence restrictions in (9). The interpretation of the

perceptual asymmetries in (10c,d) is that the presence of one [long VOT] stop interferes with the perception of another [long VOT] contrast elsewhere in the root. Long-distance perceptual interference, as well as long-distance phonological restrictions, are sensitive to shared auditory properties. This interpretation of the results in (10) can be tested by showing that marked segments that do not share an auditory feature do not interact long-distance. For example, short lag, creaky ejectives should not interfere with the perception of aspiration contrasts, and vice-versa.

The analysis of long-distance restrictions is grounded in perceptual asymmetries. Laryngeal cooccurrence restrictions are driven by constraints on perceptually indistinct contrasts in certain auditory features. This analysis differs from previous accounts of long-distance phonological restrictions in that it predicts asymmetries between different features. Not all features are predicted to interact non-locally in the phonology; rather, only those features that show perceptual asymmetries based on a non-local context should be subject to long-distance phonological restrictions.

While it is clear that not all features are subject to long-distance restrictions (e.g. there are no known cases of assimilation in major place), it remains to be tested experimentally that those features that do not show long-distance interactions phonologically also do not show long-distance interactions perceptually. The lack of long-distance restrictions on continuancy, for example, predicts that the perception of continuancy contrasts should be unaffected by the long-distance environment, as shown in (11).

(11)   no long-distance perceptual interference for [continuant]
        {F-K, F-X}   ≮   {P-K, P-X}   e.g. {faki, faxi} ≮ {paki, paxi}

In (11), the perception of a contrast in continuancy, [k] vs. [x], should be equally strong in the context of a continuant [f] as in the context of a non-continuant [p].

Further research may lead to the discovery of other motivations behind featural asymmetries. Some long-distance restrictions may have articulatory bases, for example. The main point behind the research program outlined here is that the phonetic content of features explains the disparate restrictions on different features in phonological systems. The long-distance perceptual dependencies found for ejectives and aspirates support the hypothesis that the particular disposition of these types of segments to long-distance phonological restrictions is based in the substantive properties of these sounds. This is a particularly interesting discovery, as phonetic explanations for phonological patterns have typically been grounded in perceptual asymmetries linked to the availability of acoustic cues. The experiments in Chapter 4 show that perceptual asymmetries may arise even when all cues to a contrast are available.

8.4   The identity effect

One outstanding property of laryngeal cooccurrence restrictions is the interaction between dissimilation and assimilation with place of articulation in some languages. As was mentioned briefly in Chapter 2, languages with dissimilation, either with or without an ordering restriction, may treat heterorganic and homorganic pairs of consonants differently. While pairs of heteroganic laryngeally marked stops are unattested, pairs of identical laryngeally marked stops are attested. Moreover, when identical laryngeally marked stops are allowed, pairs of stops that differ only in a laryngeal feature are absent. Put differently, languages of this type show

dissimilation in pairs of heterorganic stops and assimilation in pairs of homorganic stops. The pattern is schematized in (12).

(12)   Dissimilation with the identity effect: *K'-T'   ✓K'-T
                                                    ✓K'-K'   *K'-K

Of the languages analyzed in the previous chapters, Chol, Hausa, Tz'utujil and Bolivian Aymara are characterized by the identity effect. In Souletin Basque and Quechua, roots with heterorganic and homorganic pairs of stops show the same laryngeal cooccurrence pattern.

This pattern gives further support to the idea that dissimilation and assimilation arise from the same grammatical constraint, favoring neutralization of the 1 vs. 2 contrast in laryngeal features. A single language can exhibit different restrictions on heterorganic and homorganic pairs of stops, but these restrictions both neutralize the same contrast, albeit in different directions. A crucial point to note is that the identity effect is never an identity exemption, it is always assimilation. That is, there is no language that shows dissimilation in heterorganic stops, but show *no* restriction on homorganic stops.

(13)   Unattested language: *K'-T'   ✓K'-T
                                                    ✓K'-K'   ✓K'-K

The absence of languages like that in (13) support the idea that there are no syntagmatic markedness constraints against roots with one or two laryngeally marked stops. Rather, these types of roots are only marked when they contrast with one another.

To account for a language with dissimilation and the identity effect, LarDist(1v2)-[F] must be high-ranked, as in languages with all of the other patterns analyzed in preceding chapters. The constraint that favors assimilation over dissimilation must refer to place of articulation. The idea is that a more specific LARDIST(1v0)$_{HOM}$ constraint penalizes a 1 vs. 0 only between roots with two homorganic stops. This constraint would penalize a contrast like {k'aki, kaki} but not {k'api, kapi}. This constraint is defined in (14).

(14)   LARDIST(1v0)$_{HOM}$-[F]   No minimal contrast in [F] between roots with another homorganic segment that minimally contrasts for [F].

                                        Given two contrasting roots R_1, R_2 such that R_1 and R_2 each contain two homorganic segments that minimally contrast for [F], assign one violation mark if R_1 and R_2 are identical except for a minimal contrast in [F].

In a language with the identity effect, LARDIST(1v0)$_{HOM}$ outranks IDENT, which in turn outranks the more general LARDIST(1v0) constraint. This analysis is shown in (15) and is the analysis argued for in Gallagher (under review).

(15) The identity effect with LarDist(1v0)ₕₒₘ

a.

{/kʰapʰi, kʰapi, kapʰi, kapi/}	LD(1v2) [VOT]	LD(1v0)$_{HOM}$ [VOT]	IDENT	*[sg]	LD(1v0) [VOT]
i. {[kʰapʰi, kʰapi, kapʰi, kapi]}	** !			****	****
ii. → {[kʰapi, kapʰi, kapi]}			*	**	**
iii. {[kʰapi, kapi]}			** !	*	*
iv. {[kʰapʰi, kapi]}			** !	**	
v. {[kapi]}			*** !		

b.

{/kʰakʰi, kʰaki, kakʰi, kaki/}	LD(1v2) [VOT]	LD(1v0)$_{HOM}$ [VOT]]	IDENT	*[sg]	LD(1v0) [VOT]
i. {[kʰakʰi, kʰaki, kakʰi, kaki]}	** !	****		****	****
ii. {[kʰaki, kakʰi, kaki]}		** !	*	**	**
iii. {[kʰaki, kaki]}		* !	**	*	*
iv. → {[kʰakʰi, kaki]}			**	**	
v. {[kapi]}			*** !		

In (15b), high-ranking LarDist(1v0)$_{HOM}$ forces neutralization of the contrast between one and zero aspirates in roots with homorganic stops. This constraint says nothing about contrast between roots with heterorganic stops, and thus the direction of neutralization of the 1 vs. 2 contrast in (15a) falls to faithfulness (in a language with dissimilation and an ordering restriction, the outcome of neutralization is determined by the ranking of articulatory markedness over the general LarDist(1v0) constraint). In a language without the identity effect, LarDist(1v0)hom and LarDist(1v0) are both ranked below all other relevant constraints.

The distinction between LarDist(1v0) and LarDist(1v0)$_{HOM}$ may be correct, but the motivation for this distinction is still a mystery. The first experiment in Chapter 3 looked for an asymmetry in the perception of the 1 vs. 0 contrast based on place of articulation, but found none. A 1 vs. 0 contrast between roots with two homorganic stops, e.g. {[k'aki, kaki]}, is equally perceptible as a 1 vs. 0 contrast between roots with two heterorganic stops, e.g. {[k'api, kapi]}. There is thus no perceptual basis for distinguishing between 1 vs. 0 contrasts based on place of articulation. Thus, if this distinction is adopted it must be motivated by other factors.

A second possibility is that the distinction between homorganic and heterorganic pairs of stops is not based on the relative perceptual strength of contrasts in homorganic vs. heterorganic pairs. Rather, in languages with the identity effect, identical consonants are explicitly preferred. This could be the result of an articulatory markedness constraint that penalizes pairs of stops that differ only in a laryngeal feature [k-k'], due to the difficulty in coordinating and executing highly similar but distinct segments. Or the relevant constraint could be a markedness constraint favoring identical consonants (MacEachern 1999) or roots with a pseudo-reduplicative structure (Zuraw 2002). It is left to future research to explore these possibilities. The identity effect, however, does not constitute a counter example to the contrast based analysis of cooccurrence restrictions, but rather underscores the idea that markedness is a property of contrasts.

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