Acoustic and articulatory features in Phonology – the case for [long VOT]*

Gillian Gallagher (New York University)
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Abstract
This paper argues that phonological features must represent both the articulatory and acoustic properties of speech sounds. Evidence for this claim comes from the long-distance restrictions on ejectives and aspirates in Quechua (MacEachern 1999), which require both that ejectives and aspirates be referred to as a class and that they be distinguishable. The standard, articulatory features [constricted glottis] and [spread glottis] can distinguish ejectives and aspirates, but it is not possible to group these two types of segments in articulatory terms. While ejectives and aspirates are articulatorily disparate, they can be grouped in acoustic terms. Both types of segments are characterized by a long lag between the release of the oral constriction and the onset of voicing in a following sonorant, referred to by the proposed feature [long VOT]. Introducing acoustic features allows for a simple and restrictive account of the phonological behavior of laryngeally marked segments, both in Quechua and cross-linguistically.

1. Introduction
This paper provides evidence for acoustic features in phonological representations (Flemming 2002; Steriade 1997) from the typology of laryngeal cooccurrence restrictions. The main argument comes from long-distance restrictions on ejectives and aspirates in Quechua, as described by MacEachern (1999). The range of restrictions in Quechua requires reference to ejectives and aspirates as a class, a grouping that cannot be achieved with the standard, articulatory features [constricted glottis] ([cg]) and [spread glottis] ([sg]). I propose that ejectives and aspirates may pattern together in the phonology because they share an acoustic property, long VOT. While ejectives and aspirates are articulatorily disparate, both sounds are characterized by a long lag between the release of the stop constriction and onset of voicing in a following sonorant, an acoustic property to which the phonological grammar may refer.

Defining laryngeal contrasts in acoustic terms allows for a simple and restrictive account of the behavior of ejectives and aspirates, and laryngeally marked categories more generally. These two types of sounds can be grouped in acoustic terms or distinguished in articulatory terms, both of which are necessary in Quechua. Further support for representing laryngeal contrasts with both articulatory and acoustic features comes from MacEachern’s (1999) survey of laryngeal cooccurrence restrictions. It is shown that cooccurrence restrictions always target a class of segments that can be defined in either articulatory or acoustic terms.

The standardly assumed feature set of SPE (Chomsky & Halle 1968) and subsequent developments in feature geometry (Sagey 1986) is heavily based on the articulatory properties of speech sounds and contrasts, while more recent work emphasizes the role that auditory dimensions play in explaining phonological patterns (Steriade 1997; Flemming 2002). In particular, Flemming (2002) argues for detailed auditory representations, largely based on CV assimilations and dissimilations. The contribution of this paper is to show that auditory or

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acoustic representations, and particularly the acoustic property of long VOT, allow for a restrictive and explanatory account of the patterning of laryngeally marked segments in cooccurrence restrictions.

The paper is organized as follows. Section 2 details the complex restrictions on laryngeally marked segments in Quechua. Section 3 lays out the proposed feature specifications and discusses the articulatory and acoustic properties of laryngeal contrasts, including an acoustic study of ejectives and aspirates in Quechua. In Section 4 I present the analysis of laryngeal restrictions in Quechua, employing the acoustic feature [long VOT]. Section 5 discusses the advantages of a theory with both acoustic and articulatory features to the analysis of laryngeal cooccurrence restrictions cross-linguistically, and Section 6 concludes.

2. The laryngeal phonology of Quechua

2.1. Background on Quechua
Dialects of Quechua are spoken by about 10 million people throughout Ecuador, Peru, Bolivia, Northern Argentina and Chile (Ethnologue 2010: www.ethnologue.com). This paper is concerned with restrictions on laryngeal contrasts found in Cusco Quechua, as described in MacEachern 1999. This language contrasts three series of stops and affricates: voiceless unaspirated or plain, aspirated and ejective. While MacEachern 1999 is the main source for the restrictions in this paper, the data has been augmented by the Ajacopa et al. (2007) dictionary of Bolivian Quechua, a dialect with the same cooccurrence restrictions as Cusco Quechua, and my own fieldwork in Cochabamba, Bolivia. The consonantal inventory of the relevant dialects of Quechua is given in Table 1, from MacEachern (1999:29).

<table>
<thead>
<tr>
<th></th>
<th>labial</th>
<th>alveolar</th>
<th>postalveolar</th>
<th>velar</th>
<th>uvular</th>
<th>glottal</th>
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<tr>
<td>plain</td>
<td>p</td>
<td>t</td>
<td>tʃ</td>
<td>k</td>
<td>q</td>
<td>?</td>
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<tr>
<td>aspirate</td>
<td>pʰ</td>
<td>tʰ</td>
<td>tʃʰ</td>
<td>kʰ</td>
<td>qʰ</td>
<td></td>
</tr>
<tr>
<td>ejective</td>
<td>p’</td>
<td>t’</td>
<td>tʃ’</td>
<td>k’</td>
<td>q’</td>
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<tr>
<td>fricative</td>
<td>s</td>
<td>j</td>
<td>h</td>
<td></td>
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</tr>
<tr>
<td>nasal</td>
<td>m</td>
<td>n</td>
<td>n</td>
<td></td>
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<tr>
<td>liquid</td>
<td>l</td>
<td>r</td>
<td>n</td>
<td></td>
<td></td>
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<tr>
<td>glide</td>
<td>w</td>
<td>j</td>
<td>h</td>
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Quechua has three phonemic vowels /i a u/ and two allophones [e, o], which result from lowering of /i u/ adjacent to uvulars. Roots in Quechua are primarily CV(C)CV, where the optional coda is a continuant or nasal in almost all cases. [ʔ] is restricted to root initial position; there are no vowel initial roots. While most dictionaries of Quechua do not transcribe glottal stop, I follow MacEachern in transcribing orthographically vowel initial words with an initial glottal stop. Ejectives and aspirates occur only in onset position, and are subject to a range of long-distance restrictions discussed in the next subsection.

2.2. Long-distance restrictions on laryngeal features
The ejective and aspirated stops and affricates, as well as the glottals [ʔ, h], are subject to long-distance restrictions in Quechua. For expository purposes, I will refer to two classes of
restrictions, cooccurrence restrictions and ordering restrictions. Cooccurrence restrictions prohibit a root from containing two ejectives, two aspirates, or one ejective and one aspirate (1b). Ejectives and aspirates may cooccur with plain stops, and plain stops may occur in pairs (1a). The examples in (1) are taken from Ajacopa et al. (2007). The (un)grammaticality of a given pair of segment types is represented schematically in a column to the right of the representative examples.

(1) a. k’inti  ‘a pair’ ✓ K’-T
    p’atʃa  ‘clothes’ ✓ K’-T
    kʰastuj  ‘to chew’ ✓ Kₕ-T
    pʰaskaj  ‘to tie up’ ✓ K-T
    kintu  ‘a bunch’ ✓ K-T
    puka  ‘red’

    b. *k’int’i ✓ *K’-T
    *kʰastiuj ✓ *Kʰ-Tʰ
    *k’intʰi / *kʰint’i ✓ *K’-Tʰ

Additional cooccurrence restrictions govern the combination of the glottal consonants [ʔ, h] with laryngeally marked stops. Glottal stop freely cooccurs with aspirates, and [h] freely cooccurs with ejectives (2a). Ejectives may not, however, occur in roots with initial glottal stop and aspirates may not cooccur with [h] (2b). Examples again are from Ajacopa et al. (2007).

(2) a. ḥantʰíj  ‘to moan’ ✓ ḥ-Tʰ
    ḥaqʰa  ‘fermented corn drink’ ✓ ḥ-T
    harkʰaj  ‘to protect’ ✓ ḥ-T
    hayt’a  ‘kick’

    b. *ḥantʰi’j ✓ *ḥ-T
    *harkʰaj ✓ *ḥ-Tʰ

While glottal stop is restricted to initial position, [h] occurs in medial position in a handful of roots. MacEachern gives two roots with initial glottal stop and medial [h] from Hornberger and Hornberger (1983), showing that the two glottal consonants may cooccur: [ʔahoja] ‘wild duck’ and [ʔuhu] ‘cough’. Of these two examples, the second is also found in the Ajacopa et al. dictionary. MacEachern also gives two examples of medial [h] in ejective initial roots, showing that ejectives and [h] may occur in either order: [k’ahaj] ‘to spit’ and [tʃ’uhu] ‘cough’. One of these examples, [tʃ’uhu] ‘cough’, is given in Ajacopa et al. as being a variant of [ʔuhu].

The ordering restrictions in Quechua prohibit an ejective or aspirate from following a plain stop or affricate in a root. Ejectives and aspirates may occur in medial position in roots with other non-stops (3a), but never in a root with an initial stop or affricate (3b). Ejectives and aspirates may occur in initial position regardless of whether there is another stop or non-stop in the root (3c).

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1 Final [j] is the infinitival suffix and is not part of the root.
(3) a. ruk’iy ‘to pack tightly’ ✓ M-K’
sut’i ‘clear, visible’ ✓ M-K
ruk’h ‘decrepit’ ✓ M-K
map’a ‘wax’

b. *kap’a *K-T’
*kap’h a *K-T’h

c. k’apa ‘cartilage’ ✓ K’-T
k’hapa ‘step’ ✓ K’h-T
k’iri ‘injury’ ✓ K’-M
q’h asa ‘ice’ ✓ K’h-M

The restrictions on ejectives and aspirates are summarized schematically in (4).

(4) K’-T’ * K’-T ✓
K’h-T’h * K’h-T ✓
K’-T’h / K’h-T’ * K-T ✓
K-T’ * M-T’ / K’-M ✓
K-T’h * M-T’h / K’h-M ✓
ʔ-T’h * ʔ-T ✓
h-T’h * h-T’ ✓
ʔ-h ✓

The patterning of ejectives and aspirates is largely parallel in Quechua. Both ejectives and aspirates are prohibited from cooccurring in pairs (*K’-T’, *K’h-T’h), following a plain stop (*K-T’, *K-T’h), or with one another (*K’-T’h). Ejectives and aspirates show different behavior with respect to the glottal consonants [ʔ, h], however. Only ejectives are prohibited from cooccurring with glottal stop, and only aspirates may not cooccur with [h]. An analysis of Quechua must account both for the uniformity in the patterning of ejectives and aspirates, and the independence of these two classes of segments with respect to the glottal consonants.

3. Acoustic and articulatory features for laryngeal contrasts

The main proposal in this paper is that the acoustic feature [long VOT], which defines both ejectives and aspirates, must be available to the phonological grammar. Ejectives and aspirates are articulatorily disparate sounds, but they share the acoustic property of long VOT, and this shared acoustic property is relevant to their phonological patterning.

The long-distance restrictions on ejectives, aspirates, glottal stop and [h] require three groupings of these consonants: 1. ejectives and aspirates, 2. ejectives and glottal stop, 3. aspirates and [h]. The grouping of ejectives with glottal stop and aspirates with [h] are accomplished with the standard articulatory features [constricted glottis] ([cg]) and [spread glottis] ([sg]). The feature [cg] refers to the constriction of the vocal folds in an ejective or a glottal stop, as well as glottalized sonorants and some implosives, and [sg] refers to the spreading wide of the vocal folds in an aspirate or [h]. Both [cg] and [sg] are articulatory features, describing the state of the glottis.
Ejectives and aspirates cannot be described as a class with articulatory features, as the glottal states in the two classes of sounds are antagonistic. While ejectives and aspirates are articulatorily disparate, they may be grouped in acoustic terms. Both ejectives and aspirates require a particular glottal gesture in addition to an oral closure. In languages like Quechua where the glottal constriction or opening gesture is aligned to follow the release of the oral constriction, both ejectives and aspirates are characterized by a lag between the oral release burst and the onset of voicing in a following sonorant: long VOT. Introducing the acoustic feature [long VOT] to the feature set allows for all the necessary groupings of laryngeally marked sounds in Quechua, as shown in Table 2. For more discussion of acoustic and auditory features in phonology more generally, see Flemming (2002).

Table 2: Featural specifications for laryngeally marked segments in Quechua.

<table>
<thead>
<tr>
<th></th>
<th>[long VOT]</th>
<th>[cg]</th>
<th>[sg]</th>
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<tr>
<td>ejectives:</td>
<td>[p', t', tʃ', k', q']</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>aspirates:</td>
<td>[pʰ, tʰ, tʃʰ, kʰ, qʰ]</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>glottal stop:</td>
<td>[ʔ]</td>
<td>+</td>
<td></td>
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<tr>
<td>[h]</td>
<td>[h]</td>
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</table>

The novel proposal is that ejectives and aspirates share a feature, [long VOT]. Restrictions on ejectives and aspirates in Quechua necessitate reference to these two types of sounds as a class, to the exclusion of the laryngeal consonants [ʔ, h]. The crucial data point, which will be analyzed formally in Section 4, is that ejectives and aspirates are prohibited from cooccurring with one another (*K' - Tʰ).

Avery and Idsardi (2001) propose that [cg] and [sg] are grouped together, distinct from other laryngeal features, as dependents of the articulatory feature [Glottal Width]. The current proposal differs from theirs in two important ways. First, Avery and Idsardi explicitly argue that [cg] and [sg] are never contrastive, and are grouped together for exactly this reason. The inventory and phonology of Quechua and many other languages that contrast ejectives and aspirates show that this claim cannot be true. Second, [Glottal Width] groups together all [cg] and [sg] segments, whereas [long VOT] picks out only ejectives and aspirates. It will be shown in Section 5 that ejectives must be distinguished from glottalized sonorants and implosives, as well as glottal stop, all of which are [cg]. The acoustic feature [long VOT] accomplishes this distinction.

It should be noted that while [long VOT] defines the phonologically relevant class of ejectives and aspirates in Quechua, this feature is not needed to define any contrast in the language. Ejectives and aspirates are differentiated from one another by the articulatory features [cg] and [sg], and from the glottal segments by place of articulation. In this sense, [long VOT] is a redundant feature in Quechua. The idea that phonological representations contain non-contrastive information is supported by a wide range of evidence showing that phonological patterns reflect sub-phonemic properties of speech sounds (see in particular Flemming 2003 and Hayes et al. 2004). The restrictions in Quechua further show that phonological restrictions may target non-contrastive information. I leave open the question of whether some formal distinction between contrastive and non-contrastive features is desirable or necessary.

In the rest of this section I present the articulatory and acoustic properties of laryngeally marked consonants that support the featural distinctions in Table 2, first by showing representative examples of laryngeally marked segments in Section 3.1 and then with an acoustic
study of ejectives and aspirates in Section 3.2. Section 3.3 discusses Ohala’s (1981, 1993) account of laryngeal dissimilation in light of the Quechua data.

3.1. Phonetic overview of laryngeal distinctions in Quechua
Laryngeal distinctions on stops in Quechua are aligned with the release of the oral constriction. The oral release of an ejective is followed by a period of silence corresponding to the glottal constriction; in an aspirate, the oral release is followed by a period of aspiration corresponding to the glottal spreading gesture. Representative examples of an ejective and an aspirate in Quechua are given in Figures 1 and 2, taken from my own recordings of Quechua speakers in Cochabamba, Bolivia.

Figure 1: Example of an ejective from [k’ata] ‘unique, single’.

Figure 2: Example of an aspirate from [kʰaʎay] ‘to cut, slice’.
The spectrograms and waveforms in Figures 1 and 2 show a substantial lag between release of the oral constriction and onset of the following vowel. The long VOT associated with both ejectives and aspirates in Quechua contrasts with the short VOT in a voiceless unaspirated or plain stop, as shown in Figure 3. In addition to distinctions in VOT, ejectives as in Figure 1 have a greater burst amplitude than aspirates and plain stops.

Figure 3: Example of a voiceless unaspirated stop from [kata] ‘father-in-law’.

The acoustic feature [long VOT] refers to the distinctive lag between oral release and voice onset that characterizes ejectives and aspirates, and thus groups these two articulatory disparate segment types.

While both ejectives and aspirates have a similarly long VOT, the acoustics of the transition period between consonant and vowel is substantially different between the two types of stops. In an ejective, the lag between release of the constriction and onset of the following vowel is silence, while in an aspirate this period is filled with noise. Additionally, the burst amplitude of an ejective is much greater than for an aspirate, and thus the delimitation of the period of VOT also differs between the two stop series. These acoustic differences mean that the feature [long VOT] refers explicitly to the duration of the lag between release of the oral constriction and onset of the vowel, regardless of the acoustic properties of the lag itself or the burst that marks the beginning of the VOT period.

The laryngeal consonants [ʔ, h] are not [long VOT]; they have no supra-glottal constriction, and thus no release burst. The feature [long VOT] refers to both ejectives and aspirates, but distinguishes these two types of laryngeally marked segments from the articulatorily related laryngeal consonants. Examples of glottal stop and [h] are given in Figures 4 and 5. These examples are taken from the UCLA phonetics lab database.
In Figure 4, a glottal stop in initial position is simply silence, followed by the abrupt onset of the following vowel. Recall that there are no vowel initial words in Quechua, so glottal stop does not contrast with nothing. In Figure 5, an initial [h] is a period of aspiration that gradually increases in amplitude.

Ejectives and glottal stop share an articulatory property: constriction of the glottis. In an ejective, the glottal constriction occurs during the oral closure and is accompanied by lowering of the glottis (Ladefoged and Maddieson 1996). The glottal lowering and alignment of the glottal constriction to overlap and follow release of the oral constriction results in a large burst
amplitude and a long, silent VOT (Lindau 1986; Kingston 1985). In a glottal stop there is no oral constriction, and thus the glottal constriction is simply silence. While ejectives and glottal stop differ in many salient acoustic properties, they may also share an acoustic property. In some languages, both glottal stop and ejectives are associated with some degree of creaky phonation in the following vowel (Lindau 1986; Kingston 1985; Wright et al. 2002), and this seems to be true in Quechua as well. The acoustic study in Section 3.2 does not include glottal stop initial forms, and thus the phonation type following ejectives and glottal stop cannot be compared.

Aspirates and [h] share both articulatory and acoustic properties. In articulatory terms, aspirates and [h] are characterized by a spread glottis, allowing air to flow freely through the glottis and the oral cavity. In both types of segments, the acoustic result of the spread glottis is aspiration noise. In an aspirate, the aspiration period follows the release of the oral constriction, while in [h] the aspiration noise characterizes the entire segment. While aspirates and [h] share the articulatory feature [sg] and the acoustic property of aspiration noise, only aspirates have an oral release and thus only aspirates are [long VOT].

To summarize, while ejectives share articulatory properties with glottal stop, and aspirates share both articulatory and acoustic properties with [h], [long VOT] is not a shared feature between the supra-glottal and glottal consonants.

3.2. Acoustic study of ejectives and aspirates in Quechua
A small acoustic study of laryngeal contrasts among stops supports the claim that ejectives and aspirates form a natural class in terms of long VOT in Quechua.

3.2.1. Methods. Recordings for acoustic analysis were taken on-site in Cochabamba, Bolivia with 6 middle-aged female speakers of Bolivian Quechua, all of whom 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 (5).

(5)  
   Noga 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. For each speaker, there were 152 target words taken from the Ajacopa et al. dictionary (2007), balanced to contain plain, ejective and aspirated stops at the labial, alveolar and velar places of articulation. Target words were chosen to balance target consonants in three positions: initial pre-vocalic (#CV…), intervocalic (…VCV…) and post-consonantal pre-vocalic (…CCV…).

The recordings were analyzed using the Praat software for speech analysis (Boersma & Weenink 2010: http://www.fon.hum.uva.nl/praat/). For each target stop, 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. Finally, two measures of voice quality in the following vowel were taken: the difference between the amplitude of H1 and H2 in the first 30 ms of the vowel (Ladefoged 2003), and F0 in the first and second 30 ms of the vowel. Only H1-H2 was taken for the last 30 ms of the preceding vowel.

3.2.2. Results. The three laryngeal categories in Quechua are distinguished primarily by VOT, burst amplitude and voice quality of the following vowel. Ejectives and aspirates contrast with plain stops in having extremely long VOT. Ejectives are further characterized by a greater burst amplitude and lowered pitch in the first 30 ms of the following vowel compared to plain stops, and aspirates correlate with raised pitch compared to plain stops. There is also a small effect of closure duration, which is slightly shorter in plain stops than in the other two series.

VOT values are plotted in the graph in Figure 6. A Linear Mixed Model confirms that the VOT of plain stops is significantly shorter than the VOT of both ejectives ($\beta = 103, t = 36.4, p < .0001$) and aspirates ($\beta = 98, t = 33.4, p < .0001$). The VOT of ejectives and aspirates does not differ significantly.

Burst amplitude also distinguishes ejectives from both plain stops ($\beta = -.34, t = -19.3, p < .0001$) and aspirates ($\beta = -.32, t = -17.9, p < .0001$). Burst amplitude was measured in arbitrary units, directly off the waveform in Praat by taking the difference between the highest and lowest points in the burst. Average values for each of the three series of stops are graphed in Figure 7.
The two measures of voice quality in the following vowel yield different results. For H1-H2, aspirates are found to be characterized by breathy phonation, distinguishing them from plain stops ($\beta = -3$, $t = -9$, $p < .0001$) and ejectives ($\beta = -3.3$, $t = -9.9$, $p < .0001$), but there is no difference between ejectives and plain stops. Average values for H1-H2 in vowels following stops of each of the three laryngeal series are compared in Figure 8.

The average F0 in the first 30 ms of the following vowel does distinguish ejectives from plain stops ($\beta = 2.09$, $t = -3.16$, $p < 0.01$), as well as plain stops from aspirates ($\beta = 7$, $t = 7.18$, $p < .0001$). Unlike the H1-H2 measure, F0 suggests the presence of tenseness following an ejective. One reason for this difference could be that in vowels that were visibly extremely creaky, the harmonics were not visible in the spectral slice taken in Praat. Thus, H1-H2 could not be measured in just those cases where there was a clear distinction between ejectives and plain stops.
stops. The pitch tracker in Praat also failed to find F0 immediately following some tokens of ejectives. In addition to the quantitative data on voice quality, an impressionistic observation of whether the vowel following an ejective was creaky or not was also taken. In 34% of the vowels following ejectives, I judged the waveform to show irregularly timed pulses in the transition between ejective and vowel, indicating creaky phonation.

The average F0 of the second 30 ms of the vowel only distinguishes plain stops from aspirates ($\beta = 1.1$, $t = 4.68$, $p < .0001$), indicating that ejectives effect only the first 30 ms of the following vowel. Average F0 is graphed in Figure 9.

In addition to the large effects of VOT, burst amplitude and voice quality in the following vowel, the three laryngeal series in Quechua are also differentiated to a small degree by closure duration. Closure duration was measured in post-vocalic and post-consonantal stops, and it was found that plain stops have a significantly shorter closure than ejectives ($\beta = 11.9$, $t = 3.4$, $p < .001$) or aspirates ($\beta = 8.5$, $t = 2.3$, $p < .03$). The effect is very small, however, as the average closure duration of a plain stops is only 12 ms shorter than an ejective (99 vs. 111 ms.) and 8 ms shorter than an aspirate (99 vs. 107 ms.). Finally, there was no significant effect of V1 voice quality.

3.3. Coarticulation in dissimilation
The possible phonetic motivation for long-distance dissimilation in laryngeal and other features is discussed in Ohala (1981, 1993). Ohala proposes that coocurrence restrictions are the phonologization of misperception resulting from coarticulation. The basic idea is that certain features, among them ejection and aspiration, often affect adjacent segments, e.g. creakiness or breathiness on the following vowel. Coarticulation poses an analytical problem for the listener who must decide whether a certain phonetic cue is due to coarticulation or to underlying specification. For example, a listener hearing a form pronounced [k’ap’i] with two ejectives must decide whether glottalization on [p’] is due to the segment being specified as such, i.e. the surface realization of /k’ap’i/, or is a result of coarticulation with preceding [k’], i.e. the surface
realization of /k’api/. Ohala’s proposal relies on hypothesized coarticulation between a laryngeally marked stop and the surrounding segments. To support this hypothesis, it must be shown both that ejectives and aspirates have coarticulatory effects on surrounding segments and that the attested degree of coarticulation creates an ambiguous percept. Only in this case would an output like [k’ap’i] be interpreted as the surface realization of /k’api/, thus obscuring a contrast between /k’ap’i/ and /k’api/. ²

There are a few reasons to think that coarticulation is not responsible for dissimilation, particularly in Quechua. First, while ejectives and aspirates may generally have coarticulatory effects cross-linguistically, this coarticulation is often unidirectional. In the majority of languages, ejectives are post-glottalized and aspirates are post-aspirated (Ladefoged and Maddieson 1996). The acoustic study of Quechua emphasizes this point. While aspirates induce breathy phonation on a following vowel and raise pitch, and ejectives lower pitch, a preceding vowel is unaffected. Thus, it seems unlikely that breathy voice or glottalization would be attributed to a following consonant, e.g. that something like [k’api] would be interpreted as /k’ap’i/. Second, it seems equally unlikely that breathy voice or glottalization spreads all the way through to the right side of the second consonant, e.g. that /k’api/ would be realized as [k’api]. Indeed, the acoustic study of Quechua show that the coarticulatory effects of ejection are limited to the first 30 ms of the following vowel.

A third and final point is that Ohala’s hypothesis equates creaky or breathy phonation with ejection and aspiration, respectively. Even if creakiness from one ejective or breathiness from one aspirate did spread all the way through the following two syllables, as in [k’api], the assumption that a plain stop followed by a glottalized vowel is confusable with a true ejective stop is non-trivial. As the acoustic study of Quechua shows, the large burst amplitude and long VOT are distinctive correlates of ejective stops, neither of which can result from coarticulation. Similar arguments apply to aspirates, which are crucially characterized by a long, noisy VOT period as well as breathiness in the following vowel.

3.4. Summary
The phonetic correlates of laryngeal contrasts in Quechua support the grouping of ejectives and aspirates in terms of [long VOT]. Both ejectives and aspirates are consistently realized with comparably long VOTs, distinguishing these laryngeally marked stops from the plain, voiceless unaspirated stops.

The representation of both ejectives and aspirates as [long VOT] reflects the language specific realization of ejectives in Quechua, but is not a universal property of ejectives in all languages. Research into the realization of ejectives cross-linguistically reveals a great deal of inter- and intra-language variation (Lindau 1984; Kingston 1985; Wright et al. 2002). While ejectives are consistently realized with a constriction of the glottis (and thus are consistently [cg]), the alignment of the glottal gesture with the supra-glottal constriction determines the acoustic consequences of glottal constriction. In a language like Quechua or Navajo (Lindau 1984), the glottal constriction overlaps and follows the oral constriction, resulting in long VOT and a loud burst. In other languages, like Hausa (Lindau 1984), the glottal constriction is simultaneous with and follows the release of the oral closure, resulting in a short VOT and weak burst but substantial glottalization on a following sonorant. Wright et al. (2002) find that while

---

² The assumption here is that the perceptual system will only attribute a given set of acoustic cues to coarticulation if there is independent evidence that coarticulation could be responsible for these acoustic cues in the language in question.
ejectives in Witsuwit’en have a somewhat longer VOT than voiceless unaspirated stops, the VOT in ejectives is much shorter than in aspirates. Finally, VOT itself is only defined when a stop is released into a following sonorant. In languages where ejectives and aspirates are contrastive in pre-obstruent or pre-pausal positions, these segments cannot be said to be [long VOT] (more on this last point in Section 5).

The degree of variation in ejective VOT means that [long VOT] is not a universal feature, assigned to all [-cont, +cg] segments. Rather, as discussed earlier, it is a non-contrastive feature that represents the language specific realization of ejectives. Much recent work does not assume a single, universal set of contrastive phonological features (see in particular Mielke 2008), and thus the language particular nature of [long VOT] is not a novel proposal. Assuming that phonological representations include language specific, non-contrastive features raises the question of what a possible phonological feature is. This is a broad question that I do not aim to answer here; the claim in this paper is simply that [long VOT] is one.

4. The analysis of Quechua

Long-distance restrictions on laryngeal features in Quechua result from markedness constraints on the acoustic feature [long VOT] as well as the articulatory features [cg] and [sg]. Constraints on the cooccurrence and alignment of [long VOT] account for the uniform patterning of ejectives and aspirates; no two [long VOT] segments may cooccur in a root, whether ejective or aspirate, and no [long VOT] segment may occur following a plain stop. Constraints on the cooccurrence of [cg] and [sg] account for the disparate patterning of ejectives and aspirates with respect to cooccurrence with the glottal consonants [ʔ, h].

4.1. Restrictions on [long VOT]

First consider restrictions on the cooccurrence of ejectives and aspirates: pairs of ejectives, pairs of aspirates and ejective-aspirate pairs are all disallowed in Quechua. These restrictions are schematized in (6).

\[ \begin{align*}
& *K'\text{-}T' \\
& *K^h\text{-}T^h \\
& *K'\text{-}T^h 
\end{align*} \]

The three disallowed combinations in (6) show that roots in Quechua may not contain two [long VOT] segments. This type of restriction is standardly assumed to be a result of the Obligatory Contour Principle (OCP), which prohibits adjacent identical elements on a given autosegmental tier (Leben 1973; Goldsmith 1976; McCarthy 1986, 1988). Suzuki (1988) reformalizes the OCP within a constraint-based framework. Constraints based on the Generalized Obligatory Contour Principle (GOCP) prohibit multiple instances of a given feature in some domain. The GOCP constraint active in Quechua prohibits multiple instances of [long VOT] in a root, defined in (7).

\[ \text{GOCP}[\text{long VOT}] \quad \text{No two [long VOT] segments in a root.} \]
GOCP[long VOT] conflicts with a faithfulness constraint that favors realizing all input
[long VOT] specifications (McCarthy and Prince 1995).³

(8)  IDENT[long VOT]  If an input segment is [long VOT], then its
output correspondent is [long VOT].

If GOCP[long VOT] outranks IDENT[long VOT], then inputs with multiple [long VOT] segments
will surface unfaithfully, with only a single [long VOT] segment.

(9)  a.  /k’ap’i/  GOCP[long VOT]  IDENT[long VOT]
     i.  k’ap’i  * !
     ii.  → k’api  *

   b.  /k’hap’hi/  GOCP[long VOT]  IDENT[long VOT]
     i.  k’hap’hi  * !
     ii.  → k’hapi  *

   c.  /k’hap’hi/  GOCP[long VOT]  IDENT[long VOT]
     i.  k’hap’hi  * !
     ii.  → k’api  *

The analysis in (9) succeeds in accounting for the absence of roots with ejective-aspirate pairs,
because both of these segments are specified as [long VOT]. Given the acoustic feature
[long VOT], cooccurrence restrictions on pairs of ejectives, pairs of aspirates and ejective-
aspirate pairs have a unified analysis.

The ordering restrictions on ejectives and aspirates are also given a unified treatment with the
proposed feature [long VOT]. Recall that both ejectives and aspirates are prohibited from
occurring in medial position if there is an initial plain stop, but may occur in medial position if
the initial consonant is a non-stop.

(10)  *K-T’  ✓ M-T’
      *K-Tʰ  ✓ M-Tʰ

The restriction schematized in (10) is analyzed as the interaction of an alignment constraint on
[long VOT] and faithfulness constraints on [long VOT]. The absence of roots with plain stops
followed by ejectives or aspirates reveals a dispreference for medial [long VOT] segments. The
Generalized Alignment constraint (McCarthy and Prince 1993) in (11) below requires every
instance of [long VOT] to be aligned with the left edge of a root.

An anonymous reviewer asks why the cooccurrence restrictions in Quechua are not reduced
to a single restriction demanding that ejection or aspiration occur on the first stop in the root.
From this perspective, both [kapʰi] and [k’apʰi] are ungrammatical because aspiration occurs on
a non-initial stop. Such an analysis is in principle possible for Quechua (and is pursued for

³ Faithfulness to [long VOT] is not strictly necessary, and is used here for transparency. A violation of IDENT[long
VOT] entails a violation of either IDENT[cg] or IDENT[sɡ]. Consequently, whether a markedness constraint on [long
VOT] is satisfied depends on its ranking with respect to faithfulness constraints on [long VOT], [cg] and [sg].
related data in Mackenzie 2009), but it misses the broader generalization that cooccurrence and ordering restrictions are cross-linguistically independent. Quechua, Peruvian Aymara and Bolivian Aymara have the same ordering restriction on ejectives and aspirates (*[kap’i], *[kap’h]), but differ in their cooccurrence restrictions (MacEachern 1999). Additionally, without the feature [long VOT], the fact that both ejectives and aspirates are subject to the same ordering restriction is missed.  

(11) \( \text{ALIGN}([\text{long VOT}]; \text{Rt}, \text{L}) \) Every instance of [long VOT] is aligned with the left edge of a root.

The existence of medial ejectives and aspirates in roots with other non-stops shows that \( \text{ALIGN}([\text{long VOT}]) \) is satisfied by reassociating [long VOT] to an initial stop (/kap’i/ \( \rightarrow \) [k’api]), but not at the expense of deleting [long VOT] (/map’i/ \( \rightarrow \) [map’i] *[mapi]). This asymmetry shows the variable ranking of faithfulness constraints on [long VOT]. \( \text{IDENT}([\text{long VOT}]) \), defined in (8) above, requires corresponding input-output segments to have the same specification for [long VOT]. This constraint is violated both by deleting an instance of [long VOT] from input to output, and by reassociating [long VOT]. The additional faithfulness constraint in (12) below, however, requires preservation of a feature specification from input to output, regardless of segmental association. This constraint is violated in a mapping like /map’i/ \( \rightarrow \) [mapi], where an instance of [long VOT] has been deleted entirely, but is satisfied in a mapping like /kap’i/ \( \rightarrow \) [k’api], where [long VOT] has simply been associated to a different segment from input to output.

(12) \( \text{MAX}([\text{long VOT}]) \) Every instance of [long VOT] in the input is present in the output.

The restrictions on medial ejectives and aspirates result from the ranking of \( \text{ALIGN}([\text{long VOT}]) \) over \( \text{IDENT}([\text{long VOT}]) \), but not over \( \text{MAX}([\text{long VOT}]) \), as shown in (13) and (14).

(13) a. 

<table>
<thead>
<tr>
<th>Input</th>
<th>( \text{MAX}([\text{long VOT}]) )</th>
<th>( \text{ALIGN}([\text{long VOT}]) )</th>
<th>( \text{IDENT}([\text{long VOT}]) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>/kap’i/</td>
<td>* !</td>
<td>* !</td>
<td>**</td>
</tr>
<tr>
<td>i. kap’i</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ii. ( \Rightarrow ) k’api</td>
<td></td>
<td></td>
<td>**</td>
</tr>
<tr>
<td>iii. kapi</td>
<td>* !</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

b. 

<table>
<thead>
<tr>
<th>Input</th>
<th>( \text{MAX}([\text{long VOT}]) )</th>
<th>( \text{ALIGN}([\text{long VOT}]) )</th>
<th>( \text{IDENT}([\text{long VOT}]) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>/kap’h/</td>
<td>* !</td>
<td>* !</td>
<td>**</td>
</tr>
<tr>
<td>i. kap’h</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ii. ( \Rightarrow ) k’hapi</td>
<td></td>
<td></td>
<td>**</td>
</tr>
<tr>
<td>iii. kapi</td>
<td>* !</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4 For this latter point to be a conclusive criticism of such an analysis, it must be shown that the unified patterning of ejectives and aspirates is in fact a part of the phonotactic knowledge of a Quechua speaker.

5 Note that the existence of medial ejectives and aspirates in roots with only a single stop makes an analysis in terms of positional faithfulness (Beckman 1998) untenable. Contrasts in ejection and aspiration are attested outside of root initial position.
The full analysis of roots like [map’i] and [map’hi] requires additional constraints to be high-ranked. Non-stops must both be prohibited from hosting a [long VOT] feature and must be blocked from turning into stops in order to host [long VOT]. A more complete analysis is shown in (15), with the markedness and faithfulness constraints relevant to a labial nasal.

(15) a. /map’i/ | MAX[long VOT] | ALIGN[long VOT] | IDENT[long VOT]
   i. → map’i | * | | *
   ii. mapi | *! | | *

   b. /map’hi/ | MAX[long VOT] | ALIGN[long VOT] | IDENT[long VOT]
   i. → map’hi | * | | *
   ii. mapi | *! | | *

While [long VOT] is never deleted to satisfy alignment, it is deleted to satisfy GOCP[long VOT], as can be seen from the fact that inputs with two instances of [long VOT] must surface with only one instance, /k’ap’hi/ → [k’api]. GOCP[long VOT] must outrank not only IDENT[long VOT], but also MAX[long VOT]. The full constraint ranking up to this point is given in (16). Well-formedness constraints like *m’ and *mh from (15) and non-laryngeal faithfulness constraints are excluded.


4.2. Restrictions on [cg] and [sg]
Constraints on [long VOT] account for restrictions where ejectives and aspirates pattern as a class. Cooccurrence restrictions involving the glottal consonants [ʔ, h] are not accounted for with [long VOT]. Neither glottal stop nor [h] is [long VOT], and, moreover, ejectives and aspirates do not pattern as a class with respect to cooccurrence with laryngeal consonants. Instead, restrictions on the glottal consonants show that articulatory features are also restricted in Quechua. The relevant data are repeated schematically in (17).
The restrictions in (17) show that ejectives are prohibited from cooccurring with glottal stop and aspirates are prohibited from cooccurring with [h]. These two ungrammatical pairs reveal that in addition to the restrictions on the cooccurrence and alignment of [long VOT] segments, Quechua also restricts the cooccurrence of segments that share the articulatory features [cg] and [sg]. The ungrammatical pairs in (17) share articulatory features, while the grammatical pairs are both articulatorily and acoustically distinct, sharing neither [long VOT], [cg] nor [sg]. The two additional GOCP constraints needed to account for the data in (17) are defined in (18).

(18) \[\begin{align*}
\text{GOCP}[\text{cg}] & : \text{No two [cg] segments in a root.} \\
\text{GOCP}[\text{sg}] & : \text{No two [sg] segments in a root.}
\end{align*}\]

Roots with both glottal stop and an ejective violate GOCP[cg] and roots with both [h] and an aspirate violate GOCP[sg]. The high-ranking of GOCP[cg] and GOCP[sg] over faithfulness to [cg], [sg] and [long VOT] accounts for the restrictions on ejectives and aspirates with the laryngeal consonants. The analysis is shown in (19).

(19) \[\begin{align*}
\text{(19) a. } /\text{ʔap'i}/ & \quad \text{GOCP} \quad \text{GOCP} \quad \text{GOCP} \quad \text{Max} \quad \text{Max} \quad \text{Max} \\
& \quad \text{[cg]} \quad \text{[sg]} \quad \text{[long VOT]} \quad \text{[cg]} \quad \text{[sg]} \quad \text{[long VOT]} \\
\text{i. } & \text{ʔap'i} & * ! & & & & \\
\text{ii. } & \text{ʔapi} & & * & & *
\end{align*}\]

\[\begin{align*}
\text{(19) b. } /\text{hap'i}/ & \quad \text{GOCP} \quad \text{GOCP} \quad \text{GOCP} \quad \text{Max} \quad \text{Max} \quad \text{Max} \\
& \quad \text{[cg]} \quad \text{[sg]} \quad \text{[long VOT]} \quad \text{[cg]} \quad \text{[sg]} \quad \text{[long VOT]} \\
\text{i. } & \text{hap'i} & * ! & & & & \\
\text{ii. } & \text{hapi} & & * & & *
\end{align*}\]

Glottal stop may cooccur with aspirates and [h] may cooccur with ejectives because these pairs of segments do not share any articulatory or acoustic features, and thus do not violate high-ranked markedness constraints. Similarly, the glottal consonants [ʔ, h] may cooccur.

(20) \[\begin{align*}
\text{(20) a. } /\text{ʔap'h}/ & \quad \text{GOCP} \quad \text{GOCP} \quad \text{GOCP} \quad \text{Max} \quad \text{Max} \quad \text{Max} \\
& \quad \text{[cg]} \quad \text{[sg]} \quad \text{[long VOT]} \quad \text{[cg]} \quad \text{[sg]} \quad \text{[long VOT]} \\
\text{i. } & \text{ʔap'h} & & & & \\
\text{ii. } & \text{ʔapi} & & * ! & & *
\end{align*}\]

\[\begin{align*}
\text{(20) b. } /\text{hap'i}/ & \quad \text{GOCP} \quad \text{GOCP} \quad \text{GOCP} \quad \text{Max} \quad \text{Max} \quad \text{Max} \\
& \quad \text{[cg]} \quad \text{[sg]} \quad \text{[long VOT]} \quad \text{[cg]} \quad \text{[sg]} \quad \text{[long VOT]} \\
\text{i. } & \text{hap'i} & & & & \\
\text{ii. } & \text{hapi} & & * ! & & *
\end{align*}\]
The analysis presented here references both articulatory and acoustic features, which overlap in the sets of segments they define; all [long VOT] segments are either [cg] or [sg]. The violations of faithfulness constraints in (20) show this overlap: deletion of ejection violates both MAX[cg] and MAX[long VOT], deletion of aspiration violates both MAX[sg] and MAX[long VOT]. The overlap in violations of faithfulness constraints means that the ranking of faithfulness to [long VOT] relative to GOCP[cg] and GOCP[sg] is relevant, as shown in (20). Additionally, the relative ranking of faithfulness constraints to [cg] and [sg] and markedness constraints on [long VOT] is crucial. MAX[cg] and MAX[sg] must, like MAX[long VOT], be ranked below GOCP[long VOT]; IDENT[cg] and IDENT[sg] must, like IDENT[long VOT], be ranked below ALIGN[long VOT]. These ranking arguments are given in (21) where faithfulness constraints to [cg] are used to illustrate the point for both [cg] and [sg].

The ranking of MAX[long VOT] over ALIGN[long VOT] is sufficient to block deletion of medial ejection and aspiration when the initial consonant is a non-stop. The relative ranking of MAX[cg] and MAX[sg] relative to ALIGN[long VOT] is irrelevant, since any candidate that violates MAX[cg] or MAX[sg] also violates MAX[long VOT].

4.3. Summary of the analysis
The full ranking of constraints needed to account for the range of long-distance restrictions on laryngeal features is given in Figure 10.
The laryngeal restrictions in Quechua require both acoustic and articulatory features. The grouping of ejectives and aspirates under the acoustic feature [long VOT] accounts for the largely uniform patterning of these two types of sounds in Quechua. The restriction against ejective-aspirate pairs is a challenge for standard, articulatorily based feature theories because ejectives and aspirates do not share any articulatory properties. Indeed, previous analyses have been forced to stipulate that ejectives and aspirates may not cooccur (MacEachern 1999; Mackenzie 2009 for similar restrictions in Peruvian Aymara). With the acoustic feature [long VOT], the interaction of ejectives and aspirates is easily accounted for.

The articulatory features [cg] and [sg] group ejectives with glottal stop and aspirates with [h], accounting for why these combinations of sounds are also disallowed. With GOCP constraints on [cg], [sg] and [long VOT], the analysis of roots with pairs of ejectives and pairs of aspirates is ambiguous. These pairs are ruled out by both GOCP constraints on [cg] and [sg], or GOCP[long VOT]. It is the ungrammaticality of ejective-aspirate pairs, which can only be analyzed as a restriction on [long VOT], and [ʔ]-ejective and [h]-aspirate pairs, which can only be analyzed as restrictions on [cg] and [sg] respectively, that shows the necessity of all three features to the analysis of Quechua.

4.4. The relevance of Quechua to the laryngeal node hypothesis

The main challenge for an analysis of Quechua is the ungrammaticality of ejective-aspirate pairs, *K'-T₃, a restriction that initially seems like an argument for the laryngeal node (Mohanan 1983; Clements 1985), which dominates all laryngeal features, as in (22).

(22)
```
  Root
 /   \
|     |
| laryngeal place…|
| [voice] [cg] [sg] |
```

Evidence for an abstract node grouping all laryngeal features comes from phonological phenomena that target multiple laryngeal features. Initially the uniform patterning of ejectives and aspirates in Quechua seems to be an example of just this type of phenomenon. An analysis of Quechua that appeals to the laryngeal node would account for the absence of ejective-aspirate forms with a constraint against multiple laryngeal nodes in a root, under the assumption that plain stops and non-stops are unspecified for laryngeal features and thus lack a laryngeal node.
The absence of pairs of ejectives, pairs of aspirates and ejective-aspirate pairs in Quechua would all be accounted for with a single constraint against multiple laryngeal nodes.

(23) a. *K’…P’
    lar lar
    [cg] [cg]

b. *K^h…P^h
    lar lar
    [sg] [sg]

c. *K’…P^h
    lar lar
    [cg] [sg]

d. ✓ K…P
    lar lar
    [cg] [sg]

The trouble, however, is that such an analysis cannot account for the patterning of the glottal consonants. Crucially, roots in Quechua may contain multiple laryngeal nodes, as in roots with two glottal consonants, an ejective and [h] or an aspirate and [ʔ].

(24) a. ✓ ?…h
    lar lar
    [cg] [sg]

b. ✓ h…P’
    lar lar
    [sg] [cg]

c. ✓ ?…P^h
    lar lar
    [cg] [sg]

An analysis based on the laryngeal node fails because it does not distinguish ejective-aspirate pairs from the other, grammatical combinations of laryngeally specified consonants in (24). MacEachern (1999) deals with this problem by proposing that the OCP in Quechua targets pairs of consonants with both laryngeal nodes and place nodes, under the assumption that glottal segments are unspecified for place. While such a constraint can correctly account for the Quechua data, any reference to the laryngeal node makes faulty predictions. If OCP constraints may refer to the laryngeal node, then we predict that any set of laryngeal features may pattern as a class, e.g. that voiced and ejective plosives may be restricted as a class, or that ejectives, aspirates and glottal segments may all be restricted from cooccurring. As will be shown in greater detail in the next section, restrictions on articulatorily and acoustically disparate groups of laryngeally marked segments are unattested.

This examination of an analysis based on the laryngeal node shows that the range of restrictions in Quechua makes a particularly compelling case for acoustic features in phonology. It is not the case that all laryngeally marked consonants are prohibited from cooccurring. Rather, it is only combinations of consonants that share an acoustic or an articulatory feature that are disallowed. The restriction against ejective-aspirate pairs shows that articulatorily disparate sounds may pattern together if they share an acoustic property, and the restriction against ejective-[ʔ] and aspirate-[h] pairs show that acoustically disparate sounds may pattern together if they share an articulatory property.

5. Extensions and predictions

The essence of the proposal is that sounds pattern together in the phonology because they are naturally grouped in either articulatory or acoustic terms. The previous section has shown that acoustic features are necessary to account for laryngeal restrictions in Quechua. This section looks at the survey of laryngeal cooccurrence restrictions in MacEachern (1999) and shows that all attested interactions between laryngeally marked sounds can be stated in articulatory or acoustic terms. The survey shows that laryngeal cooccurrence restrictions do not target arbitrary groupings of laryngeally marked sounds, but rather target articulatorily or acoustically natural
groupings of segments. The extension of the feature set to include acoustic features makes more restricted and accurate predictions about possible laryngeal cooccurrence restrictions than the analysis of MacEachern, which employs only the standard articulatory features [cg] and [sg], and thus must use multiple, phonetically unrelated features to pick out acoustic sound classes.

MacEachern’s survey looks at cooccurrence restrictions in 11 languages, from 9 language families and 8 geographical areas. The survey includes one language from the Afro-Asiatic family (Hausa), one Caucasian language (Old Georgian), one Mayan language (Tz’utujil), one Salishan language (Shuswap), one Siouan language (Ofo) and one Quechuan language (Cusco Quechua), as well as one isolate (Souletin Basque). There are two languages taken from the Indo-Aryan family (Gojri and Sanskrit), as well as two Aymaran languages (Bolivian and Peruvian Aymara). Aymaran and Quechuan languages are geographically close, both are spoken in the Andes mountains.

5.1. Restrictions on the articulatory features [cg] and [sg]
MacEachern surveys cooccurrence restrictions in eleven languages from a diverse group of language families. Five of these languages have restrictions on one of the articulatory features, [cg] or [sg], and are thus easily accounted for. These languages are summarized in Table 3 below. The tables throughout this section show a language name, the segment types that must form a natural class to account for the restriction in that language, and the feature that accomplishes this grouping. Below this, a schematic representation of the grammatical and ungrammatical combinations are given. In the schematic representations, T is used to represent any voiceless unaspirated stop, Th any voiceless aspirated stop, T’ any ejective stop, D any voiced stop, Dh any voiced aspirated stop, d’ any implosive and N’ any glottalized sonorant; order is irrelevant.

In Souletin Basque and Sanskrit, a root may not contain two [sg] segments. In Souletin Basque, the [sg] segments are the voiceless aspirated stops and the glottal [h]. In Sanskrit, there are three types of [sg] segments that are all prohibited from cooccurring: voiceless aspirates, voiced aspirates and [h].

In Old Georgian, ejectives are prohibited from cooccurring. Since there is no glottal stop in this language, [cg] picks out the class of ejectives alone. In Bolivian Aymara, there is both a series of ejective stops and [ʔ], both of which are subject to a cooccurrence restriction. The inventory of Bolivian Aymara is the same as that of Quechua, but in Bolivian Aymara, only the [cg] segments are restricted. Finally, Hausa has a single series of glottalized consonants that includes both implosives and ejectives, as well as [ʔ]. In this language [cg] refers to all three of these segment types and all three types are restricted.
Table 3: Languages with restrictions on [sg] or [cg]\(^6\)

<table>
<thead>
<tr>
<th>Language</th>
<th>Segment grouping</th>
<th>Feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Souletin Basque (isolate)</td>
<td>aspirates and [h]; not voice</td>
<td>[sg]</td>
</tr>
</tbody>
</table>
|                                 | \begin{tabular}{l|lll}
| T      | T\(^h\) | D | h       \\
| T\(^h\)| *       | * |         \\
| D      | *       |   |         \\
| h      |         |   |         \\
| \end{tabular}                  |         |         |
| Sanskrit (Indo-Aryan)\(^7\)    | voiceless aspirates, voiced aspirates and [h]; not voiced unaspirated | [sg]    |
|                                 | \begin{tabular}{l|llllll}
| T      | T\(^h\) | D | D\(^h\) | h       \\
| T\(^h\)| *       | * | *        | *       \\
| D      | *       |   | *        | *       \\
| D\(^h\)| *       | * | *        |         \\
| h      |         | * | *        |         \\
| \end{tabular}                  |         |         |
| Hausa (Afro-Asiatic)            | ejectives, implosives and [?]; not voiced or aspirated | [cg]    |
|                                 | \begin{tabular}{l|lllll}
| T\(^h\) | D | T' | d' | ?       \\
| T\(^h\)| * | * | *   |         \\
| D      |   |   | *   |         \\
| T'     | * |   | *   |         \\
| d'     |   | * | *   |         \\
| ?      | * |   | *   |         \\
| \end{tabular}                  |         |         |
| Old Georgian (Caucasian)        | ejectives; not voiced or aspirated                     | [cg]    |
|                                 | \begin{tabular}{l|ll}
| T\(^h\) | D | T'       \\
| T\(^h\)|   |           \\
| D      |   | *        \\
| T'     | * |           \\
| \end{tabular}                  |         |         |
| Bolivian Aymara (Aymaran)       | ejectives and [?]; not aspirated or [h]                | [cg]    |
|                                 | \begin{tabular}{l|llll}
| T      | T\(^h\) | T' | h | ?       \\
| T\(^h\)| *       |   | * |         \\
| T'     | *       | * |   |         \\
| h      | *       |   |   |         \\
| ?      |         |   | * |         \\
| \end{tabular}                  |         |         |

\(^6\) In tables 3, 4 and 5 pairs of identical glottal segments (h-h and - - pairs) are not marked as ungrammatical though in many of these languages such combinations are absent. In some cases, this is due to a grammatical restriction, while in others it is simply due to the fact that glottal segments are only common in initial position.

\(^7\) The dissimilatory restriction in Sanskrit and Ancient Greek is commonly referred to as Grassmann’s Law.
5.2. Restrictions on the acoustic feature [long VOT]

Two of the languages in MacEachern’s survey show a restriction on [long VOT] alone, and two show a restriction on [long VOT] and one or both of [cg] and [sg]. These languages are summarized in Table 4.

Table 4: Languages with restrictions on [long VOT].

<table>
<thead>
<tr>
<th>language</th>
<th>segment grouping</th>
<th>feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ofo (Siouan)</td>
<td>aspirates; not [h]</td>
<td>[long VOT]</td>
</tr>
</tbody>
</table>
|                | \[
| T             | T^h | h                  |         |
| T^h           |     | *                  |         |
| h             |     |                    |         |
| Gojri (Indo-Aryan) | aspirates; not voiced or [h]               | [long VOT] |
|                | \[
| T             | T^h | D | h                      |         |
| T^h           |     | *                  |         |
| D             |     |                    |         |
| h             |     |                    |         |
| Peruvian Aymara (Aymaran) | ejectives, aspirates, ejectives and aspirates, ejectives and [?]; not [h], not aspirates and [?] | [long VOT] [cg] |
|                | \[
| T             | T^h | T’ | h | ?                     |         |
| T^h           |     | * | * | *                    |         |
| T’            |     | * | * | *                    |         |
| h             |     | * | * | *                    |         |
| ?             |     | * | * | *                    |         |
| Cusco Quechua (Quechuan) | ejectives, aspirates, ejectives and aspirates, ejectives and [?], aspirates and [h]; not ejectives and [h], not aspirates and [?], not [h] and [?] | [long VOT] [cg] [sg] |
|                | \[
| T             | T^h | T’ | h | ?                     |         |
| T^h           |     | * | * | *                    |         |
| T’            |     | * | * | *                    |         |
| h             |     | * | * | *                    |         |
| ?             |     | * | * | *                    |         |

In Gojri and Ofo, pairs of aspirates are disallowed, but aspirates may cooccur with [h]. The acoustic feature [long VOT] picks out aspirates to the exclusion of [h], a distinction [sg] does not make. To account for Gojri and Ofo, MacEachern assumes that [h] is distinguished from the aspirates in being [+sonorant], and that the cooccurrence restriction in these languages applies to
[+sg, -sonorant] segments. This solution is unsatisfactory because there is no theory of why it should be only the [-sonorant] spread glottis segments that are targeted by a GOCP constraint, nor why the combination of [+sg] and [-sonorant] is special in any way. Thus, the prediction is that cooccurrence restrictions may target segments that share any two features, a prediction that is clearly much too permissive. Many classes of segments that share two features are not subject to cooccurrence restrictions, e.g. restrictions on [+sg, -strident] segments, or [+sg, +coronal] segments are unattested. Known restrictions either prohibit the cooccurrence of any two [sg] segments, whether an aspirated obstruent or glottal [h], or of any two aspirates. By accounting for the patterning of aspirates to the exclusion of [h] with the acoustic feature [long VOT], we are able to maintain a more restrictive theory: cooccurrence restrictions always target a single acoustic or articulatory property.

Peruvian Aymara and Quechua both show cooccurrence restrictions on multiple features. Peruvian Aymara is identical to Quechua except that aspirates may cooccur with [h]. In both of these languages, ejectives may not cooccur in pairs nor with glottal stop, showing a restriction on [cg]; in Quechua only, aspirates may not cooccur with [h] showing a restriction on [sg]. In neither language may aspirates cooccur in pairs or with ejectives, revealing a restriction on [long VOT].

As discussed above, picking out the set of ejectives and aspirates is problematic for standard feature theory. To pick out ejectives and aspirates to the exclusion of the glottal consonants, MacEachern proposes a constraint against any two segments with both a laryngeal node and a place node. This analysis is again overly predictive in that it assumes that a cooccurrence restriction may target segments that share any two properties (here structural nodes as opposed to features), but the reference to the laryngeal node introduces an additional problem. If ejectives and aspirates pattern together because they both have a laryngeal node (and a place node), then we predict other languages where all segments with a laryngeal node are restricted. Namely, we predict languages where aspirates and voiced stops can’t cooccur, or ejectives and voiced stops can’t cooccur. Five of the nine languages summarized in Tables 3 and 4 above have voiced stops, and in all cases voiced stops do not participate in the cooccurrence restrictions. The prediction that the laryngeal node may be targeted by a cooccurrence restriction is not supported, as voiced stops seem to systematically not pattern with other laryngeally marked segments.

When multiple laryngeally marked segments are restricted in some languages, the restricted segments always share an articulatory or acoustic property: voiced and voiceless aspirates are both [sg] (Sanskrit), ejectives and implosives are both [cg] (Hausa), and ejectives and aspirates are both [long VOT]. It is not the case that any combination of two laryngeal features may be restricted, as predicted by reference to the laryngeal node, a point made for Quechua alone in Section 4.4 above. Rather, the range of attested cooccurrence restrictions is limited and easily defined in articulatory and acoustic terms. The non-participation of voiced stops in laryngeal cooccurrence restrictions follows from the fact that no single feature or phonetic property groups voiced stops with either ejectives or aspirates.

5.3. Extending acoustic features - [loud burst]
The remaining two languages in MacEachern’s survey, Shuswap and Tz’utujil, provide additional support for extending the feature set to include acoustic properties of sounds. These languages show restrictions on ejectives, but not other [cg] sounds like glottal stop, glottalized sonorants and implosives. While [long VOT] picks out ejectives from the other [cg] segments (neither glottal stop nor implosives are [long VOT]), the specifics of the realization of ejectives
in these languages means that not all ejectives can be specified for [long VOT]. Shuswap and Tz’utujil both allow ejectives in pre-consonantal and final position, where VOT is undefined (Steriade 1997).

The restrictions in Shuswap and Tz’utujil require reference to ejectives, both with and without long VOT, but not other [cg] segments, and thus provide additional evidence for acoustic features for laryngeal contrasts beyond [long VOT]. Regardless of whether an ejective is realized with long VOT or not, the distinctive properties of the release burst, namely its increased amplitude, are available (cf. Steriade 1997). Shuswap and Tz’utujil may thus be analyzed as prohibiting pairs of segments with a large burst amplitude, referred to in Table 5 by the acoustic feature [loud burst].

Table 5: Languages with restrictions on [loud burst]

<table>
<thead>
<tr>
<th>Language</th>
<th>Segment grouping</th>
<th>Feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shuswap (Salishan)</td>
<td>ejectives; not [ʔ] or glottalized sonorants</td>
<td>[loud burst]</td>
</tr>
<tr>
<td></td>
<td>T</td>
<td>T’</td>
</tr>
<tr>
<td></td>
<td>T</td>
<td>T’</td>
</tr>
<tr>
<td></td>
<td>N’</td>
<td></td>
</tr>
<tr>
<td></td>
<td>?</td>
<td></td>
</tr>
<tr>
<td>Tz’utujil (Mayan)</td>
<td>ejectives; not implosives or [ʔ]</td>
<td>[loud burst]</td>
</tr>
<tr>
<td></td>
<td>T</td>
<td>T’</td>
</tr>
<tr>
<td></td>
<td>T</td>
<td>T’</td>
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<tr>
<td></td>
<td>d’</td>
<td></td>
</tr>
<tr>
<td></td>
<td>?</td>
<td></td>
</tr>
</tbody>
</table>

The idea that ejectives in Shuswap and Tz’utujil are defined by their burst properties is largely conjectural at this point, as there are no comprehensive acoustic studies of laryngeal contrasts in either language. The distribution of ejectives in these two languages requires that ejectives and plain stops differ in properties other than their transition phases into a following vowel or sonorant. The increased burst amplitude of ejectives, identified for ejective-plain contrasts in other languages, is a promising candidate for distinguishing ejectives and plain stops in the absence of VOT.

The restrictions in Shuswap and Tz’utujil further support the claim that cooccurrence restrictions target sounds that share a single articulatory or acoustic property. While ejectives in these languages cannot be isolated with the previously motivated features [cg], [sg] and [long VOT], they can be referenced as a class, distinct from other [cg] segments, via their hypothesized loud burst amplitude.

5.4. Summary
This section has shown that all of the laryngeal cooccurrence restrictions identified by MacEachern are accounted for as restrictions on single articulatory or acoustic dimensions. Cooccurrence restrictions may target groups of sounds that cannot be classified with the standard laryngeal features [cg] and [sg], but far from requiring random groupings of laryngeally marked
sounds, these outstanding restrictions target sounds that share an acoustic property, either [long VOT] or [loud burst]. The acoustic feature [long VOT] picks out ejectives and aspirates as a class, and also distinguishes ejectives from glottal stop/implosives and aspirates from [h]. In languages where ejectives are not consistently realized with long VOT, these sounds can still be distinguished from other laryngeally marked segments by their characteristic burst amplitude.

6. Conclusion

This paper has argued for representing both the acoustic and articulatory properties of speech sounds. The main argument comes from the cooccurrence restrictions on ejectives and aspirates in Quechua, which require representing these two types of sounds as a class. The uniform patterning of ejectives and aspirates and the restriction on ejective-aspirate pairs is problematic for articulatorily based features, as these sounds are articulatorily disparate. I propose that the behavior of ejectives and aspirates as a phonological class is evidence for representing acoustic dimensions of contrast, specifically [long VOT]. When both acoustic and articulatory features are assumed, the restrictions in Quechua, as well as the range of laryngeal cooccurrence restrictions surveyed in MacEachern (1999), are neatly accounted for.

References