Articulatory Phasing of Glottal Stop

Marianne L. Borroff
Stony Brook University

1. Introduction[1]

It has been noted in the literature that glottal stop patterns differently from the supralaryngeal consonants, particularly in exhibiting transparency to spreading[2]. The examples in (1) exemplify this pattern; in Sundanese, nasality spreads through an intervening glottal stop but not through an oral stop, (1a). Likewise, in the Chemehuevi examples in (1b), the features of the vowel preceding the glottal stop spread across it onto the following vowel. Corresponding spreading across oral consonants does not occur.

(1)	a.	nĩʔĩs	‘relax in a cool place’
		ŋãtur	‘arrange’
			(Sundanese; Cohn 1993)
	b.	/nukwij**ɨʔu**mi/ → [nukwij**ɨʔɨ**mi]	‘run (pl.)’
		[ɨv**ɨju**ni]	‘ill/bad’
			(Chemehuevi; Press 1979)

A common approach to explaining the patterning of glottal stop is to attribute its transparency to lack of a specification for oral place (see, for example, Steriade 1987 for a placeless approach to translaryngeal harmony). Under this approach, spreading of vocalic features across a glottal stop is possible because such spreading does not involve crossing an intervening consonantal place specification, while spreading across oral consonants is ruled out by constraints against crossing of association lines of an intervening element.

While the placeless approach to the patterning of glottal stop provides an account of its transparency to spreading, I suggest here that it cannot provide a unified analysis of certain other phenomena involving glottal stop. In this paper I discuss three such phenomena; the fact that many languages require the vowels flanking glottal stop to be identical, that in some language hiatus resolution-like processes occur across glottal stop, and that in some languages glottal stop triggers echo epenthesis. These phenomena are illustrated in (3)-(5) below, respectively.

(3) Required Identity Across Glottal Stop

a.	/h**eʔ** **i**m b’ineʔ/ → [h**iʔ** **i**m b’ineʔ]	‘I will go’
		(Yucatec Maya; Ola Orie & Bricker 2000)
b.	/h**iʔe**yewise/ → [h**eʔe**yewise]	‘he is peaceful’
		(Nez Perce; Aoki 1970)

(4) Echo epenthesis across [ʔ]

a.	/kw**aʔ** + k/ → [kwaʔak]	‘to eat (transitive)’
		(Kekchi; Hall 2003)

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[2] Where possible I also give data from [h], which, sometimes patterns with [ʔ]. The analysis presented herein should be taken as applying only to [ʔ], however; further research is needed on the patterning and temporal characteristics of [ʔ].

b. /be:ʔ-t-aw/ → [be:ʔtaw] ~ [beʔetaw] 'my wound'
(Arbore; Hayward 1984)
c. /siʔukatʃa/ → [siʔiukatʃa] 'I see them (dual)'
(Acoma; Miller 1965)

(5) Hiatus Resolution across [ʔ]
a. /tʃx**i** + -**oʔ**/ → [tʃx**joʔ**] 'you clean'
/tʃz**iʔ** + -**oʔ**/ → [tʃz**jo̤**] 'you buy'
/tʃx**i** + -**choʔ**/ → [tʃx**ichoʔ**] 'we clean'
(Yatzachi Zapotec; Borroff 2003)
b. /tʃ**iʔ eh**/ → [tʃ**iye**h] 'bite it!'
(Yucatec Maya; Ola Orie & Bricker 2000)
c. /isk**iʔu**cʔasirrirʔi/ → [isk**i:**cʔasinnʔI] 'make me some shoes'
(Wichita; Rood 1976)

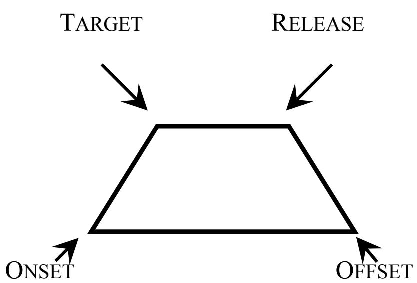
I propose that a unified analysis of all these patterns is possible if we shift our focus from the traditional featural representation of glottal stop to consider its gestural and temporal characteristics. In the next section, I present a novel approach to the glottal stop's gestural make-up, giving a principled account of the divergence in patterning between it and the supralaryngeal consonants in terms of a divergence in gestural make-up. In brief, I propose that the gestural make-up of glottal stop is such that it fails to participate in phasing relationships with flanking vowels. In section 3, I go on to show how this approach helps to explain the above-discussed patterning of glottal stop.

2. The Gestural Representation of Glottal Stop

2.1 Gestural Landmarks

In this paper, I take an approach to the patterning of glottal stop that combines insights from both Optimality Theory and Articulatory Phonology. Where this approach diverges from standard OT is in its conception of the nature of phonological inputs; here, phonological inputs are sets of abstract gestural specifications and accompanying phasing relations. This contrasts with more traditional approaches in which the phonology specifies inputs as sequences of discrete segments, which are themselves bundles of feature specifications (e.g. [-high, -low, +round] for [o]). For a more detailed discussion of these issues, see Browman and Goldstein 1986, et. seq, among others for Articulatory Phonology and Prince and Smolensky 1993, among others for Optimality Theory. The diagram below in (6) shows the standard gestural landmarks of a gestural representation, following Gafos 2002.

(6)

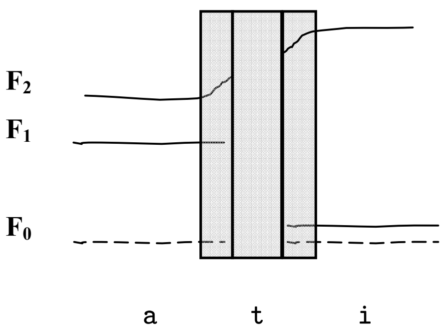


Definition of Gestural Landmarks: (Gafos (2002))

ONSET: The onset of movement towards the target gesture
TARGET: The point in time at which the gesture achieves its target
RELEASE: The onset of movement away from the target of the gesture
OFFSET: The end of all movement associated with the gesture

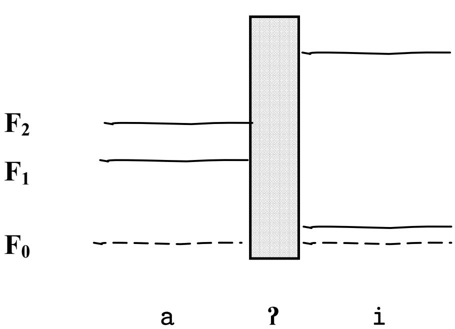
The diagram in (6) represents each specified gesture as unfolding in time as a set of gestural-temporal landmarks. It is these gestural landmarks that stand in phasing relations with landmarks of other gestures, and serve as anchoring points between two gestures (but see Byrd 1996's phase window account of gestural coordination, which allows a wider range of possible anchor points between gestures). I propose that not all of the proposed components of a gestural representation listed in (6) are present for every sound. I suggest that the acoustic consequences of the articulation of a gesture play an essential role in how the speaker represents that gesture in terms of its gestural landmarks. Only those components justified by reliable acoustic evidence are posited to be present by learners. To illustrate, consider the schematic diagram of the acoustic results of the articulation of a gesture of full closure at the alveolar ridge associated with the stop consonant 't'.

(7) TTCD={closure}, TTCL={Alveolar}



In the diagram in (7), the articulation of the alveolar closure associated with 't' is represented as having three acoustic consequences; formant transitions on the immediately preceding vowel, total silence during the period of closure, and formant transitions on the immediately following vowel. This diagram abstracts away from context sensitive aspects of the acoustics of stop closure, for example, aspiration before a stressed vowel. Compare to this the acoustic cues of the articulation of the gesture of glottal constriction associated with a glottal stop, as shown schematically in (8).

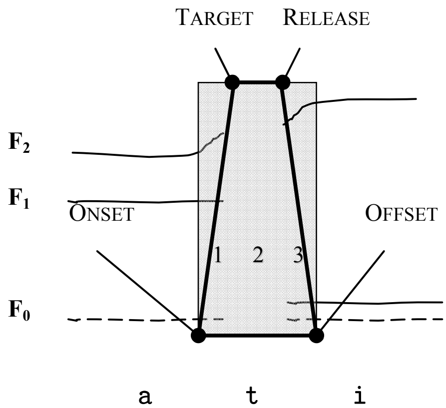
(8) GL.TD={closure}, GL.CL={glottis}



This diagram represents [ʔ] as causing no formant transitions on flanking vowels, supported by findings in Kent and Read (1992) who found that for "glottal stop … adjacent vowels are not associated with a marked formant transition." (cited in Shank and Wilson (2000), pge. 4.) Moreover, as Ladefoged and Maddieson 1996 note, glottal stop is not characterized by an immediate cessation of vocal fold pulses. Thus, a more accurate characterization would be a series of vocal fold pulses with periods of varying length, rather than silence. For the purposes of this paper, however, I believe we lose nothing by abstracting away from this particular difference between [ʔ] and other stops.

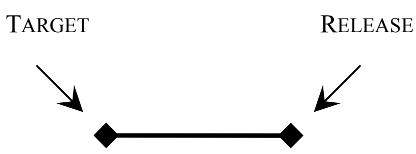
The divergence in the acoustics of the articulation of laryngeal and supralaryngeal constrictions, particularly with respect to formant transitions, is the source of a divergence in the gestural representations of laryngeal and supralaryngeal gestures. For clarity, I will refer to the internal make-up of a single gesture in terms of its gestural landmarks as its micro-gestural representation. The gestural representation of a sound or utterance in terms of the target specification of the gesture or gestures that comprise it would be its macro-gestural representation, or simply its gestural representation. I propose that it is exactly the presence of the acoustic cues of formant transition and silence associated with the articulation of closure for /t/ and other oral stops that gives the speaker the evidence necessary to posit the micro-representation in (6). In other words, oral consonantal gestures, at least stops, are specified micro-gesturally as containing the landmarks of ONSET, TARGET, RELEASE and OFFSET because these landmarks are acoustically recoverable in the speech stream. Crucially, these landmarks are not *a priori* present for gestures of stop closure, and by extension, neither are they necessarily present for any other gesture; the learner posits these landmarks if and only if they have recoverable acoustic reflexes. The diagram in (9) shows the correspondence of the proposed gestural landmarks for the tongue tip gesture associated with 't' and the acoustic cues associated with that gesture.

(9)

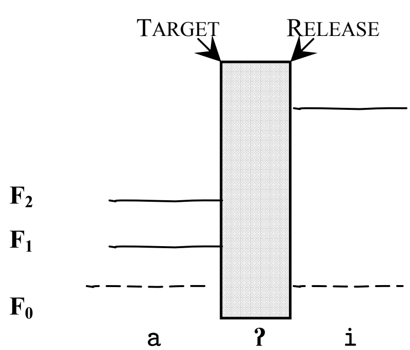


Given an approach to the construction of micro-gestural representations whereby only acoustically recoverable gestural landmarks are posited, what are the consequences for the nature of the micro-gestural representation of glottal stop? As discussed above, the articulation of a gesture of glottal constriction associated with glottal stop does not result in formant transitions on flanking vowels. Thus, in the articulation of this gesture there is no acoustic evidence for its being specified for the gestural landmarks of ONSET and OFFSET, since these landmarks are canonically indicated by the beginning of formant transitions on a preceding vowel and the end of formant transitions on a following vowel, respectively. (10) gives a schematic diagram of the proposed micro-gestural representation for glottal stop, in which only the gestural landmarks of TARGET and RELEASE are present. (11) shows the correspondence of the gestural landmarks for the gesture of glottal constriction with the acoustic results of the articulation of this gesture.

(10) Gestural representation of [ʔ]:



(11)



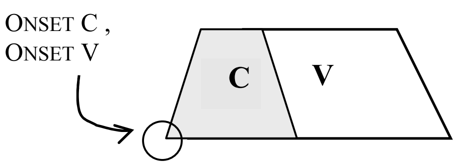
In this section, I have proposed that abstract phonological gestures may differ in their micro-gestural representations, and that these differences are rooted in differences in the acoustics of each particular gesture. In particular, I have suggested that the acoustic cues resulting from the articulation of a glottal constriction are such that the speaker is unable to posit the gestural landmarks of ONSET and OFFSET. In the next sub-section, I consider the consequences that this reconsideration of the micro-gestural representation of glottal stop has for its phonological patterning, proposing that the particular micro-gestural representation of this gesture precludes it from syllabifying as an onset to a following vowel.

2.2. Gestural Phasing of Glottal Stop

A long-standing issue in Articulatory Phonology is the extent to which sound constituents that are key to traditional approaches to phonology (e.g. the segment, the syllable, the foot) carry over into a gestural approach to phonology. The approaches that researchers have taken to this issue vary with the constituent; for example, the segment is generally considered an unnecessary notion within AP since the percept of a segment results from the overlap of independent gestures. At the same time, previous frameworks posited the existence of structure within the grammar based on recurring support for its presence; it would therefore be short-sighted to reject the notion of constituents like the syllable wholesale. If we are to incorporate the notion of the syllable into AP, then we must show that the syllable, and syllabic relations, are grounded in the relations holding among the gestures in an utterance. Browman and Goldstein (2000), for example, attempted to account for one particular pattern that supports the existence of syllable structure; that there are stable phasing relationships between the gestures of members of syllable onsets, and between syllable onsets and following vowels (their C-CENTER effect).

A related approach to how onset consonants are phased with respect to a following vowel comes from Goldstein (2004), who proposed that consonants that have traditionally been considered to be members of a syllable onset have a particular phasing relation with the following vowel. Specifically, the observed phasing relation holding between onset consonants and following vowels is such that the ONSET of the consonantal gesture is synchronous with the ONSET of the vocalic gesture. By extension, we can state this observation as a requirement on the phasing relations that must hold in order for a pre-vocalic consonantal gesture to be considered an onset; the required phasing relation is one in which the ONSET of both the consonantal and vocalic gestures are synchronous. The required phasing relationship is illustrated schematically in (12) below.

(12) Onset Phasing: In a CV sequence, the ONSET of the consonantal gesture is synchronous with the ONSET of the vocalic gesture.



(Goldstein 2004)

Given this elaborated understanding of the gestural grounding for the onset relation, we can now reconsider the formulation of the OT constraint ONSET, as in (13). (13a) gives the standard OT definition of this constraint, and (13b) gives the revised definition of this same constraint, incorporating Goldstein 2004's insights regarding the gestural relationship holding between syllabic onsets and syllabic nuclei.

(13) a. Standard ONSET: All syllables should have onsets.
b. Revised ONSET: For every vocalic gesture, the ONSET of a consonantal gesture should be synchronous with the ONSET of that vocalic gesture.

The revised ONSET constraint differs from its standard instantiation in being gesturally grounded, and is more targeted in its application; while the presence of any consonant is sufficient to satisfy standard ONSET, only those consonantal gestures that can be phased with a following vowel in the relevant manner will satisfy the revised constraint. At the same time, the necessity of a gesturally grounded revision of the ONSET constraint arises with the adoption of an AP approach to the phonology, under the assumption that gestures are the basic units of phonological specification; strictly speaking, the traditional notion of an 'onset' as a pre-vocalic consonant is senseless because 'consonants' do not exist independently of the gestures that compose them in this approach (e.g. 'consonant' is a pre-theoretic term).

The consequence of the proposed redefinition of the OT constraint ONSET, for the gesture of glottal constriction is that it will never be syllabified as an onset because it lacks the gestural landmark of ONSET necessary for it to stand in the required phasing relation with a following vowel. I suggest that the independently motivated gestural re-consideration of the onset relation, and the consequent redefinition of the OT constraint ONSET, taken along with the proposed micro-gestural representation for glottal constriction, give an account of each of the observed glottal stop patterns in (3)-(5): required identity across glottals, hiatus resolution across glottals and echo epenthesis across glottals.

3. Analysis

3.1 Required Identity Across Glottals

The data presented below in (14) give examples of languages in which the vowels flanking glottal stops must be identical. This requirement holds across intervocalic laryngeals in mono-morphemic words and also holds across morpheme boundaries when the underlying vowels are not identical. The Wichita and Chemehuevi data in (14c,d) serve to illustrate that in some languages only a subset of VʔV sequences undergo repair; in Wichita only aʔi and iʔa sequences undergo coalescence, and in Chemehuevi only those vowels that are disallowed in VV sequences will be repaired through coalescence in VʔV.

(14) a. Yucatec Maya (Mayan);Vowels flanking [ʔ,h] must be identical:
w**iʔi**t' — 'loincloth'
t**oho**l — 'price, value'
h**eʔ** + **i**m b'ineʔ → h**iʔ i**m b'ineʔ — 'I will go'
(Ola Orie and Bricker 2000)

b. Nez Perce (Penutian); vowel flanking [ʔ,h] on the surface must be identical
wisk**eʔe**ytx — 'go on a trip!'
h**iʔe**lwice → h**eʔe**lwice — 'he spends winter'
h**íhe**qtise → h**éhe**qtise ~ h**é**qtise — 'he is getting old'
(Aoki 1970)

c. Wichita (Caddoan); underlying [aʔi] and [iʔa] undergo spreading
n**a** + **ʔi**caki + h → n**eʔe**cekih — 'sitting'
t**i** + **ʔa**k + hisha → t**aʔa**khisha — 'he is holding it in his arms'
(Rood 1976)

d. Chemehuevi (Uto-Aztecan); illegal VʔV sequences undergo spreading
na-ravasɯ-t**uʔi**-vɯɯ → naravasɯt**uʔi**vɯ / ***uʔu** — 'dried oneself'
nukwi-j**ɯ-ʔu**mi → nukwi-j**ɯʔɯ**mi — 'run (pl.)'
(Press 1979)

The present analysis of the micro-gestural representation of glottal stop can straightforwardly handle the patterns exhibited by harmony-across-glottals languages like those shown in (14); repair of the offending non identical vowels in an underlying $V_1ʔV_2$ sequence is a result of a constraint ranking in which the constraint ONSET is high ranked. Because the gesture of glottal constriction associated with the glottal stop fails to syllabify as an onset to the second vowel in a VʔV sequence, the fully faithful output candidate will incur a fatal violation of ONSET. Thus, the winning output candidate will diverge from the input in having undergone repair of the onsetless syllable. In the case of harmony-across-glottals languages, the actual output candidate avoids the ONSET violation at the cost of violating the constraint UNIFORMITY[3]. The result is an optimal candidate in which the two underlying vowels have coalesced into one. The percept of two vowels is an illusion of the fact that the output vowel spans the glottal constriction. Turning now to the case of hiatus resolution-like patterns occurring in VʔV despite the presence of the glottal stop, I suggest that a similar account is available for this phenomenon.

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[3] UNIFORMITY: Output segments (gestures) should have at most one input correspondent. (McCarthy andPrince 1995, LaMontagne and Rice 1995, deLacy 1999)

3.2 Hiatus Resolution Across Glottals

The data in (15) give representative examples from languages in which hiatus resolution-like patterns occur in VʔV despite the presence of a glottal stop. These patterns present a problem for standard OT approaches to hiatus resolution, which attribute it to the action of the constraint Onset; presumably, glottal stop should provide an onset to the following vowel and block hiatus resolution. However, given the gesturally grounded redefinition of the Onset constraint proposed here, the fact that [ʔ] doesn't block hiatus in the languages in (15) is easily explained.

(15) a. Yatzachi Zapotec (YZ; Oto-Manguean); VV sequences repaired through coalescence or diphthongization:

zetʃ**a**	+	-**a**ʔ	→	ze.tʃ**a**ʔ	'I stand'
tʃbezə	+	-**a**ʔ	→	tʃbe.z**a**ʔ	'I wait'
tʃn̠**e**	+	-**o**ʔ	→	tʃn̠j**o**ʔ	'you speak'

b. YZ; VʔV sequences repaired through spreading/coalescence:[4]

tʃʃagn**a**ʔ	+	-**a**ʔ	→	tʃʃag.n**a***a̤*	'I marry'
tʃselǝʔ	+	-**a**ʔ	→	tʃse.l**a***a̤*	'I send'
tʃb**e**ʔ	+	-**o**ʔ	→	tʃb**j***o̤*	'he sits'

(from Butler-Haworth 1980, Borroff 2003)

c. YM; A glide is epenthesized into VV sequences and some Vʔ,hV sequences:

le mees**a**	+	**e**ʔ	→	le mess**aye**	'that table'
m**aʔ**	+	**ʔa**k-taan	→	m**awa**k-taan	'it is not opposite to me'
s**ih**	+	**e**h	→	s**iye**h	'present it!'

(Orie and Bricker 2000)

d. Wichita; VV sequences coalesce, some Vʔ,hV undergo coalescence:

ʔir**i**	+	**a:**has	→	ʔir**a:**has	'wet the bed'
isk**iʔu**cʔasirrirʔi			→	isk**i:**cʔasinnʔI	'make me some shoes'
re::his			→	**re::**s	'buy'

(Rood 1976)

As for languages that require the vowels flanking glottal stop to be identical, languages that repair 'hiatus' in VʔV sequences rank the constraint Onset high, as exhibited by the fact that hiatus does not survive into the output in VV sequences. Thus, under the proposal that [ʔ] does not satisfy the revised Onset constraint, VʔV sequences will fatally violate Onset. The type of repair strategy (e.g. coalescence, epenthesis, diphthongization, etc…) that a form will undergo is determined by the language specific ranking of constraints in the grammar. Essentially, the phenomena of required identity across glottal stop and hiatus resolution across glottal stop are subcases of the same phenomenon; the apparent divergence between the two patterns results from the language specific ranking of the Onset constraint with respect to constraints ruling out repair (e.g. Uniformity, Dep, NoDiphthong, etc…). For example, a constraint ranking of Dep, NoDiphthong >> Onset >> Uniformity will mark a language in which the vowels flanking a glottal stop must be identical, while a ranking of Onset >> Dep, Uniformity, NoDiphthong will mark a language exhibiting hiatus resolution across glottals.

In the next section, I turn to explaining the observation that the presence of a glottal stop tends to trigger the epenthesis of a copy vowel. I propose that the apparent echo epenthesis across a glottal stop

[4] The [ʔ]s in YZ VʔV forms are realized in casual speech as creakiness on the vowel, as represented by italics in the handout. However, data gathered in the field by the author show that, in careful speech, VʔV forms are realized with a full [ʔ].

occurring in some language is a result of the fact that the gesture of glottal constriction does not participate in a phasing relationship with a flanking vowel.

3.3 Echo Epenthesis Across Glottals

Echo epenthesis across glottal stop often occurs as a means of breaking up an illegal cluster of which [ʔ] is a member. The data in (16) give examples of languages exhibiting echo epenthesis across glottals in this environment.

(16) a. Kekchi (Mayan); apparent echo epenthesis breaks up a [ʔC] cluster:

kw**aʔ** + k	→	kw**aʔa**k		'to eat (transitive)'
kwuʔt**eʔ** + k	→	kwuʔt**eʔe**k		'to howl'
				(Hall 2003)

b. Arbore (Cushitic); long vowels surface either with both moras preceding the [ʔ] or one preceding and one following:

be:k-t-aw	→	b**e:ʔt**aw	~ b**eʔet**aw	'my wound'
di:k-t-e	→	d**i:ʔt**e	~ d**iʔik**te	'(she) bled'
gaad-ne	→	g**a:ʔn**e	~ g**aʔan**e	'(we) buried'
				(Hayward 1984)

c. Acoma (Keres); a vowel preceding [ʔ] underlyingly spans it on the surface:

/s**iʔu**katʃa/	→	[s**iʔiu**katʃa]		'I see them (dual)'
				(*Miller 1965)*

While the data in (16) are often considered to be examples of epenthesis of a copy vowel immediately following the glottal stop, data from Arbore given in (16b) suggest that epenthesis may not be the right approach here. In Arbore, long vowels preceding [ʔC] clusters vary with respect to their surface realizations; either both moras precede or one mora precedes and one follows the [ʔ]. I propose that this is in fact evidence of the temporal mobility of [ʔ] with respect to the preceding vowel; here the gesture of glottal constriction is articulated such that it is overlapped, and entirely contained by, the vocalic gesture. The data from Kekchi in (16a) likewise suggest that this is the right approach; Campbell 1976 and Hall 2003 note that Kekchi speakers treat VʔV sequences created through putative echo epenthesis as mono-syllabic, while underlying VʔV is treated as disyllabic.

I propose that the variation in the temporal position of the articulation of the glottal constriction gesture for glottal stop results from its failing to participate in any phasing relation with flanking vowels. Oral consonantal gestures are temporally anchored with respect to surrounding gestures by means of the phasing relations holding between it and those surrounding gestures. Because glottal stop does not participate in these phasing relations, it is not temporally anchored and is free to vary in temporal position.

4. Conclusion

This paper has presented an Optimality Theoretic Articulatory Phonology approach to the patterning of glottal stop that unified seemingly disparate facts regarding the patterning of glottal stop and the divergence in patterning between the laryngeal and supralaryngeal consonants. I have proposed that speakers make use of evidence from the acoustics of the speech signal, not only to create gestural representations of sounds and utterances, but also to create the micro-gestural representations of gestures. Under this approach, speakers will only posit a gestural landmark to be present within the micro-gestural representation of a given gesture if and only if there is direct acoustic evidence for its presence. Thus, the micro-gestural representation of the glottal constriction gesture differs from that of other stop consonants exactly because they differ acoustically. This divergence in micro-gestural representation was in turn responsible for the inability of glottal stop to syllabify as an onset, and for the patterns described in this paper. In addition, this paper makes the contribution of challenging the idea that all gestures are micro-gesturally identical. This paper also complements previous research which has shown a link between perception and observed gestural organization, including Silverman 1997 and Chitoran et al. 2002.

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