SOME NEW GENERALIZATIONS CONCERNING GEMINATE INALTERABILITY

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I. INTRODUCTION

• *Geminate inalterability*: failure of a phonological processes which apply to short segments to apply to corresponding long segments.

• A classic example of inalterability:

(1) Tigrinya (Kenstowicz 1982, Hayes 1986, Schein & Steriade 1986)

a.	kətəma-**x**a	'town-2sg.m.'
	ʔa-**x**alɨb	'dogs'
	ʔɨti **x**albi	'the dog'
	mɨra**x**-na	'calf-3sg.f.'
	tɨ-**χ**ətl-i	'kill-2sg.f. imperfect'
b.	fə**kk**əra	'boast'
	qətəl-na-**kk**a	'we have killed you (masc.)'

• This phenomenon of geminate inalterability has been the subject of a number of influential proposals, including Guerssel 1977, Hayes 1986, Schein & Steriade 1986, Selkirk 1990, and Inkelas & Cho 1993.

• Churma 1988: geminate inalterability has an important typological connection with lenition processes, which none of the previous approaches captures.

• In this talk, I attempt to clarify the nature of this connection, and present a phonetically based Optimality Theoretic account of the generalizations, couched within a broader theory of lenition.
- I characterize lenition as spatial or temporal reduction of articulatory gestures. Traditionally, this class of processes includes degemination, medial voicing, spirantization, flapping, debuccalization, and elision.

II. THE LENITION CONNECTION

• I am **not** claiming that geminate inalterability effects only occur in lenition processes.

• For example, rounding harmony is sometimes (e.g. Maltese: McCarthy 1979, Schein & Steriade 1986), but not always (cf. Khalkha Mongolian: Street 1962, Schein & Steriade 1986) blocked by long vowels .
- This particular blocking effect can be attributed to a *positional faithfulness* constraint (cf. Beckman 1997): IDENT(rnd/long V).
- Under general assumptions of OT, the cross-linguistic variation in this blocking effect follows from the ranking of IDENT(rnd/long V) relative to the harmony-inducing constraint:

(2) If IDENT(rnd/long V) » HARMONY ⇒ geminate blocking, e.g. Maltese
If HARMONY » IDENT(rnd/long V) ⇒ no blocking, e.g. Khalkha Mongolian

• In contrast, the behavior of geminates under lenition displays **hard generalizations**, cf. Churma 1988, Elmedlaoui 1993, and lenition surveys of Lavoie 1996, Kirchner (in progress):

(3) Geminate Lenition Generalizations (see Appendix A for documentation)
A. No process converts a consonant (geminate or otherwise) to a geminate with reduced oral constriction (cf. Churma 1988, Elmedlaoui 1993).
B. No process converts a (tautomorphemic) geminate stop to a "half-spirantized" cluster, e.g. /kk/ – *[xk].
C. No process converts a voiceless segment (geminate or otherwise) to a voiced geminate obstruent (cf. Churma 1988, Elmedlaoui 1993).
D. "Partial geminates" (i.e. homorganic nasal + stop or lateral + stop clusters) behave identically to full geminates with respect to reduction of oral constriction; but, unlike full geminates, they readily undergo voicing.
E. No occlusivization nor obstruent devoicing process targets singletons to the exclusion of geminates (Churma 1988).

III. AN EFFORT-BASED OT APPROACH TO LENITION

Core proposal: LAZY ("minimize articulatory effort," generally favors reduction of articulatory gestures) vs. lenition-blocking constraints (e.g. faithfulness, favoring preservation of underlying specifications)[1]

• Spirantization, for example, follows from rankings where LAZY dominates faithfulness to continuancy.

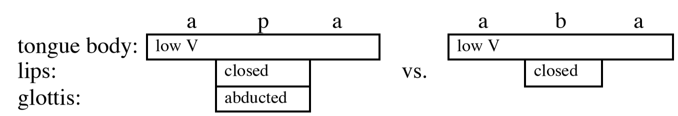
(4) a. Spirantization occurs

	/b/	LAZY	IDENT(cont)
	b	**!	
☞	β	*	*

b. Spirantization is blocked

	/b/	IDENT(cont)	LAZY
☞	b		**
	β	*!	*

• See Westbury & Keating 1986: in utterance-medial position, obstruents of normal duration (typically 50-80 msec) undergo *passive voicing*, unless they are devoiced by active abduction (or constriction) of the glottis. Voicing lenition can therefore be understood as the elimination of a glottal abduction gesture.[2]

(5)


• More generally, the lenition processes occurring in a given language depend upon which of the faithfulness constraints are ranked below LAZY:

(6) if LAZY » IDENT(voi) ⇒ voicing lenition
if LAZY » IDENT(place features) ⇒ debuccalization
if LAZY » IDENT(length) ⇒ degemination
etc.

[1] In addition, lenition can be blocked by *fortition* constraints, which actively favor more fortified outputs, as in occlusion and devoicing processes (see section VI). Plausibly, such constraints are grounded in considerations of perceptual enhancement, see generally Flemming 1995. The *interaction* between LAZY and lenition-blockers is essentially the same for purposes of understanding lenition typology, whether the blockers are faithfulness or fortition constraints.

[2] Furthermore, in many languages the oral closure gesture in voiceless stops is of greater magnitude than in voiced stops, an observation reflected in the traditional notion that voiceless stops are "fortis," i.e. involving greater muscular force. For languages in which this is the case, the greater effort cost of the more fortis gesture would provide additional impetus for voicing lenition. See generally Ladefoged & Maddieson 1996, chapter 3.

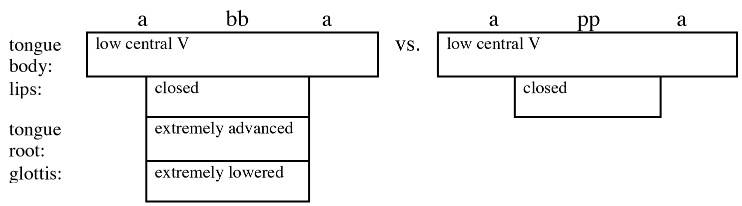
- This approach is part of an emerging research program which weds the substance of functional phonetic explanation with the formalism of OT constraint interaction, cf. Steriade 1993, 1995, 1996; Kaun 1994; Flemming 1995, 1997; Jun 1995; Silverman 1995; Frisch 1996; MacEachern 1996; Myers 1996; Beckman 1997; Boersma 1997a, 1997b, 1997c, 1997d; Gafos 1997; Hayes 1997; and Kirchner 1997, (in progress). More generally, the approach continues a line of research on phonetic explanation in phonology, associated with phoneticians such as Grammont (1939), Ohala (1981, 1983), Lindblom (1983, 1990a, 1990b) and Kohler (1991).

- Additional assumptions and results of this effort-based approach, including accounts of the common intervocalic context for lenition, and the phenomenon of fast-speech lenition, are discussed in Appendix B.

IV. EFFORT IN GEMINATES

- Voicing:
  - For aerodynamic reasons, geminate stops tend to devoice (Ohala 1983). Voicing can nevertheless be sustained by means of cavity expansion gestures (e.g. pharyngeal expansion, larynx lowering), Rothenberg 1969.

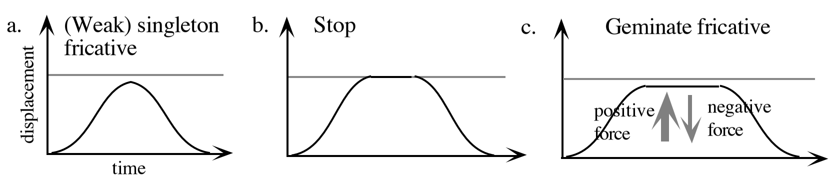
(7)



Due to the additional effort cost of these accompanying cavity expansion gestures, **voiced geminate stop $>_{\text{effort}}$ voiceless geminate stop** (the reverse of the situation in medial singletons).
  - Air is vented during the nasal or lateral portion of a partial geminate, preventing significant build-up of oral pressure. Cf. Hayes & Stivers (in progress).

- Spirantization:
  - Key claim: **geminate fricative $>_{\text{effort}}$ geminate stop**.

(8)



  - To explore the relation between effort and articulator movement more explicitly, Hayes & Kirchner (in progress) have developed a simplified computational mass-spring model of consonant articulation:

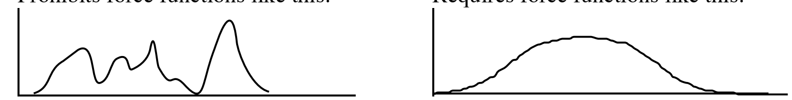
¶ The user specifies temporal and spatial targets for articulator movement. The model finds, by gradient-ascent learning, the function of force against time which achieves these targets with the least possible effort.

¶ Effort is equated with the absolute value of the area under the force function.

¶ In the current version of the model, the force function is subject to an additional restriction: the targets are achieved using at most one positive and one negative (bell-shaped) force "impulse."

(9) <u>"Impulse" restriction on mass-spring model</u>:

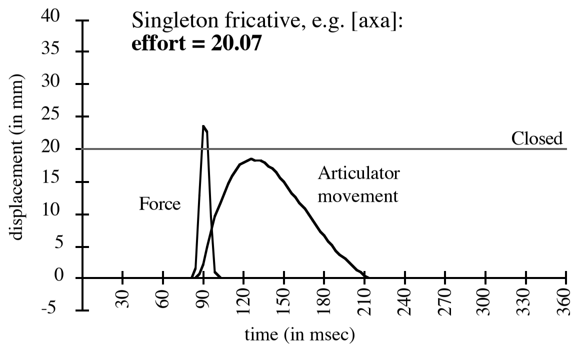
Prohibits force functions like this: Requires force functions like this:



¶ Further details of the model are given in Appendix C.

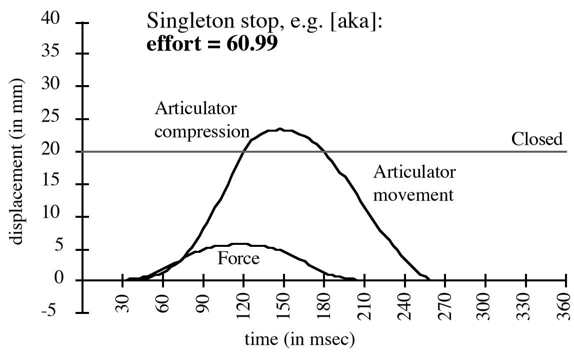
- Results (annotated output of mass-spring model):[3]

(10) a.



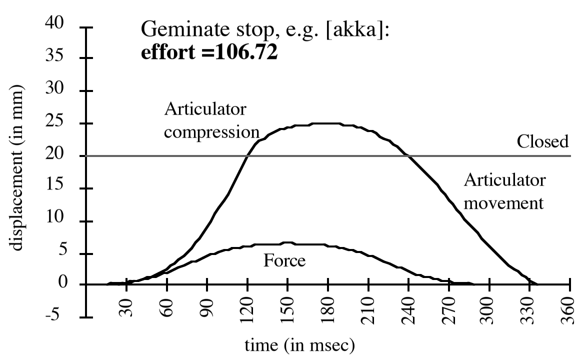
Singleton fricative, e.g. [axa]:
effort = 20.07

b.



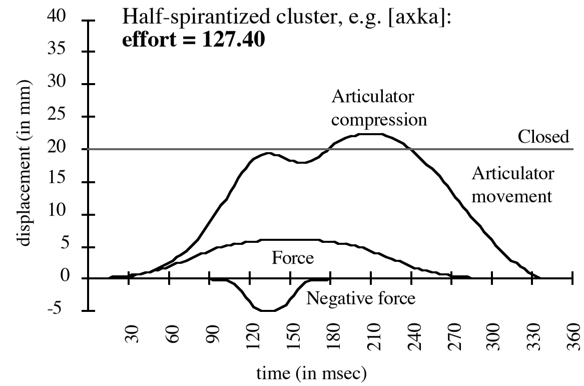
Singleton stop, e.g. [aka]:
effort = 60.99

c.



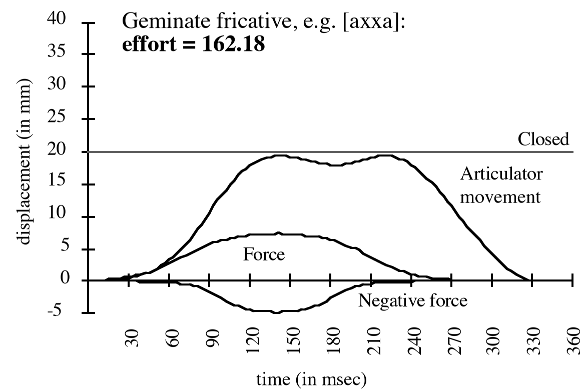
Geminate stop, e.g. [akka]:
effort =106.72

d.



Half-spirantized cluster, e.g. [axka]:
effort = 127.40

e.



Geminate fricative, e.g. [axxa]:
effort = 162.18

- Effort hierarchy under this model:
  Geminate fricative (162.18) **> half-spirantized cluster** (127.40) **> geminate stop** (106.72) **> singleton stop** (60.99) **> singleton fricative** (20.07)

- These inferences concerning spirantization of geminate stops apply equally to partial geminates: for the effort relations above refer to oral constriction gestures, which are equivalent in full and partial geminates, as schematized in (11):

(11)

	a. Full geminate: □□□ [tt]	b. Homorganic nasal + stop cluster: [nd]	c. Homorganic lateral + stop cluster: [ld]
Velum:		lowering	
Tongue tip:	closure	closure	closure
Tongue body:			transverse constriction

Hence, **spirantized partial geminate $>_{\text{effort}}$ unreduced partial geminate.**

[3]The force values shown in these graphs (though not the effort figures appearing in the captions) are multiplied by a factor of 30, for display purposes.

V. INCORPORATING THESE RESULTS INTO A FORMAL GRAMMAR

• No ranking of IDENT(cont) and LAZY allows an input stop (geminate or otherwise) to map to an output geminate continuant, nor to a half-spirantized geminate (Generalizations 3A, B) :

(12)

	ap(p)a	LAZY	IDENT(cont)
☞	appa	*	
	aϕpa	**	*
	aϕϕa	***	*

• By similar reasoning, geminate stops cannot undergo voicing (Generalization 3C):

(13)

		LAZY	IDENT(voi)
☞	appa - appa	*	
	appa - abba	**	

- and a partial geminate cannot undergo spirantization:

(14)

		LAZY	IDENT(cont)
☞	ampa - ampa	**	
	ampa - amϕa	***	*
	ampa - aw̃ϕa	****	*

- but it can undergo voicing, if LAZY » IDENT(voi) (Generalization 3D):

(15)

		LAZY	IDENT(voi)
	ampa - ampa	**!	
☞	ampa - amba	*	*

• For an account of half-spirantization of *heteromorphemic* geminates (as an effect of output-output faithfulness, e.g. Benua 1995), and of the occlusivization and devoicing generalization (3E), see Appendix D.

VI. CONCLUSION

• Geminate inalterability is not a unified phenomenon:
- We must distinguish between:
  ¶ geminate inalterability as a special case of generalized (language-specific) blocking effects, as discussed by Inkelas & Cho 1993, and
  ¶ geminate inalterability under lenition, which constitutes a robust cross-linguistic generalization.

• Indeed, Inkelas & Cho (p. 569) seem well aware of what is missing from their analysis, and hint at the sort of further account which is needed:

> *Although they are arbitrary under our analysis, certain of the allophonic alternations involving geminates have a plausible phonetic basis. For example, the fact that voicing is harder to maintain over longer durations might motivate the distribution of [voice] in Berber ... in which singletons but not geminates are voiced.*

This is precisely the sort of account which I have outlined here.

• Recap:
- Lenition patterns can be analyzed in terms of interaction between LAZY and lenition-blocking constraints.
- The geminate lenition generalizations in (3) fall out from this effort-based approach to lenition, under the further assumption that voiced geminate obstruents $>_{effort}$ voiceless geminate (for aerodynamic reasons), and spirantized geminates $>_{effort}$ unspirantized geminates (due to the isometric tension involved in a prolonged partial constriction).

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APPENDIX A: DOCUMENTING THE GEMINATE LENITION GENERALIZATIONS

A. NO ORALLY REDUCED GEMINATES. *No process converts a consonant (geminate or otherwise) to a geminate with reduced oral constriction.*

- Cf. Churma (1988): "[A]side from degemination, no weakening process may affect a geminate consonant."

Table 1: Blocking of oral reduction in geminates

Language	Reference	Description of process
Florentine Italian	Giannelli & Savoia 1979	Lenition (ranging from spirantization to complete elision, depending on rate and register), blocked in geminate obstruents and non-continuants (except in very fast speech, where the "geminates" are presumably phonetically degeminated)
Hausa	Hayes 1986	b,d,g – w,r,w in coda, blocked in geminates
Malayalam	Mohanan 1986	Stops – approximants (or apical tap) in the context /[+son,-nas]__V, blocked in geminates
Persian	Hayes 1986	v – w in coda position, blocked in geminates
(Proto-) Berber	Hayes 1986	Stops – fricatives (context-free), blocked in geminates
Tamil	Keating et al. 1983	Voicing and spirantization in medial position, blocked in geminates
Tiberian Hebrew	Hayes 1986, Elmedlaoui 1993	Post-vocalic non-emphatic stops spirantize, blocked in geminates
Tigrinya	Hayes 1986, Schein & Steriade 1986	Post-vocalic velars and uvulars spirantize, blocked in geminates
Tümpisa Shoshone	Dayley 1989	Spirantization, flapping of oral and nasal plosives, blocked in geminates

- In contrast, cases where these processes apply to geminates (without concomitant degemination) appear to be completely unattested, based on the previous inalterability literature, and the lenition surveys of Lavoie 1996 and Kirchner (in progress).

- It is not correct that geminates resist *all* lenition processes:
  - Geminates can lenite by degeminating, e.g. Tiberian Hebrew: guttural (pharyngealized) consonants degeminate, context-free (Hayes 1986). Although such degemination does constitute (temporal) reduction, the output ceases to be a geminate, and thus the NO ORALLY REDUCED GEMINATES generalization is maintained. Also, the behavior of geminates in Florentine indicates that geminates can spirantize, provided that they concomitantly degeminate. (As Elmedlaoui (1993) points out, the generalization properly focuses not on whether geminates can be the *input* to a lenition process, but whether the *output* of such a process can be a geminate.)
  - Geminates also commonly undergo loss of a distinct release of the first half of a geminate, e.g. in English /bʊk/ (with optionally released [k]) + /keis/ – [bʊk˺kʰeis] ('book-case'); see also Ancient Greek deaspiration of the first half of a geminate stop (Hayes 1986). This elimination of the opening gesture is clearly a species of articulatory reduction, although this occurs so ubiquitously in geminates that its status as a lenition process is easily overlooked.

B. NO HALF-SPIRANTIZATION. *No process converts a (tautomorphemic) geminate non-continuant to a "half-spirantized" cluster, e.g. /kk/ – *[xk].*

- We have already seen in Table 1 that oral reduction processes are completely blocked in geminates. Thus, in Tigrinya, /fəkkərə/ – *[fəxkərə] and *[fəxxərə] are equally impossible outputs.

- More generally, cases of spirantization of the first half of a (tautomorphemic) geminate appear to be unattested, based on the previous inalterability literature and the lenition surveys.

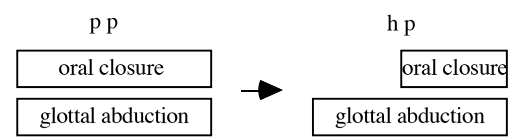
- Qualifications:
  - In heteromorphemic geminates, however, half-spirantization is attested, e.g. Tigrinya /mɨrax-ka/ – [mɨrax-ka] ('calf-2.sg.m). N.B. this distinct behavior of heteromorphemic geminates under spirantization is not universal: in Tiberian Hebrew, heteromorphemic geminates resist spirantization just as the tautomorphemic geminates do: e.g. [kaarattii] ('I cut'), cf. [kaaraθ] ('he cut').
  - Half-*spirantization* (in the narrow sense of reduction to a fricative) must be distinguished from half-*gliding* of geminates, attested in Maxakalí (Gudschinsky, Popovich and Popovich 1970, Hayes 1986):

(A1) /mattɨk/ – [mᵇaətɨx] 'happy'
/kaktʃoppit/ – [kakʃoəpiyə] 'boy'
/kɨtʃakkɨk/ – [kaʃaɨkɨx] 'capybara (species of rodent)'

For our purposes, the crucial observation is that the Maxakalí vocoid corresponding to the first half of the geminate is not a *steady-state constriction*, but a (somewhat attenuated) transition from the vowel into the following (singleton) obstruent, as Gudschinsky et al. explicitly characterize it.

  - Half-spirantization distinguished from half-debuccalization, attested in the Icelandic process of "pre-aspiration," Thráinsson 1979, Hayes 1986, whereby voiceless geminate stops reduce to h + stop clusters (e.g. /kappi/ – [kahpi] 'hero'). As Clements 1985 has observed, this process is simply *degemination of the oral constriction,* leaving the long glottal abduction gesture unchanged, as shown in (A2). Since the oral constriction degeminates, this process is not problematic for the generalizations.

(A2)



C. NO VOICING OF GEMINATES. *No process converts a voiceless segment (geminate or otherwise) to a voiced geminate obstruent.*

- Blocking of voicing in geminate obstruents is exemplified in Tümpisa Shoshone:

(A3)	a.	taziumpi	–	taziumb**i**	'star'
		ɨntamiʔi	–	ɨn**d**aw̃iʔi	'your little brother'
		puhakantɨ	–	puhaɣan**dɨ**	'shaman'
		tɨppisipuŋki	–	tɨppiʃiβuŋ**gi**	'stinkbug'
	b.	tapettʃi	–	ta**β**ettʃi	'sun'
		tɨppisipuŋki	–	tɨppiʃi**β**uŋgi	'stinkbug'
		tsitoohi	–	tsi**ð**oohi	'push'
		patɨasippɨ	–	pa**ɾ**ɨasippɨ	'ice'
		sɨɨmɔɔtɨ	–	sɨɨw̃ɔɔ**ɾ**ɨ	'ten'
		puhakantɨ	–	puha**ɣ**andɨ	'shaman'
		kimmakinna	–	kimma**ɣ**inna	'to come here'
	c.	tɨppisipuŋki	–	tɨ**pp**iʃiβuŋgi	'stinkbug'
		patɨasippɨ	–	paɾɨasi**pp**ɨ	'ice'
		uttunna	–	u**tt**unna	'to give'
		tapettʃi	–	taβe**ttʃ**i	'sun'
		punikka	–	puni**kk**a	'see, look at'

Post-nasal stops undergo voicing, as shown in (A3a); and post-vocalic stops undergo spirantization or flapping, as well as voicing (A3b). That is to say, all non-initial stops voice; but this voicing, as well as the spirantization and flapping, are blocked in geminates (A3c).

Table 2: Blocking of voicing in geminates

Language	Reference	Description of process
Berber	Inkelas & Cho 1993	Pharyngealized obstruents – voiced (context-free), blocked in geminates
Cuna	Keating et al. 1983	Voicing in medial position, blocked in geminates
Florentine Italian	Giannelli & Savoia 1979	In fast/casual speech styles, voiceless stops, which otherwise spirantize to voiceless fricatives or approximants, further reduce to voiced approximants; this is blocked in geminates.
Gallo-Romance	Jacobs & Wetzels 1988	Sound change: intervocalic /t/ underwent voicing, while /tt/ degeminated without voicing
Malayalam	Mohanan 1986	Stops become voiced in the context /+son__V or /+nas__; blocked in geminates
Somali	Armstrong 1964	Intervocalic voicing, blocked in geminates
Tamil	Keating et al. 1983	Voicing (and spirantization) in medial position, blocked in geminates
Tümpisa Shoshone	Dayley 1989	Non-initial obstruents are voiced, blocked in geminates

- In contrast, voicing processes which do apply to full geminates appear to be unattested, based on the previous inalterability, and the lenition surveys. (See also Hock 1991, who concurs that such processes are unattested, but treats this as an accidental gap.)

> D. NO REDUCTION OF PARTIAL GEMINATES. *"Partial geminates" (i.e. homorganic nasal + stop or lateral + stop clusters) behave identically to full geminates with respect to reduction of oral constriction; but, unlike full geminates, they readily undergo voicing.*

- Example: Tümpisa Shoshone (A3) data are also illustrative of this generalization. Recall that it is in post-nasal position -- that is, when part of a homorganic nasal + stop cluster -- that the stops resist spirantization. However, these partial geminates do undergo voicing. Additional examples appear in Table 3:

Table 3: Blocking of spirantization, flapping in partial geminates

Language	Reference	Description of process
Lamani	Trail 1970	Flapping blocked after a homorganic nasal or lateral
Malayalam	Mohanan 1986	Spirantization, flapping blocked after a homorganic nasal; no blocking of voicing in this context
Mexico City Spanish	Harris 1969	Spirantization of voiced stops, blocked after a homorganic nasal or lateral
Proto-Bantu	Greenberg 1948	Spirantization of voiced stops (context-free), blocked after homorganic nasal
Tümpisa Shoshone	Dayley 1989	Spirantization blocked in homorganic nasal-stop clusters; no blocking of voicing in this context

- More generally, oral reduction of all or part of a tautomorphemic homorganic nasal stop or lateral-stop cluster is unattested in the inalterability literature and the lenition surveys.

> E. NO EXCLUSIVE OCCLUSIVIZATION OR DEVOICING OF SINGLETONS. *No occlusivization or obstruent devoicing process targets singletons to the exclusion of geminates.*

- This generalization, the flip side of geminate resistance to oral reduction and voicing, is due to Churma (1988).[4]

Table 4: Patterns of occlusivization

Singleton and geminate obstruents occlusivize, i.e. no fricatives, e.g. Warray, Mayali (Evans 1996)	Geminates occlusivize to the exclusion of singletons, e.g. Modern Berber (Schein & Steriade 1986), Luganda (/jj, ww/ – [ɟɟ, gg^w], Clements 1986, Churma 1988), Malayalam (/rr/ – [tt], Mohanan 1986)
No occlusivization of singletons or geminates, e.g. English	Singletons occlusivize to the exclusion of geminates: *unattested*

- Again, for purposes of spirantization/occlusivization, partial geminates behave identically to full geminates: consonants tend to occlusivize when adjacent to a homorganic nasal, as in the following Kikuyu post-nasal alternations (Padgett 1992):

(A4)	mbureetɛ	'lop off'	cf. βura
	mbaareetɛ	'look at'	cf. βaara
	ndeheetɛ	'pay'	cf. reha
	nduɣeetɛ	'cook'	cf. ruɣa
	ŋgoreettɛ	'buy'	cf. ɣora
	ŋgaeetɛ	'divide'	cf. ɣaja

Similarly, pre-nasal occlusivization is seen in certain dialects of American English, e.g. [bɪdnəs] ('business'), ɪdn.nɪt ('isn't it').

Table 5: Patterns of devoicing

Singleton and geminate obstruents devoice, i.e. no voiced obstruents, e.g. Delaware (Maddieson 1984)	Geminates devoice to the exclusion of singletons, e.g. Nubian (Ohala 1983)
No devoicing of singletons or geminates, e.g. Italian	Singletons devoice to the exclusion of geminates: *unattested*

- Again, for purposes of (de-)voicing, partial geminates do *not* pattern with full geminates. Indeed, Hayes & Stivers (in progress) observe that stops very commonly undergo voicing in post-nasal position (regardless of homorganicity), as seen in the following alternations from Wembawemba:

(A5)	a.	/taka/	takə	'to hit'
		/milpa/	mɪlpə	'to twist'
	b.	/jantin/	jandɪn	'me'
		/panpar/	panbər	'shovel'

Additional cases of post-nasal voicing cited by Hayes & Stivers include Arusa, Eastern Armenian, Japanese (Yamato vocabulary), Modern Greek, Waorani, Western Desert Language, and Zoque.

[4]As Elmedlaoui 1993 notes, Churma's claim bears some resemblance to the earlier "Inertial Development Principle" of Foley 1977, which states, in essence, that "weak" segments are preferentially targeted by weakening processes, and "strong" segments for strengthening processes. But since Foley explicitly refuses to attribute any consistent phonetic content to his notions of weakening or strengthening, it is difficult to evaluate the empirical predictions which follow from this principle.

APPENDIX B: FURTHER ASSUMPTIONS, RESULTS OF EFFORT-BASED APPROACH TO LENITION

- What blocks reduction all the way to Ø?
  Note that under the analysis of spirantization above, further lenition, to an approximant or Ø, is blocked by other faithfulness constraints, namely MAX and IDENT(son).

(B1)

	/b/	MAX	IDENT(son)	LAZY	IDENT(cont)
	b			***!	
☞	β			**	*
	w, β̞		*!	*	
	Ø	*!			

- Context-sensitive blocking.
  Restriction of lenition to particular contexts can be obtained through context-sensitive IDENT constraints, an enrichment motivated in Jun 1995, Steriade 1995, 1996, and Beckman 1997, and grounded in the phonetic observation that many distinctions are perceptually more salient, or more crucial to lexical access, in particular contexts, such as word-initial, onset, and stressed position. Intuitively speaking, there is greater impetus to lenite in contexts where there is relatively little perceptual "bang" for the articulatory "buck." Thus, coda lenition (e.g. Hausa) can be captured as follows: IDENT(cont/onset) outranks the general IDENT(cont) constraint; and LAZY falls between these:

(B2)

		IDENT(cont /onset)	LAZY	IDENT(cont)	IDENT(son)
	abda - ab.da		**!		
☞	abda - aw.da		*	*	*
☞	aba - a.ba		**		
	aba - a.wa	*!	*	*	*

Blocking of lenition in other perceptually prominent positions, e.g. word-initial and stressed positions, can similarly be attributed to context-sensitive faithfulness constraints: IDENT(F/#__), IDENT(F/stressed), etc. Restriction of lenition to particular *places* of articulation may similarly be obtained in terms of place-specific faithfulness constraints, e.g. {IDENT(cont/lab), IDENT(cont/cor)} » LAZY » IDENT(cont/dors) results in spirantization of dorsal consonants exclusively.

- Fortition constraints as lenition-blockers.
  Note, however, that for cases of *complementary distribution*, e.g. no word-initial fricatives, and no non-initial stops, the use of faithfulness constraints as lenition-blockers is insufficient.

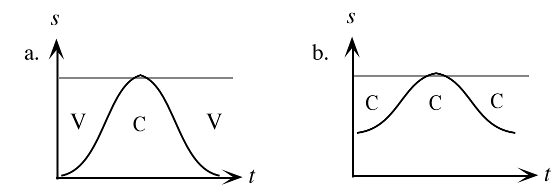
(B3)

		IDENT(cont/#__)	LAZY	IDENT(cont)
☞	a. #ka - #ka		**	
	#ka - #xa	*!	*	*
	b. #aka - #aka		**!	
☞	#aka - #axa		*	*
	c. #xa - #ka	***!**	**	*
☞	**#xa - #xa**		*	
	d. #axa - #aka		**!	*
☞	#axa - #axa		*	

If, as in (B3c), some word-initial obstruent is underlyingly [+cont] (and the OT tenet of Richness of the Base (Prince & Smolensky 1993, ch. 9) prevents us from excluding such an input), both faithfulness and LAZY favor the fricative candidate; thus it is impossible to rule out word-initial fricatives. An additional class of lenition-blocking constraints is required: these must not only block lenition, but actively *induce fortition*, e.g. requiring word-initial obstruents to be realized as stops (*[+cont,-son]/#__). It seems plausible that these fortition constraints are, like the context-sensitive faithfulness constraints, grounded in perceptual considerations. For example, the release burst of a stop contains salient place of articulation cues (e.g. Wright 1996); thus, by militating in favor of consonants with a release burst, this constraint can be viewed as enhancing the perceptibility of the consonant; and the allocation of more robust cues to word-initial position may be viewed as reflecting the greater importance of word-initial consonants in lexical access (see Flemming 1995 for a more general treatment of perceptual enhancement in phonology).

- Intervocalic position.
  This context, however, may be attributed to the greater displacement (hence effort) required to achieve a given degree of consonantal constriction when flanked by more open segments (cf. Grammont 1939, Beckman et al. 1992).

(B4)



To formally capture this idea, the scalar LAZY constraint is decomposed into a series of constraints, with an internally fixed ranking ($\text{LAZY}_{\geq n}$ » $\text{LAZY}_{\geq n-1}$ » $\text{LAZY}_{\geq n-2}$, etc.) each of which prohibits effort at or above a particular threshold.

(B5)

		$\text{LAZY}_{\geq x+1}$	PRES(cont)	$\text{LAZY}_{\geq x}$
	b - b /i_i	*!		*
☞	b - β /i_i		*	*
☞	b - b /r_i			*
	b - β /r_i		*!	

If x+1 denotes the minimum level of effort required to achieve closure in a [b] in intervocalic context, a pattern of spirantization of /b/ in intervocalic position, but not in, e.g., post-rhotic position, obtains under the ranking of effort thresholds shown in (B5). *Post-vocalic* lenition contexts (e.g. Tigrinya, Tiberian Hebrew) can be understood as the union of the coda context and the intervocalic context.

- Rate- and register-sensitive lenition.
  Ceteris paribus, the faster the speech rate, the greater the velocity (hence effort) required to achieve a given degree of consonantal constriction. Rate-conditioned lenition thus can likewise be captured in terms of a ranking of effort thresholds.

(B6)

		$\text{LAZY}_{\geq x+1}$	PRES(cont)	$\text{LAZY}_{\geq x}$
	b - b /r_i (fast rate)	*!		*
☞	b - w /r_i (fast rate)		*	*
	b - b /r_i (normal rate)			*
☞	b - w /r_i (normal rate)		*!	

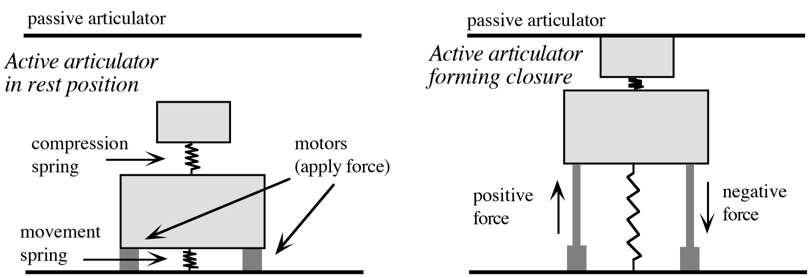
Assuming that [b] in the context /r__i involves effort ≥ x+1 in fast speech (though not in normal speech), under the same ranking as (B5), we obtain the result that lenition in a particular context is triggered in fast speech but not at normal rates.[5]

- Relation to (local) assimilation processes.
Finally, this constraint system is motivated not merely by lenition phenomena: essentially the same system is deployed by Jun 1995 to handle place assimilation in consonant clusters. Jun demonstrates that casual speech gradient assimilation (e.g. English /fon bʊk/ - [fombʊk]), attributed by Browman and Goldstein (1990) to gestural overlap, in fact involves gestural reduction of C_1, to the point where the percept of C_1's place of articulation is lost; moreover, categorical "phonological" assimilations can be analyzed in the same terms, where the reduction of the C_1 gesture is total. Local assimilations,[6] then, emerge as a special case of lenition, where gestural reduction is accompanied by temporal extension of the gesture of C_2, in order to preserve other underlying properties of the target segment, such as non-continuancy.

APPENDIX C: COMPUTATIONAL MODEL OF MASS-SPRING SYSTEM (Hayes & Kirchner, in progress)

- Articulatory movement is modeled in terms of forces applied to a spring-loaded mass, with an additional spring for compression during closure, as schematized in (C1):

(C1)



- The equations implemented by this model are:

(C2)

$$a_{net}(t) = \frac{U_{pos}(t) + U_{neg}(t)}{m} - (g + b_m v(t) + k_m s(t))$$

If $s(t) > h$ then

$$a_{net}(t) = \frac{U_{pos}(t) + U_{neg}(t)}{m} - (g + b_m v(t) + k_m s(t) + b_c v(t) + k_c s(t-h))$$

$$v(t) = v(t-1) + a_{net}(t-1)$$

$$s(t) = s(t-1) + v(t-1)$$

$$E = \sum_{t=1}^{t=n} \left(|U_{pos}(t)| + |U_{neg}(t)| \right)$$

(C3)

Symbol	Meaning	Value assigned (if constant)
a_{net}	Net acceleration	
U_{pos}	Positive force	
U_{neg}	Negative force (a non-positive number)	
v	Velocity	
s	Displacement	
t	Time	
E	Effort	
n	number of timeslices in gesture	
m	Articulator mass	1
g	Gravity	.001
b_m	Damping of articulator movement spring	.1
k_m	Stiffness of articulator movement spring	.008
b_c	Damping of articulator compression spring	.2
k_c	Stiffness of articulator compression spring	.016
h	Height of passive articulator, relative to active articulator's rest position	20 mm

- Criteria for the different consonant types are defined as follows:

(C4)

	Upper bound of spatial target (in mm)	*Lower bound of spatial target (in mm)*	*Consonant start (in msec)*	*Consonant end (in msec)*	*Articulator must return to 0 by: (in msec)*
Singleton fricative	19.33	18	120	125	245
Singleton stop	n/a	20	120	180	300
Geminate fricative	19.33	18	120	240	360
Geminate stop	n/a	20	120	240	360
Half-spirantized geminate:					
fricative portion	19.33	18	120	175	n/a
(transition interval)	n/a	n/a	175	185	n/a
stop portion	n/a	20	185	240	360

- The learning algorithm perturbs the magnitude, time, and breadth of the positive and negative force impulses, and then checks to see if the result reduced the error. If so, the new values are adopted; if not, the old ones are retained. Error is defined first as failure to meet the temporal and spatial criteria as defined above; once error in this sense falls below some threshold (set to 1.0 in the current version), error reduction takes the form of minimization of total effort.

[5]Effort-based lenition environments (e.g. intervocalic and post-vocalic) which are *insensitive* to rate variation pose a non-trivial problem for this approach. A possible treatment of such patterns, involving an extension of the notion of paradigmatic faithfulness, is sketched in Kirchner (in progress).
[6]Harmonic (long-distance) assimilations appear to be perceptually driven, see e.g. Kaun 1994.

Hetromorphemic geminates and the half-spirantization generalization

- The behavior of heteromorphemic geminates in Tigrinya (see Appendix A, Generalization B) is analyzable as an output-output faithfulness effect (see Benua 1995; Flemming 1995; Kenstowicz 1995; McCarthy and Prince 1995; Steriade 1996; Burzio 1997).

(D1)

	Input: /mɨrak-ka/ (base = [mɨrax])	IDENT(BASE/ DERIVATIVE, cont)	LAZY	IDENT(I/O, cont)
	mɨrakka	*!	*	
☞	mɨraxka		**	*

That is, spirantization occurs in [mɨraxka] not because it serves the goal of effort minimization (indeed, it fares worse on this score than the competing candidate [mɨrakka]), but because it promotes similarity between the output and its base, [mɨrax], in which spirantization *is* motivated by LAZY. If LAZY » IDENT(BASE/DERIVATIVE, cont), heteromorphemic geminates will be inalterable under spirantization, just like tautomorphemic geminates, as we find in Tiberian Hebrew (see Appendix A).

(D2) Tiberian Hebrew: [kaarattii] ('I cut')

	Input: /karaat-ti/ (base = [kaaraθ])	LAZY	IDENT(BASE/ DERIVATIVE, cont)	IDENT(I/O, cont)
☞	kaarattii	*	*	
	kaaraθtii	**!		*

- In tautomorphemic geminates, paradigmatic concerns do not enter the picture (there can be no separate base containing a spirantized singleton), and so half-spirantization is ruled out under any ranking.

- It is thus possible to account for the distinct inalterability behavior of hetero- and tautomorphemic geminates, without reifying this in terms of a (phonetically unmotivated) representational distinction between "true" and "fake" geminates.

No exclusive occlusivization or devoicing of singletons (Generalization (6E)

- I assume that (singleton) occlusivization and devoicing are attributable to two fortition constraints, OCCLUDE, and DEVOICE:[7]

(D3) OCCLUDE: *[+cont,+cons]
DEVOICE: *[+voi,-son].

- Factorial typology:

(D4) If OCCLUDE » IDENT(cont), singletons and geminates occlusivize (regardless of LAZY's ranking):

		OCCLUDE	IDENT(cont)	LAZY
☞	ϕ - p		*	**
	ϕ - ϕ	*!		*
☞	ϕϕ - pp		*	***
	ϕϕ - ϕϕ	*!		****

(D5) If LAZY » IDENT(cont), geminates occlusivize (regardless of OCCLUDE's ranking):

		LAZY	IDENT(cont)	OCCLUDE
☞	ϕϕ - pp	*	*	
	ϕϕ - ϕϕ	**!		*

(D6) If IDENT(cont) is undominated, neither singletons nor geminates occlusivize:

		IDENT(cont)	OCCLUDE	LAZY
	ϕ - p	*!		**
☞	ϕ - ϕ		*	*
	ϕϕ - pp	*!		***
☞	ϕϕ - ϕϕ		*	****

(D7) Summary: under no ranking do singletons occlusivize to the exclusion of geminates

	Singletons occlusivize	Geminates occlusivize
IDENT(cont) » LAZY » OCCLUDE		
IDENT(cont) » OCCLUDE » LAZY		
OCCLUDE » LAZY » IDENT(cont)		√
LAZY » IDENT(cont) » OCCLUDE		√
OCCLUDE » IDENT(cont) » LAZY	√	√
LAZY » OCCLUDE » IDENT(cont)	√	√

(D8) By the same reasoning, singletons cannot devoice to the exclusion of geminates

	Singletons devoice	Geminates devoice
IDENT(voi) » LAZY » DEVOICE		
IDENT(voi) » DEVOICE » LAZY		
DEVOICE » LAZY » IDENT(voi)		√
LAZY » IDENT(voi) » DEVOICE		√
DEVOICE » IDENT(voi) » LAZY	√	√
LAZY » DEVOICE » IDENT(voi)	√	√

[7]This is intended merely as a treatment of context-free devoicing, for purposes of perceptual enhancement. Context-sensitive patterns such as final devoicing, and assimilatory devoicing, presumably have an aerodynamic/effort-based account. But this distinction in the nature of the devoicing-inducing constraint does not affect the factorial typological result presented here.