

Sonorancy and geminacy

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Abstract

This paper establishes the claim that geminate sonorants are cross-linguistically marked, and furthermore, that the relative sonority of a geminate positively correlates with its markedness, i.e., the universal ranking *GEMGLIDE » *GEMLIQUID » *GEMNASAL holds. This ranking is supported by a cross-linguistic survey of geminate inventories (Podesva 2002; Taylor 1985) as well as by a number of phonological alternations. Second, this paper proposes that this markedness hierarchy derives from the confusability of geminacy contrasts for sonorant segments: the more sonorous a segment is, the more difficult it is to perceive its segmental duration, and hence the less perceptible its geminacy contrasts are. A perceptual experiment on Arabic is reported to support this proposal, which shows that discriminability of geminacy contrasts negatively correlates with relative sonority. The results add to a growing body of literature that claims that languages avoid making a phonological contrast that is not very perceptible, as in Adaptive Dispersion Theory (Flemming 1995; Liljencrants and Lindblom 1972; Padgett 2003) and Licensing-by-Cue (Steriade 1997).

1. Introduction

Geminates are characterized by having constriction durations that are longer than those of their corresponding singletons. Past phonological analyses of geminates have mainly focused on prosodic aspects of geminates, the central question being how geminates should be phonologically represented (Hayes 1989, among many others). Little attention has been paid, however, to restrictions on the segmental composition of geminates, with some few exceptions (Jaeger 1978; Morén 1999; Podesva 2002; Taylor 1985). Few languages allow all kinds of geminates, but then what kinds of geminates are cross-linguistically preferred? To the extent that some kinds of geminates are dispreferred, is there a phonetic reason behind such dispreference? In this regard, the case of voiced obstruent geminates (Hayes and Steriade 2004; Jaeger 1978; Ohala 1983; Taylor 1985) is relatively well studied: voiced obstruent geminates are cross-linguistically disfavored, because with long closure, it is difficult to maintain a transglottal air pressure drop sufficient to produce voicing. Restrictions on other kinds of geminates, however, have not been satisfactorily investigated.

This work is one attempt to fill this gap by studying the relationship between sonorancy and geminacy. In particular, based on a cross-linguistic survey, this paper argues that geminate sonorants are marked, and further, that the more sonorous a geminate is, the more marked it is. Second, this paper seeks a phonetic reason for this markedness hierarchy. I propose that sonorant consonants have a disadvantage in signaling their duration because of blurry transitions into and out of flanking vowels. Since a phonological geminacy contrast crucially relies on a constriction duration difference between singletons and geminates, sonorant segments, whose constriction durations are hard to perceive accurately, do not make a very perceptible minimal pair in terms of geminacy. A perceptual experiment was conducted to support this hypothesis, the results of

which indeed show that the more sonorous a segment is, the more difficult it is to hear its geminacy distinction. This result nicely correlates with the cross-linguistic generalization that the more sonorous a geminate is, the more marked it is.

There are two main implications of this study. First, it shows that the markedness of geminate sonorants derives from their perceptual confusability with their corresponding singletons. Thus, this study adds to a growing body of literature that claims that perception, and in particular perceptual contrasts among segments in the inventory, plays an important role in shaping phonological patterning (e.g., Boersma 1998; Flemming 1995; Liljencrants and Lindblom 1972; Lindblom 1986; Padgett 2003). Second, despite the fact that the phonological markedness of geminate sonorants is derived from their confusability with corresponding singletons, geminate sonorants are resolved not only by degemination, but also by a wide variety of other phonological processes. This finding shows that not all phonological patterns originate from misperception, although a number of recent proposals suggest that phonological patterns are a direct consequence of diachronic changes caused by the listener's misperception of ambiguous acoustic signals (Barnes 2002; Blevins 2004a; Blevins and Garrett 2004; Kavitskaya 2002; Myers 2002; Ohala 1981, 1991). Rather, I propose that the confusability of geminate sonorants with their corresponding singletons must be expressed as a set of constraints which bans various geminate sonorants, and these constraints induce a wide range of phonological processes through constraint interaction. Optimality Theory (Prince and Smolensky 2004) provides a suitable analytical framework within which to capture this proposal.

The rest of this paper proceeds as follows. The next section shows that geminate sonorants are marked. Evidence is taken from inventory restrictions as well as from a number of alternations. A universally fixed ranking is proposed such that the markedness of geminates correlates with their relative sonority. §3 lays out a hypothesis about the phonetic grounding of

this markedness hierarchy: blurry segmental boundaries of sonorant segments are inherently not suitable for making geminacy contrasts. §4 and §5 experimentally verify the hypothesis put forth in §3. The final section summarizes the results of the paper and considers the theoretical implications of the study.

2. The markedness of geminate sonorants

This section illustrates three points. First, languages often lack geminate sonorants in their inventory. Second, a set of constraints against geminate sonorants can induce a wide range of phonological processes—a typical case of heterogeneity of processes (McCarthy 2002; Pater 1999; see also Kisseberth 1970). These alternations are analyzed in terms of Optimality Theoretic constraints (Prince and Smolensky 2004), which have proven to be useful in capturing heterogeneity of processes. Finally, an implicational relationship is identified such that the more sonorous a geminate is, the more marked it is. This markedness hierarchy is again expressed in terms of the universally fixed ranking of Optimality Theoretic constraints. Apparent counterexamples are discussed in §2.7.

2.1 Segmental inventory

Geminate sonorants are marked. The first piece of evidence in support of this claim comes from gaps in the geminate inventories of many languages. Taylor (1985: 122) maintains, based on her cross-linguistic survey of geminate inventories, that “[s]ince all 28 languages...have at least one obstruent geminate..., if a language has at least one geminate sonorant, it will also have at least one geminate obstruent.” This implicational statement is a typical sign that geminate sonorants

are marked. Podesva (2002) has also performed an extensive study of segmental restrictions on geminates, and has identified many languages that lack some or all geminate sonorants. His survey is partially reproduced in Table 1:

	Nasals	Liquids		Glides
		Laterals	Rhotics	
(i) Finnish, Hindi, Icelandic, Karo Batak, Maithili, Persian, Ponapean, Somali, Tigre, Toba Batak ¹	√	√	√	*
(ii) Punjabi, Selkup, Yakut, Fula	√	√	*	*
(iii) Chaha, Japanese, LuGanda, Maranungku	√	*	*	*
(iv) !Xóǀ	*	*	*	*
(v) Biblical Hebrew, Wolof	√	√	*	√

Table 1: Languages that lack geminate sonorants. Based on Podesva (2002: 9).

As observed in Table 1, there are many languages that lack geminate sonorants.²

Podesva (2002) also suggests that there is a universally fixed markedness

¹ To these, Nobiin Nubian can be added (Bell 1971: 119-120, 127-133).

² Not only can geminate sonorants be entirely absent from the inventory, but geminate sonorants can also be subject to positional restrictions, as in Malayalam. According to Mohanan (1989: 600), “a sonorant consonant can be a geminate only if it is preceded by a short syllable nucleus within a morpheme. Thus, Malayalam has forms like *kammi* ‘shortage’...and *kayyā* ‘hand’, but not forms like **kalammi*...or **carayya*.” This distributional restriction on geminate sonorants can be understood as an imperative to associate geminate sonorants with a morpheme-initial syllable. The existence of such a positional restriction implies that geminate sonorants are marked (see Beckman 1998 and Zoll 1998 for a host of cases in which marked elements must be licensed by strong positions).

hierarchy—*GG (glide) » *LL (liquid) » *NN (nasals)—in which the markedness of geminates generally correlates with relative sonority. However, there are languages that disallow glide geminates but not rhotic geminates (Type (i) in Table 1), and there are also languages that disallow rhotic geminates but not glide geminates (Type (v)). One reason for this cross-linguistic inconsistency is that “rhotic” refers to a rather large set of diverse sounds (approximant, tap, flap, and trill). Second, some geminate rhotics are marked for reasons independent of sonority (see §3.3 for discussion). For these reasons, it is not realistic to locate *RR (rhotic) in a fixed position in the constraint hierarchy that prohibits geminate sonorants. Thus I instead propose a more limited universally fixed ranking: *GG » *LL (lateral) » *NN » *OBSGEM. The rest of this section shows that the constraints against sonorant segments induce a wide variety of phonological processes, and the proposed fixed ranking is further supported.

2.2 LuGanda occlusivization

The first example of an alternation that is triggered by constraints against geminate sonorants comes from LuGanda, which also partially supports the fixed ranking proposed in §2.1. The class 5 augmentative prefix causes gemination of root-initial consonants, as shown in (1). The LuGanda data are taken from Cole (1967: 30-31) and Clements (1986: 62, 68). Tones are not shown.

(1) LuGanda gemination

/μ+kubo/	→	[kk ubo]	‘path’
/μ+tabi/	→	[tt abi]	‘branch’
/μ+bala/	→	[bb ala]	‘spot’
/μ+daala/	→	[dd aala]	‘step’
/μ+sajja/	→	[ss ajja]	‘man’
/μ+fumu/	→	[ff umu]	‘spear’
/μ+zike/	→	[zz ike]	‘chimpanzee’

When root-initial consonants are liquids or glides, gemination is accompanied by occlusivization, as shown in (2):³

(2) Occlusivization of geminate approximants in LuGanda

a. *ll* → *dd*

/μ-langa/	→	[dd aanga]	‘lily’
/μ-lenzi/	→	[dd enzi]	‘boy’

b. *yy* → *ʃʃ*

/μ-yinga/	→	[ʃʃ iinga]	‘stone’
/μ-yembe/	→	[ʃʃ embe]	‘mango’

c. *ww* → *gg^w*

/μ-wanga/	→	[gg^w aanga]	‘nation’
/μ-wala/	→	[gg^w awla]	‘girl’

Thus, geminate approximants are resolved by occlusivization in LuGanda. The patterns in (2) cannot be captured as an imperative to eliminate geminate continuants, because [ff] and [ss] do not occlusivize (see §6.1 for discussion on geminate fricatives). To account for the patterns in (1)

³ Another case of occlusivization of geminate approximants is reported in Berber, where /ww/ and /RR/ are hardened to [gg^w] and [qq], respectively (Elmedlaoui 1995: 194-195).

and (2), *GG and *LL must both dominate a faithfulness constraint that militates against occlusivization; here IDENT(CONT) is used, which prevents a change in continuancy (McCarthy and Prince 1995). Further, *GG and *LL must be ranked above *OBSGEM, because the outcome of occlusivization is a geminate stop. These rankings are motivated by the tableau in (3), taking occlusivization of liquids as an example.

(3) LuGanda occlusivization

/μ+langa/	*GG	*LL	IDENT(CONT)	*OBSGEM
a. [llaanga]		*!		
b. [ddaanga]			*	*

Nasals do not pattern with approximants because [nn] remains a nasal (as in [nnoni] ‘chalk’ and [nnona] ‘I fetch’: Clements 1986: 68), with one lexical exception, [ddene] ‘large,’ which derives from a stem [nene]. To account for the fact that geminate nasals do not generally occlusivize, *NN must be ranked below IDENT(CONT), as shown in (4). The occlusivization patterns in LuGanda partially support the ranking proposed in §2.1, because by transitivity via IDENT(SON), *GG, *LL » *NN is motivated.

(4) Nasals do not occlusivize

/μ+noni/	*GG	*LL	IDENT(CONT)	*NN
a. [nnoni]				*
b. [ddoni]			*!	

2.3 Degemination in Sanskrit and Greek

The second kind of alternation induced by constraints against geminate sonorants is degemination, as found, for example, in Sanskrit and Greek. According to Whitney (1889),

geminate [r], a retroflex untrilled liquid, were completely disallowed in Sanskrit, and degemination took effect to avoid geminate [r]. A so-called visarga sound appeared as [r] before sonorants. However, when visarga preceded an [r], only a singleton [r] surfaced, with compensatory lengthening of a preceding vowel. Some illustrative data are given in (5). All Sanskrit data are taken from Whitney (1889), who does not supply glosses; the numbers in parentheses represent paragraph numbers. For the sake of exposition, I assume that visarga is underlyingly [r], although my point does not rely on this assumption (see below).

(5) Sanskrit degemination

/punar <u>r</u> ramate/	→	[puna: <u>r</u> amate]	*[punar <u>r</u> amate]	(179)
/nṛpatir <u>r</u> rajati/	→	[nṛpati: <u>r</u> ajati]	*[nṛpatir <u>r</u> ajati]	(179)
/ma:tu <u>r</u> rihan/	→	[ma:tu: <u>r</u> ihan]	*[ma:tu <u>r</u> rihan]	(179)

Further, Whitney suggests that there is a historical stage in which glides degeminated. [i] and [u] were lost before [y] and [w], respectively; e.g., /pariyan/ → [payan], which underwent an intermediate stage where degemination took place, i.e., /pariyan/ → [paryan] → [paryan] (Whitney 1889: 233). Thus, in short, geminate approximants underwent degemination in Sanskrit. On the other hand, other types of geminates (laterals, nasals, fricatives and stops) were allowed, as the examples in (6) show:

(6) Sanskrit geminates

[tan <u>n</u> amas]	(161)	[asse]	(166)
[ar <u>nn</u> a]	(189)	[atti]	(159)
[tal <u>l</u> abhate]	(162)	[arcad <u>d</u> ^h u:ma]	(159)
		[saccarita]	(202)
		[ya:taya <u>ḥḥ</u> ana]	(202)
		[ark <u>k</u> a]	(228)
		[dig <u>g</u> aya]	(159)

Degemination in Sanskrit can be analyzed as a consequence of *GG and *RR being ranked above an anti-degeminaton constraint; here, assuming that degemination involves fusion, I use UNIFORMITY, which militates against fusion of two underlying segments (McCarthy and Prince 1995). As illustrated in (7), UNIFORMITY is ranked below *GG and *RR, but ranked above *LL, *NN and *OBSEGEM, because only /r/ and geminate glides degeminated in Sanskrit. These rankings thus, by transitivity, partially support the universal ranking proposed in §2.1. In the tableaux, I assume that visarga is underlyingly [r], but the underlying representation does not matter, insofar as there is a constraint that requires visarga to be realized as [r] before a sonorant (=“VIS=[r]/_SON”). VIS=[r]/_SON is ranked above UNIFORMITY because visarga surfaces as [r] even at the cost of violating UNIFORMITY (compare (d) and (e) in (7)). I set aside the issue of how compensatory lengthening can arise (see, e.g., Goldrick 2000 for an analysis within OT).

(7) Sanskrit degemination

/par <u>y</u> ₁ - <u>y</u> ₂ an/	VIS=[r]/_SON	*GG	*RR	UNIFORMITY	*LL	*NN
a. [par <u>y</u> ₁ - <u>y</u> ₂ an]		*!				
b. [par- <u>y</u> ₁₂ an]				*		
/punar <u>r</u> ₁ + <u>r</u> ₂ amate/	VIS=[r]/_SON	*GG	*RR	UNIFORMITY	*LL	*NN
c. [punar <u>r</u> ₁ - <u>r</u> ₂ amate]			*!			
d. [puna <u>a</u> :- <u>r</u> ₁₂ amate]				*		
e. [puna <u>n</u> ₁ - <u>r</u> ₂ amante]	*!					
/ta <u>l</u> ₁ - <u>l</u> ₂ abhate/	VIS=[r]/_SON	*GG	*RR	UNIFORMITY	*LL	*NN
f. [ta <u>l</u> ₁ - <u>l</u> ₂ abhate]					*	
g. [ta:- <u>l</u> ₁₂ abhate]				*!		
/tan <u>n</u> ₁ - <u>n</u> ₂ amas/	VIS=[r]/_SON	*GG	*RR	UNIFORMITY	*LL	*NN
h. [tan <u>n</u> ₁ - <u>n</u> ₂ amas]						*
i. [ta:- <u>n</u> ₁₂ amas]				*!		

Similar to the case in Sanskrit, Greek underwent a historical change by which geminate sonorants degeminated (Crist 2001: 80-82). Unlike Sanskrit, Greek degemination targeted geminate nasals as well. The case of Greek shows that all geminate sonorants are marked, although geminate nasals are tolerated in some of the languages discussed in this paper.

2.4 Japanese coda nasalization and flopping of a floating mora

The third kind of alternation due to constraints against geminate sonorants comes from Japanese. Japanese has geminates of voiceless obstruents and nasals in the native vocabulary ([katta] ‘bought,’ [sassuru] ‘guess,’ [sonna] ‘such’), and it also has voiced obstruent geminates in recent borrowings ([eggu] ‘egg,’ [oddu] ‘odds’) (Itô and Mester 1999). However, in no strata do we observe geminate approximants, and again, the ranking proposed in §2.1 is partially corroborated: geminate nasals are least marked among the geminate sonorants. In addition to distributional evidence, Japanese actively avoids geminate approximants as well. A mimetic suffix /-ri/, with a floating mora, causes gemination of root-final consonants, including nasals, as shown by the examples in (8).

(8) Japanese gemination

/bata-μ-ri/	→	[<u>batta</u> -ri]	‘accidentally’
/poka-μ-ri/	→	[<u>pokka</u> -ri]	‘openly’
/basa-μ-ri/	→	[<u>bassa</u> -ri]	‘a lot’
/kune-μ-ri/	→	[<u>kunne</u> -ri]	‘crookedly’

When root-final consonants are liquids or glides, however, gemination is blocked; instead, a coda nasal is inserted. This phenomenon has been referred to as “coda nasalization” since Kuroda

(1965: 201-208). Some examples are shown in (9) ([N] represents a so-called moraic nasal):⁴

(9) Japanese coda nasalization

a. *rr* → *nr*

/k_ir_a+μ+ri/ → [kiN_ra-ri] ‘shiningly’

/ho_ro+μ+ri/ → [hoN_ro-ri] ‘falling’

b. *ww* → *nw*

/ya_wa+μ+ri/ → [yaN_wa-ri] ‘softly’

/hu_wa+μ+ri/ → [huN_wa-ri] ‘fluffy’

c. *yy* → *ny*

/do_yo+μ+ri/ → [doN_yo-ri] ‘cloudy’

/bo_ya+μ+ri/ → [boN_ya-ri] ‘spacing out’

These patterns again necessitate constraints against geminate glides and geminate liquids. The tableaux in (10) illustrate how these patterns can be analyzed. Since IDENT(NAS), which militates against nasalization, is ranked above *OBSGEM, non-approximants simply become geminates, as illustrated in the first tableau in (10). However, because *GG and *RR are ranked above IDENT(NAS), coda nasalization takes place to avoid geminate glides and geminate liquids.

⁴ Voiced geminates are avoided by coda nasalization as well in the strata where they are not tolerated (e.g., /u_za+μ+ri/ → [uN_za-ri] ‘annoyed’). Since voiced geminates are not the focus of this paper, this case is set aside. See §5.2.1 for a possible parallel between voiced obstruent geminates and geminate sonorants.

(10) Japanese coda nasalization

/bata+ μ +ri/	*GG	*RR	IDENT(NAS)	*OBSEGEM
a. [batta-ri]				*
b. [baNta-ri]			*!	
/horo+ μ +ri/	*GG	*RR	IDENT(NAS)	
c. [horro-ri]		*!		
d. [hoNro-ri]			*	

There is another way in which constraints against geminate sonorants manifest themselves in Japanese. Kawahara and Akashi (2005) observe that, as shown in (11a), emphatic forms of reduplicative mimetics are formed by C_2 -gemination, when C_2 is an obstruent. However, they experimentally show that Japanese speakers prefer to geminate C_3 instead of C_2 , when C_2 is a sonorant, as in (11b).

(11) Mimetic emphatic gemination in Japanese

a. C_2 gemination when C_2 is an obstruent

/ μ +pata-pata/	→	[patt <u>a</u> -pata]	‘fanning’
/ μ +kasa-kasa/	→	[kass <u>a</u> -kasa]	‘dried’

b. C_3 gemination when C_2 is a sonorant

/ μ +puni-puni/	→	[puni <u>p</u> -puni]	‘soft’
/ μ +sara-sara/	→	[sar <u>a</u> s-sara]	‘smooth’
/ μ +poyo-poyo/	→	[poy <u>o</u> p-poyo]	‘soft’

To analyze the patterns in (11), first let us assume that gemination is caused by a floating mora. Then there is a constraint, which I call μ -to- σ_1 , that requires a floating mora to dock onto an initial syllable; initial syllables are known to attract floating elements (Beckman 1998: chapter 5; Zoll 1998). As shown in the first tableau in (12), this constraint by default favors C_2 -gemination. This constraint, however, is ranked below *GG, *RR, and *NN. C_3 -gemination thus results when C_2 is a sonorant, as shown in the second tableau in (12).

(12) Flopping of a floating mora

/μ+pata-pata /	*GG	*RR	*NN	μ-to-σ ₁
a. [☞] [pa <u>tt</u> a-pata]				
b. [pata <u>p</u> -pata]				*!
/μ+poyo-poyo /	*GG	*RR	*NN	μ-to-σ ₁
c. [poy <u>yy</u> o-poyo]	*!			
d. [☞] [poyop <u>p</u> -poyo]				*

Note that the underlying geminate nasals surface faithfully (as in [sonna] ‘such’) because *NN is relatively low-ranked (i.e., FAITH » *NN); however, *NN does exert its force in the context of mimetic gemination, as evidenced by the fact that derived geminate nasals are disfavored.

2.5 Blocking of gemination in Selayarese and Ilokano

Selayarese provides yet another example of avoidance of geminate sonorants (Podesva 2000, 2002). When the prefix /taʔ/ is attached to a root that begins with a voiceless obstruent, the prefix-final glottal stop assimilates to the following consonant, resulting in a geminate, as shown in (13) (Mithun and Basri 1986: 243):

(13) Selayarese gemination

/taʔ+pelaʔ/	→	[ta <u>pp</u> eʔ]	‘get lost’
/taʔ+tuda/	→	[ta <u>tt</u> uda]	‘bump against’
/taʔ+kalupa/	→	[ta <u>kk</u> alupa]	‘faint’
/taʔ+sambaŋ/	→	[ta <u>ss</u> sambaŋ]	‘stumble, trip’

This assimilation of [ʔ] fails when root-initial consonants are nasals and liquids, as shown in

(14)⁵ (Mithun and Basri 1986: 244). There are no glides in Selayarese, so we cannot tell whether glides undergo gemination or not.

(14) Blocking of gemination in Selayarese

/taʔ+muri/	→	[taʔ <u>m</u> uri]	‘smile’
/taʔ+noʔnoso/	→	[taʔ <u>n</u> oʔnoso]	‘be shaken (liquid)’
/taʔ+ŋoaʔ/	→	[taʔ <u>ŋ</u> oaʔ]	‘to yawn’
/taʔ+lesaŋ/	→	[taʔ <u>l</u> esaŋ]	‘to be removed’
/taʔ+riŋriŋ/	→	[taʔ <u>r</u> iŋriŋ]	‘to be walled’

The blocking of gemination in Selayarese suggests that constraints against geminate sonorants dominate a constraint that requires gemination.⁶ For the latter constraint, I posit ASSIM, which requires a coda glottal stop to assimilate to the following consonant. This constraint is ranked above *OBSEGEM because assimilation creates geminate obstruents. ASSIM, on the other hand, is

⁵ Gemination also fails when roots begin with a voiced obstruent. Goldsmith (1990: 133) proposes that voiced obstruent geminates and geminate sonorants pattern together because they are both [+voice]. However, there are languages like LuGanda and Sanskrit in which these two types of geminates do not pattern together (see §2.2 and §2.3). Furthermore, for example, in Hungarian any type of geminate except a voiced obstruent geminate can be created by a gemination process in loanword adaptation (Nádasdy 1989: 105-108). This pattern shows that voiced geminates can be more marked than geminate sonorants, even though voiced obstruents are less sonorous than sonorants. I therefore set the case of voiced geminates aside, and focus solely on the markedness of geminate sonorants in this paper (though see §5.2.1).

⁶ This pattern could alternatively be analyzed as the effect of IDENT(SON), which prohibits the change of an underlying glottal stop to a sonorant. This approach, however, does not generalize to a similar pattern found in Ilokano, discussed below.

ranked below a set of constraints that prohibit geminate sonorants. The tableaux in (15) illustrate the ranking, taking the case of nasals as an example:

(15) Analysis of gemination blocking in Selayarese

/taʔ+pelaʔ/	*RR	*LL	*NN	ASSIM	*OBSGEM
a. [taʔpelaʔ]				*!	
b. [tappelaʔ]					*
/taʔ+muri/	*RR	*LL	*NN	ASSIM	
c. [taʔmuri]				*	
d. [tammuri]			*!		

Selayarese thus avoids geminate sonorants. However, root-internally, we do observe instances of geminate sonorants (e.g., [hallasa] ‘suffer,’ [rammasa] ‘dirty,’ [barroʔ] ‘eagle’). The existence of root-internal geminate sonorants suggests that root-specific faithfulness constraints that protect root-internal segments (Beckman 1998) are ranked above the constraints that prohibit geminate sonorants, as illustrated in (16):

(16) Root-internal geminate sonorants surface faithfully

/hallasa/	FAITH-ROOT	*RR	*LL	*NN	ASSIM
a. [hallasa]			*		
b. [hattasa]	*!				

Another example of gemination blocking is found in Ilokano (Hayes 1989: 270-271). The formation of a glide from an underlying vowel that occurs before another vowel causes compensatory lengthening—or gemination—of the preceding consonant. This gemination process regularly applies to obstruents, but is marginally possible for nasals and [l], and never

applies to [r, w, y].⁷

(17) Ilokano compensatory gemination

a. Gemination of obstruents applies regularly

/luto-en/	→	[luttw-én]	‘cook-goal focus’
/kina-ʔapó-an/	→	[kina-ʔappw-án]	‘leadership’
/bági-en/	→	[baggw-én]	‘to have as one’s own’
/pag-ʔáso-án/	→	[pag-ʔassw-án]	‘place where dogs are raised’

b. Gemination of nasals and [l] is marginal

/dámo-en/	→	?[dammw-én] [damw-én]	‘to be new to something’
/na-ʔalíno-an/	→	?[na-ʔalinnw-án] [na-ʔalinw-án]	‘to become sensitive’
/na-ʔaliŋó-an/	→	?[pag-ʔaliŋnw-án] [pag-ʔalinw-án]	‘place where boars are found’
/bále-an/	→	?[bally-án] [balɿ-án]	‘to change’

c. No gemination of [r, w, y]

/pag-ʔári-an/	→	[pag-ʔary-án]	‘place of leadership’
/ʔáyo-en/	→	[ʔayw-én]	‘cheer up-goal-focus’
/babáwi-en/	→	[babwy-én]	‘regret-goal focus’

Thus the gemination likelihood hierarchy in Ilokano is that obstruents are most geminable, nasals and [l] are less so, and [r] and glides are not geminable at all. This hierarchy motivates the following ranking: *RR, *GG » *LL, *NN » *GEMOBS, which nicely corroborates the universal

⁷ Hayes states that [ʔ] never geminates in Ilokano either, but no examples are given. The markedness of geminate glottals is in fact cross-linguistically motivated (e.g., Japanese allows [ss] but not [hh]). Explicating the markedness of geminate glottals is, however, beyond the scope of this paper.

ranking proposed in §2.1.

2.6 Nasalization in Ethio-Semitic languages

Yet another kind of alternation is found in a historical change in Chaha, where geminate approximants became nasalized (Polotsky 1951: 36; McCarthy 1986: 22). A parallel pattern is also found in related languages: Endegeñ (Leslau 1976) and Ezha (Leslau 1992). Data from Endegeñ are given in (18) to illustrate this sort of alternation (taken from Leslau 1976: 142-143):

(18) Endegeñ geminate nasalization

<u>Root</u>		<u>Perfect</u>	
$z_1l_2l_3$	→	[z ₁ ä <u>nn</u> ₂ är ₃ ä]	‘start to fly’
$q_1l_2l_3$	→	[q ₁ ä <u>nn</u> ₂ är ₃ ä]	‘be light’
$x_1r_2r_3$	→	[x ₁ ä <u>nn</u> ₂ är ₃ ä]	‘cut the ears of a cow’
$b_1r_2r_3$	→	[b ₁ ä <u>nn</u> ₂ är ₃ ä]	‘fly’

This alternation suggests that although geminate nasals are marked, they are not as marked as geminate approximants. This nasalization pattern then supports the ranking proposed in §2.1, as this language has the ranking *RR, *LL » *NN.

The behavior of geminate glides is not clear-cut. Very few isolated examples of [ww] are found in Leslau (1976), and geminate [yy] seems to be absent in Endegeñ. We do not, however, observe a visible alternation in which geminate glides are rendered to something else. This is because in Ethio-Semitic languages, gemination is typically found in the penultimate position of verbs, but when glides appear in the penultimate position of triliteral roots, the glides are often realized as corresponding front or back vowels, or palatalization or labialization of the other root consonants.

To analyze the patterns illustrated in (18), I suggest that geminate liquids are nasalized, rather than occlusivized, because nasalization can avoid geminate liquids while retaining sonorancy; i.e., IDENT(SON), which prohibits a change in [\pm son], is ranked high. Concretely, IDENT(SON) outranks *NN, so that changing liquids into nasals is preferred over changing them into stops, as illustrated in (19).

(19) Endegeñ geminate nasalization

/z ₁ l ₂ l ₃ , ä/	*LL	IDENT(SON)	*NN
a. [z ₁ ä <u>ll</u> ₂ är ₃ ä]	*!		
b. [z ₁ ä <u>nn</u> ₂ är ₃ ä]			*
c. [z ₁ ä <u>tt</u> ₂ är ₃ ä]		*!	

2.7 Apparent counterexamples

We have seen many cases which evince the markedness of geminate sonorants. However, there appear to be languages that possess geminate sonorants but not geminate obstruents, which seems to contradict the universal ranking proposed in §2.1. I address this issue in this subsection.

Morén (1999: 26) suggests that Hausa is such an example. However, according to Newman (1997), there *are* examples of geminate obstruents, though they may be rarer than geminate sonorants: “[a]ll Hausa consonants can be geminated...[but] [i]n underived words, only geminate nasals and liquids are common, e.g. *dannée* ‘suppress’, *hannuu* ‘hand’..., *tallee* ‘soup pot’; but others do occur sporadically in native words, e.g. *tukkuu* ‘birds crop’” (p. 540). Further, all kinds of geminates can be created via a gemination process concomitant with CV-reduplication, e.g., [dad-dakaa] ‘pound,’ [kak-kafaa] ‘affix,’ and [zaz-zaafaa] ‘hot’ (Newman 1997: 549). Since Hausa does allow geminate obstruents, though they may be rarer than geminate sonorants, it does not constitute a convincing counterexample.

Another potential counterexample is Ponapean, in which geminate nasals and geminate [ll] are allowed, as in (20a),⁸ but geminate obstruents do not occur except in loanwords from Japanese, as in (20b) (Rehg and Sohl 1981: 35-37).

(20) a. Geminate sonorants in Ponapean

[ka <u>mm</u> oal]	‘to rest’	[la <u>mm</u> ^w in]	‘majestic’
[ure <u>nn</u> a]	‘lobster’	[arewa <u>ll</u> a]	‘of animals’

b. Geminate obstruents in loanwords

[na <u>pp</u> a]	‘Chinese cabbage’	[ka <u>kk</u> o]	‘putting on airs’
[kia <u>ss</u> i]	‘catcher’		

There is an independent reason to suspect, however, that Ponapean does not counter-exemplify the claim that geminate sonorants are more marked than geminate obstruents. Ponapean resolves illegal geminates by so-called nasal substitution (Rehg and Sohl 1981: 58-64), which turns the first consonant into a nasal, as illustrated by the examples in (21):

(21) Ponapean nasal substitution

/pa <u>p</u> -pa/	→	[pa <u>m</u> pa]	‘swimming’
/ki <u>k</u> -ki/	→	[ki <u>ŋ</u> ki]	‘kicking’
/di <u>d</u> -di/	→	[di <u>n</u> di]	‘build a wall’
/sa <u>s</u> -sa/	→	[sa <u>n</u> sa]	‘stagger’

Nasal substitution requires the ranking *OBSEGEM » IDENT(NAS), as illustrated in tableau (22).

⁸ The only examples of geminate [rr] that Rehg and Sohl (1981: 36) provide are heteromorphemic, involving reduplication ([rer-rer] ‘to be trembling’ and [rar-rar] ‘to be making a static-like noise’). Hence I assume that geminate [r] is illicit within a morpheme.

(22) Ponapean nasal substitution

/p <u>pp</u> a/	*OBSEGEM	IDENT(NAS)
a. [p <u>pp</u> a]	*!	
b. [pa <u>mp</u> a]		*

However, this repair does not help either geminate nasals, because nothing happens, or geminate laterals, because it creates an even more marked structure ([nl]), which is an unattested cluster in Ponapean. The lack of [nl] is presumably due to the Syllable Contact Law, which prohibits a rise in sonority across a syllable boundary (see Gouskova 2004 for a recent overview and references to earlier work).

To flesh out these ideas, let FAITH be a set of faithfulness constraints that prohibits any change other than nasal substitution, and SYLLCON be a constraint that prohibits a sonority rise across a syllable boundary. With these constraints ranked higher than *LL and *NN, even with the fixed ranking *LL, *NN » *OBSEGEM, we obtain the right outcomes. The tableaux in (23) illustrate how hypothetical underlying geminate obstruents are resolved by nasal substitution, while geminate sonorants are not:

(23) Analyses of geminate patterns in Ponapean, assuming *LL » *NN » *OBSGEM

/t <u>pp</u> a/	FAITH	SYLLCON	*LL	*NN	*OBSGEM	IDENT(NAS)
a. [t <u>pp</u> a]					*!	
b. [t <u>am</u> pa]						*
c. [t <u>ap</u> a]	*!					
/u <u>ren</u> na/	FAITH	SYLLCON	*LL	*NN	*OBSGEM	IDENT(NAS)
d. [u <u>ren</u> na]				*		
e. [u <u>ret</u> ta]	*!				*	*
f. [u <u>re</u> na]	*!					
/t <u>all</u> a/	FAITH	SYLLCON	*LL	*NN	*OBSGEM	IDENT(NAS)
g. [t <u>all</u> a]			*			
h. [t <u>an</u> la]		*!				*
i. [t <u>att</u> a]	*!					
j. [t <u>al</u> a]	*!					

Finally, to complete the picture, there are no geminate glides in Ponapean (and perhaps no geminate [r]; see footnote 8). The lack of geminate glides suggests that *GG is ranked above FAITH, so that underlying geminate glides surface unfaithfully. The tableau in (24) illustrates this ranking, assuming that underlying geminate glides undergo degemination.

(24) Geminate glides surface unfaithfully

/t <u>ay</u> ya/	*GG	SYLLCON	FAITH	*LL	*NN	*OBSGEM	IDENT(NAS)
a. [t <u>ay</u> ya]	*!						
b. [t <u>an</u> ya]		*!					*
c. [t <u>ay</u> a]			*				

To summarize, in Ponapean, all geminates are in principle disfavored, with a hidden universal ranking of *GG » *LL » *NN » *OBSGEM. However, nasal substitution, the repair for resolving illegal geminates, does not do any good for geminate nasals, and it cannot be used for geminate laterals due to SYLLCON. However, the markedness of glide geminates is so intolerable that some other repair eliminates potential underlying geminates. Since the analyses developed

here are based on an independently motivated process of nasal substitution, I again conclude that Ponapean does not counter-exemplify the claim that geminate sonorants are more marked than geminate obstruents.

2.8 Summary

To summarize, I have identified a number of languages in which constraints against geminate sonorants cause phonological alternations. These alternations constitute a typical case of homogeneity of target/heterogeneity of processes in that a variety of processes can conspire to eliminate one particular type of structure (McCarthy 2002; Pater 1999). The proposed universal ranking *GG » *LL » *NN » *GEMOBS is supported by a number of alternation patterns. The list of alternations we have observed is summarized in Table 2.

Processes	Language	Geminate types avoided			
		Obst.	Nasal	Lateral	Glide
occlusivization	Berber	√	√	√	*
	LuGanda	√	√	*	*
nasalization	Chaha, Endegeñ, Ezha	√	√	*	--
coda nasalization	Japanese	√	√	--	*
floating mora flopping	Japanese	√	*	--	*
degemination	Sanskrit	√	√	√	*
	Greek	√	*	*	*
blocking of gemination	Ilokano	√	√/*	√/*	*
	Selayarese	√	*	*	--

Table 2: Heterogeneity of processes due to *SONGEM.

3. Phonetic grounding of *SONGEM: A hypothesis

Having established the markedness of geminate sonorants and the universal markedness hierarchy (*GG » *LL » *NN » *OBSGEM), this section proposes a phonetic grounding for these markedness patterns.

3.1 Outline

The dispreference against sonorant geminate cannot readily be attributed to an articulatory reason: there seem to be no articulatory or aerodynamic reasons for why prolonging approximant constrictions is challenging. Geminate sonorants are, in articulatory terms, expected to be relatively easy to produce because speakers can sustain voicing throughout the constriction without raising the intraoral air pressure level.⁹

I thus instead propose, along with Podesva (2000), that the markedness of geminate sonorants derives from a perceptual factor. The general idea is that since the segmental boundaries of sonorant consonants are not clear-cut, the beginnings and ends of such segments are hard to hear. This blurriness of segmental onset and offset leads to unclear perception of constriction duration for sonorant segments. Geminacy contrasts, which most crucially rely on constriction duration differences, are thus hard to perceive for sonorant segments.

⁹ Thanks to Lisa Zsiga for pointing this out.

3.2 A geminacy contrast relies on constriction duration

It is rather uncontroversial that a constriction duration difference is by far the most important perceptual correlate of a geminacy distinction. It has been shown in many experimental studies that constriction duration constitutes the primary perceptual cue for signaling geminacy contrasts (Esposito and Di Benedetto 1999; Hankamer et al. 1989; Krähenmann 2001, 2003; Lahiri and Hankamer 1988; Rochet and Rochet 1995). Experiments using continua of varying duration have shown that varying duration affects geminacy perception in many languages, including Arabic (Obrecht 1965), Bengali and Turkish (Hankamer et al. 1989; Lahiri and Hankamer 1988), English (Pickett and Decker 1960), Hindi (Shrotriya et al. 1995), Italian (Esposito and Di Benedetto 1999), and Swiss German (Krähenmann 2001, 2003).

3.3 Constriction duration is hard to perceive for sonorant segments

To the extent that constriction duration is an important perceptual cue for a geminacy distinction, it is crucial that constriction duration is accurately heard. In this respect, sonorants are at a disadvantage. There are at least three reasons why.

First, the segmental boundaries between consonants and flanking vowels are less clear-cut for sonorants than obstruents. Consider the spectrograms in Figure 1, which are based on an Egyptian Arabic speaker's pronunciation of singleton/geminate pairs of several types of consonants in Arabic (see §4 for recording conditions).

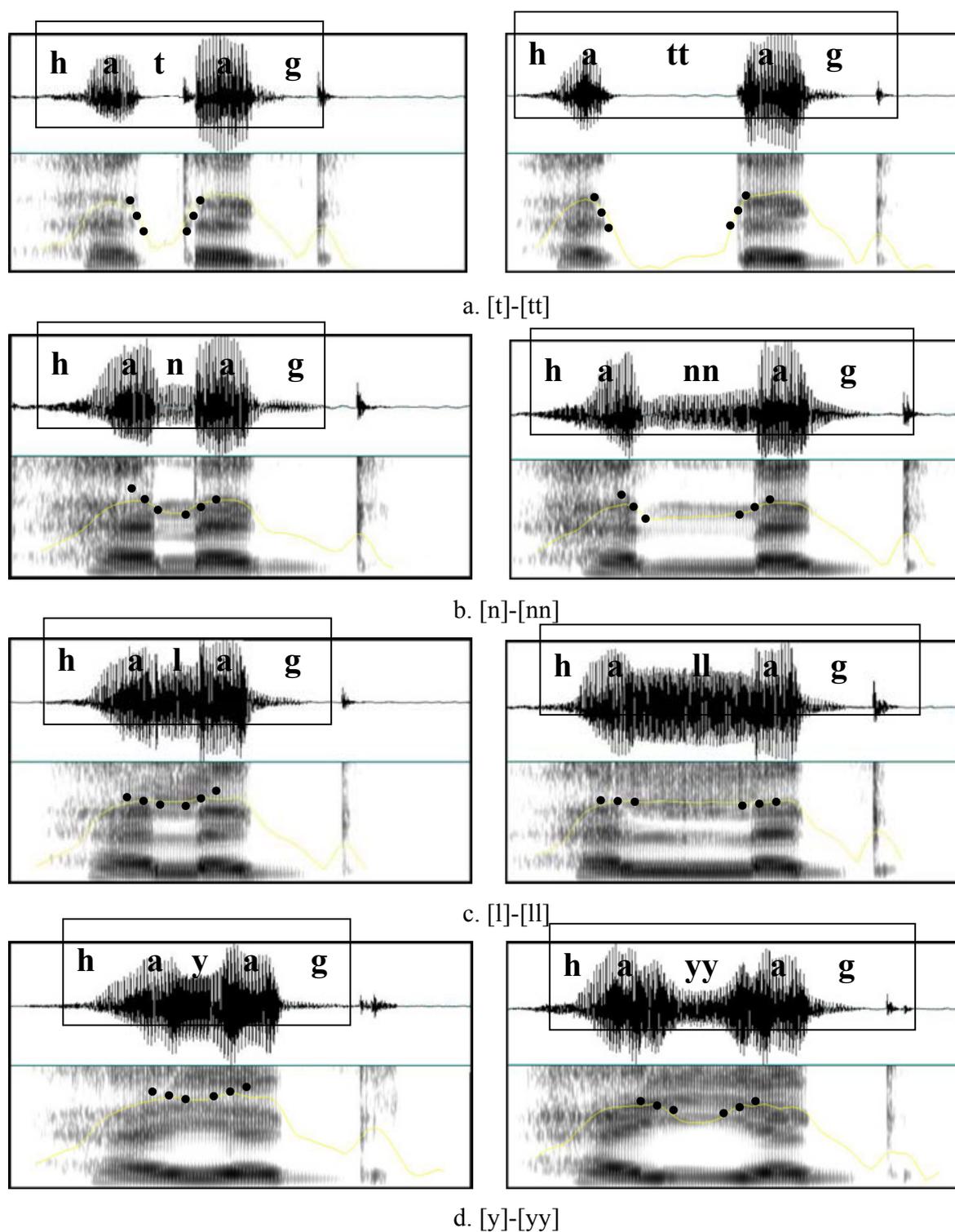
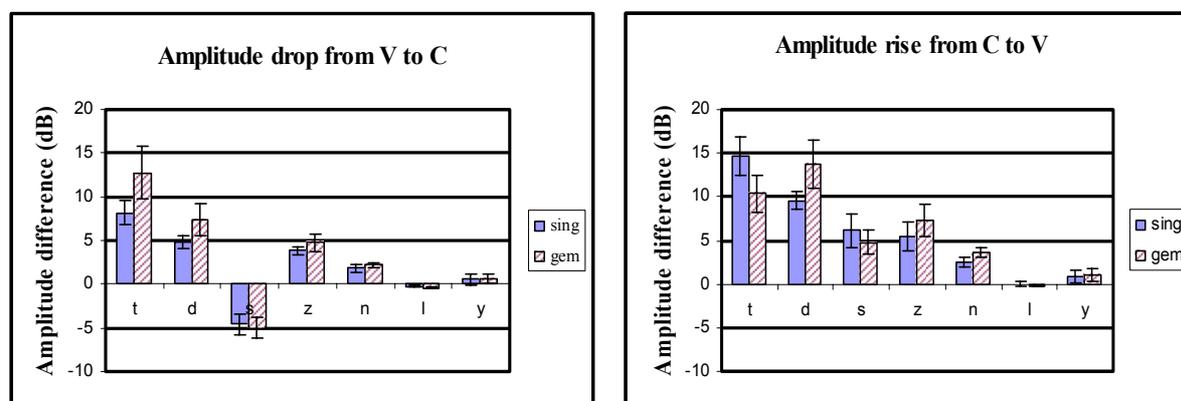


Figure 1: Spectrograms of the Arabic singleton and geminate consonants: (a) [t]-[tt], (b) [n]-[nn], (c) [l]-[ll], and (d) [y]-[yy]. The time scale is the same for all of the pictures (700 ms). Dotted lines represent the amplitude changes into and out of flanking vowels, based on Praat's amplitude track lines.

As seen in Figure 1, [t]-[tt] have very clear-cut segmental boundaries, their constriction duration being clearly signaled by complete silence. On the other hand, for [y]-[yy], the constriction phase is very vowel-like, and hence the glide's constriction phase is very hard to distinguish from the surrounding vowels. Standing between these two extremes are [n]-[nn] and [l]-[ll], which have less clear segmental boundaries than [t]-[tt], because of their spectral continuity into and out of the flanking vowels and the presence of energy during constriction. In short, the onset and offset are blurry for sonorant consonants, especially glides.

Second, the amplitude changes into and out of flanking vowels, represented by the dotted lines in Figure 1, are steep for the stops, but shallow for the sonorants. That sonorants have only shallow amplitude changes again makes the perception of segmental boundaries harder. Kato et al. (1997) show that speakers are more sensitive to a change in segmental duration when there is a steeper amplitude change into and out of that segment: "a larger loudness jump causes a higher sensitivity [to segmental boundaries]" (p. 2318). To illustrate the differences in amplitude changes for different consonants, data from Egyptian Arabic, recorded and analyzed by the author (see §4 for more details), are provided in Figure 2.



a.

b.

Figure 2: Amplitude changes in VC- and CV-transitions. (a) illustrates amplitude drop from the preceding vowel. (b) illustrates amplitude rise in CV-transitions. The error bars represent 95% confidence intervals.

Figure 2a illustrates the amplitude difference between the last periodic wave of the preceding vowel and the left edge of the consonants (15ms into the closure) for seven types of consonants ([t], [d], [s], [z], [n], [l], and [y]). Figure 2b illustrates the amplitude difference between the right edge of the consonants (just before release for voiceless consonants, and the second to last periodic wave for voiced consonants) and the first periodic wave of the following vowel. These figures reveal that the amplitude changes are large for obstruents, medium for nasals, and small for approximants. These differences are verified by independent sample t-tests (VC-transitions: obs~nas, $t(98)=5.67$, $p<.001$; nas~approx, $t(58)=10.40$, $p<.001$. CV-transitions: obs~nas, $t(98)=5.86$, $p<.001$; nas~approx, $t(58)=11.13$, $p<.001$). Therefore, as exemplified in Egyptian Arabic, the more sonorous a segment is, the smaller the amplitude change it involves in both VC- and CV-transitions. This characteristic of sonorants makes perceptual segmentation more difficult for sonorants than for obstruents.

The third factor that might make the perception of segmental boundaries difficult for

sonorants is that their cues are “stretched out,” in the words of Ohala (1993: 251-253). The cues for liquids (e.g., rhoticity), glides (e.g., labiality), and nasals (e.g., nasality) tend to extend over a domain that is larger than adjacent segments. In other words, cues for sonorants are heard well before the constriction actually begins and remain until some time after the constriction ends. Blevins and Garrett (1998, 2004) and Hume (2004) note that these segments are prone to undergo metathesis, because their locations are, due to their stretched cues, hard to pin down. This entails that the beginning and end of sonorant segments are hard to perceive.

For these three reasons ((i) blurry transitions, (ii) small amplitude changes, and (iii) stretched cues), the onsets and offsets of sonorants are perceptually hard to pin down, at least compared to obstruents.¹⁰ As a consequence, constriction duration of sonorant segments is not very perceptible, and thus, geminacy contrasts for sonorant segments are not signaled well.

This hypothesis automatically offers an explanation for the universal ranking proposed and substantiated in §2, *GG » *LL » *NN. As seen in Figure 1, the blurriness of segmental boundaries seems worst for glides, which explains the extreme markedness of geminate glides. Among the sonorant consonants, the amplitude changes are steepest for nasals, as seen in Figure 2. This characteristic of nasals might make segmental boundary identification slightly easier. Hence this would explain the tendency for a geminate contrast in nasals to be most acceptable. In a nutshell, a simple generalization is that the more sonorous a segment is, the worse the geminacy contrasts it makes, because the more sonorous it is, the less well it signals its constriction duration.

¹⁰ This paper does not attempt to determine to what degree each factor contributes to the difficulty in perceiving the segmental boundaries of sonorous segments. This topic is left for future research.

Some remarks on rhotics are now in order. Recall that there are languages that disallow geminate rhotics but not geminate glides. Malayalam, for example, prohibits geminate [rr] but not geminate glides (Mohanani 1989: 620; Mohanani and Mohanani 1984: 581-582). Given that glides are usually more sonorous than rhotics (see Parker 2002 for a recent overview of the sonority hierarchy), a language like Malayalam might appear to be inconsistent with the proposal.

There are three possible reasons why geminate rhotics can be more marked than geminate glides. First, rhotics have a very long stretched cue (see Blevins and Garrett 2004 for an overview), which might make their duration hard to determine. Second, if the rhotic in question is an approximant, then it might be very much like a vocalic segment, as is the case in English. In that case, rhotics might be more sonorous than or at least as sonorous as glides. Finally, as is the case in Malayalam, the rhotic in question may be a tap (Mohanani 1989: 595). It is then simply impossible to prolong the constriction; a tap would have to turn into a trill in order to become a geminate while keeping its rhoticity. However, a trill is presumably marked, because it requires a very precise articulatory coordination (Ladefoged and Maddieson 1996; Solé 2002). Ladefoged and Maddieson (1996) note that to make a trill, “the aperture size and airflow must fall within critical limits for trilling to occur, and quite small deviations mean that it will fail (p. 217)”. In a nutshell, since rhotics involve complicating factors in addition to sonority, their markedness cannot be fixed with respect to the markedness of other geminate sonorants.

Finally, the proposed hypothesis, which derives the markedness hierarchy for sonorant geminate from the blurriness of segmental boundaries, might hold only in intervocalic positions. This is because it is possible that the perceptibility scale for duration is different between intervocalic positions and word-edge positions, i.e., sonorants might not necessarily have a disadvantage in signaling their durations compared to obstruents at word edges, because they

have internal cues. More study needs to be done on the markedness hierarchy for non-intervocalic geminates, and its relation to the scale of perceptibility of geminacy contrasts at word-edges (e.g., Abramson 1986). However, this issue too is left for future research.

4. Acoustic preliminary

4.1 Method

4.1.1 Materials

If a geminacy contrast is hard to discriminate for sonorant consonants, then this difficulty should be observed when people attempt to discriminate continua with varying constriction durations—the speakers should be less sure about the geminacy of sonorant stimuli than that of obstruent stimuli. A perceptual experiment was conducted to verify this prediction, and the prediction was indeed borne out, as reported in §5. Arabic was chosen as a target language to test the confusability of a geminacy contrast of different kinds of consonants, because all kinds of consonants can be geminated in Arabic (see §5.3 for discussion of lexical statistics of different types of geminates in Arabic). Before reporting the results of the perceptual experiment, however, this section discusses acoustic aspects of Arabic geminates (e.g., constriction duration differences), which were important to know when creating stimuli for the perceptual experiment.

The target words were chosen in the following way.¹¹ To mimic the canonical word structure of Arabic, a set of nonce words consisting of triconsonantal roots with interleaved [a] was made up. In the stimulus set, the first consonant was [h] and the final consonant was [g], and

¹¹ Many thanks to John McCarthy for his help in constructing this set of stimuli as well as for sharing his expertise on Arabic phonology with me.

the second consonant was the target consonant. I limited my attention to the coronal consonants [t, d, s, z, n, l, y].¹² The stimuli are listed below in (25):

(25) The stimuli

hatag	~	hattag	hanag	~	hannag
hadag	~	haddag	halag	~	hallag
hasag	~	hassag	hayag	~	hayyag
hazag	~	hazzag			

Since these stimuli were used in the perceptual experiment, it was necessary to avoid using real words at either end of the continua to circumvent any lexical bias. This was done by consulting an Arabic dictionary (Wehr 1971), and further, before the recording session, a native speaker of Egyptian Arabic confirmed that none of these words are actual words.

4.1.2 Recording

A female native speaker of Egyptian Arabic was asked to read the list of words in (25) in the following frame sentence, presented to her in Arabic vocalized orthography:

(26) The frame sentence

ʔælwælæd _____ iddærs
 ‘The boy _____ lesson’

In pronouncing the target words, she was told that the words were all quasi-Arabic verbs. She was asked to pronounce these nonce words in a natural speech style. The sentences were read ten

¹² [r] was not included in the experiment because a geminate [rr] in Arabic is a trill, and it was thus impossible to make a continuum from a singleton [r] to a geminate [rr].

times, and the order of the stimuli was randomized between each repetition. In the second repetition, the speaker pronounced [hasag] twice and did not pronounce [hazag].

The recording session took place in a sound-attenuated booth at the University of Massachusetts, Amherst. The speech was recorded through a microphone (MicroMic II C420 by AKG) to a Macintosh computer at 44.100 KHz sampling rate and 16 bit quantization level. The recorded tokens were then downsampled to 22.050 KHz when they were transferred to a PC. The recording session lasted about 20 minutes. An informed consent form was obtained from the speaker before she agreed to take part in the experiment.

4.1.3 Acoustic measurements

All acoustic measurements were made using Praat (Boersma and Weenink 1992). To investigate the general acoustic characteristics of singletons and geminates of the seven target consonants, several properties of Arabic singletons and geminates were measured, including the duration of the preceding vowel (V1), constriction duration, and the amplitude difference between the consonant and the flanking vowels (the last of which was reported in Figure 2 in §3).

The criteria for segmentation were as follows. The onset of the first [a] was set at the beginning of a periodic wave in the waveform. The boundaries of consonants were determined differently for different consonants. The beginning of [-cont] consonants was set at the point where F2 disappears; the offset was set right before release. The onset of [s] was signaled by the disappearance of lower formants as well as the appearance of aperiodic friction energy. For [z], on the other hand, the onset of aperiodic friction usually lagged behind the disappearance of F2; I used the disappearance of F2 as an indication of the onset of [z]. The offset was signaled by the appearance of formants higher than F1. For [l], constriction duration was identified by weakened

F3 and F4. The boundaries for [y] were most blurry, because the formant movement of F1 and F2 was gradual and did not coincide with a weakening of wave energy. Segmental boundaries were thus identified at a point where the overall waveform pulse pattern changed from a three-peaked pattern to a two-peaked pattern, as illustrated in Figure 3.

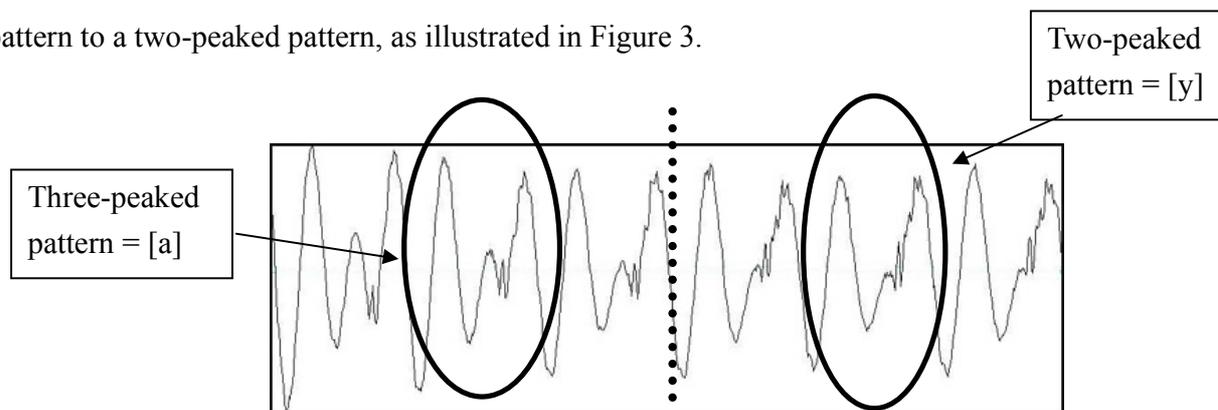


Figure 3: A putative segmental boundary between [a] and [y].

4.2 Results

4.2.1 Constriction duration

I start with the discussion of constriction duration. Figure 4 illustrates the results. Here and throughout, in illustrative figures, error bars represent 95% confidence intervals (CIs), calculated based on t-distributions.

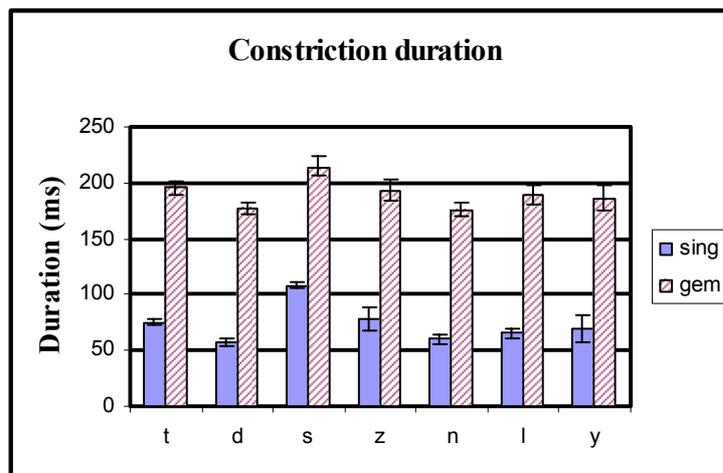


Figure 4: Mean constriction duration for each type of consonant. Error bars represent 95 percent confidence intervals based on t-distributions. Df=8 for [z], 10 for [s], and 9 for the other segments.

As seen in Figure 4, geminacy distinctions are clearly signaled by constriction duration differences. My result thus replicates and expands on Norlin (1987: 77), who shows that geminacy contrasts for stops are signaled by duration differences in Egyptian Arabic.

Second, constriction duration was different for different types of segments. For example, [s] has the longest duration among all of the consonants, and voiceless obstruents were longer than corresponding voiced obstruents. However, the duration differences between singletons and geminates are more or less consistent across all of the types of consonants (about 120 ms). To verify this observation, a between-subject ANOVA was run with two independent factors, SEGMENT TYPE (7-level) and GEMINACY (2-level). As expected, there was a large main effect of SEGMENT TYPE ($F(6, 126)=44.165$, $MS_e=105.38$, $p<.001$) and GEMINACY ($F(1,126)=4512.980$, $MS_e=105.38$, $p<.001$), but the interaction was not significant ($F(6, 126)=1.575$, $MS_e=105.38$, $p=.160$). The non-significance of the interaction term suggests that a durational difference between singletons and geminates is more or less constant across the seven consonants.

4.2.2 Duration of V1

The duration of the preceding vowel (henceforth V1) is summarized in Figure 5:

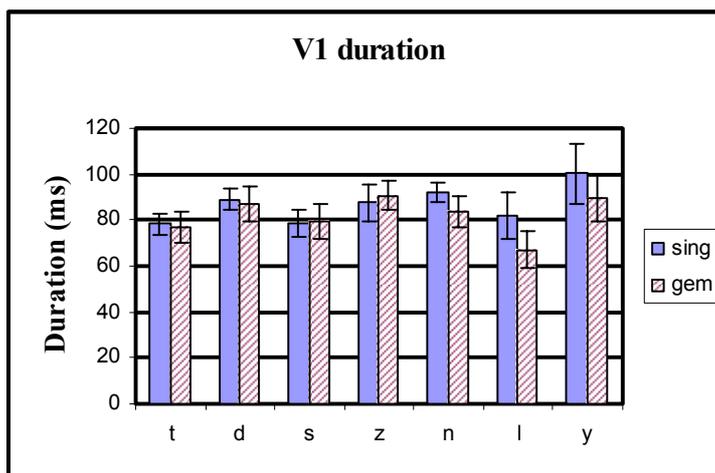


Figure 5: Mean duration of preceding vowels.

Cross-linguistically, it is common for vowels in a closed syllable to be shortened (Maddieson 1985), so generally we expect that vowels are shorter before a geminate. This, however, is clearly not true at least before obstruents in the case of Egyptian Arabic. This finding replicates Norlin's observation (1987: 77) that in Egyptian Arabic, vowel duration is not affected by the geminacy status of the following obstruent.

Yet in the case of sonorants, vowels do seem to be shorter before geminates. To confirm these patterns, a between-subject ANOVA was run with SONORANCY as one independent variable and GEMINACY as another independent variable. The result is that there was a main effect for GEMINACY ($F(1, 136)=6.932$, $MS_e=154.49$, $p<.01$), but not for SONORANCY ($F(1, 136)=1.324$, $MS_e=154.49$, $p=.252$). The significant main effect of GEMINACY shows that, overall, V1 is shorter

before geminates. However, the interaction of the two variables was significant as well ($F(1, 136)=7.650$, $MS_e=154.49$, $p<.01$), which implies that V1 is shortened *only* before geminate sonorants. In fact, V1 is not shortened before the geminate obstruents at all ($t(78)=.126$, $p=.900$).

The extent of vowel shortening before geminate sonorants is not so large. If we look at each sonorant, the differences in vowel duration before singletons and geminates are statistically significant before [l], only marginally so before [n], and clearly non-significant before [y], according to independent sample t-tests with the Bonferroni α -level adjustment ($\alpha=.05/3=.017$) ($t(18)=2.637$, $p=.017$ for [l]; $t(18)=2.394$, $p=.028$ for [n]; $t(18)=1.655$, $p=.115$ for [y]).

This section has reported on the acoustic aspects of Arabic singletons and geminates. Based on the acoustic measures discussed above, continua from singletons and geminates were created and used for a perceptual experiment, to which now we turn.

5. Perceptual Experiment

The perceptual experiment used continua that varied in duration from a singleton endpoint to a geminate endpoint. The hypothesis developed in §3 makes two predictions about the results of this experiment. First, listeners should take longer time to judge a geminacy contrast for sonorant pairs, because of their inherent high confusability. Second, the identification functions for sonorant consonants should be gradual because, for intermediate stimuli, listeners are less sure about the geminacy status of the stimuli. Both of these predictions are borne out.

5.1 Method

5.1.1 Stimuli

The stimuli used were continua from singletons to geminates for the seven coronal consonants. In making the continua, different scales were used for different consonants, because there are durational differences among different consonants, as summarized in Figure 4. For example, assuming that Arabic listeners are aware of the inherent constriction duration differences, an endpoint that is appropriate for [d] would be unnaturally short for [t] and [s]. Similarly, an endpoint that is long enough for singleton [s] would be too long to be perceived as short for the other singleton consonants. Therefore, it was necessary to use different scales for different consonants. However, since the constriction duration difference between singletons and geminates was more or less constant across all of the consonant types (ca. 120 ms), each step in the continua is constant across the seven types of consonants. Hence inherent duration differences among the seven consonants did not constitute a confounding factor in the design of this experiment.

The procedure for making the continua was as follows. The stimuli consisted of two portions: initial CV parts consisting of V1 and the first consonant [h], and the body part with varying constriction duration ((C)CVC). I prepared two kinds of V1 to investigate whether there is any perceptual effect of V1 on geminacy perception. One V1 portion was taken from a representative singleton token, and the other V1 portion was taken from a representative geminate token. By “representative” is meant those tokens that had a V1 duration value closest to the group mean, shown in Figure 5.

Second, a representative geminate token that had a closure duration closest to the group

mean was selected, and the initial CV portions were cut off. From these tokens, a continuum was produced by repeatedly splicing off a portion of the constriction duration. Splicing targeted only steady state parts. One step was about 12 ms for all of the consonants. For voiced segments, two whole voicing pulses, which were also about 12ms, were cut off.

Before combining the initial CV portions and the (C)CVC portions, the intensity of all files was adjusted to 0.70 Pascal by Praat. In combining these two portions, I ensured that there was no transient sound at their boundary. As a result of this whole process, 140 stimuli were created in total (7 types of consonants \times 10 duration steps \times 2 V1s).

5.1.2 Subjects

Seventeen native speakers of Arabic participated in this experiment. Thirteen of them were recruited from the University of Massachusetts, Amherst, and four of them were from the Tokyo University of Agriculture and Technology. An informed consent form was obtained from each subject. All of the subjects had normal hearing and were free of any speech disorders. Three subjects were complete bilingual speakers (two with English, one with Italian). They exhibited a very different pattern from the others in that they did not show sensitivity to an increase in constriction duration. Their data, therefore, were excluded from further analysis. Although most of the subjects spoke Egyptian Arabic, there were people who spoke other dialects (9 Egyptian, 3 Palestinian, 2 Lebanese). All subjects were, however, familiar with the Egyptian dialect of Arabic because of the influence of TV and movies. Further, all of these dialects have a geminacy contrast for the consonants tested in this experiment, so this dialectal variation was not expected to have a large impact on the results (see below).

5.1.3 Task

The experiment was conducted in a sound-attenuated booth. Superlab Pro (by Cedrus) was used for audio and visual presentation of each stimulus. This software automatically randomizes the order of presentation. The subjects listened to stimuli over headphones (DT 250 by Beyerdynamic). The speakers' task was to identify the geminacy status of the consonant based on what they heard; they were asked to judge whether the second consonant had "shadda" or not ("shadda" is a term for geminacy for Arabic speakers).

During a practice session, the subjects heard endpoint stimuli for all types of tokens, and they got feedback about the correctness of their response. In general, the Arabic speakers identified endpoint stimuli quite accurately. During the practice session, the subjects were also instructed to adjust the volume of their headphones to a comfortable listening level.

In the main session, the listeners were not given feedback about the correctness of their response. They were told that in the main session, there was no "right" answer so that they should respond based on their first auditory impression. The experiment consisted of fifteen blocks. Each block contained all 140 tokens; thus, the subjects heard each stimulus fifteen times. The inter-stimuli interval was one second. Between each block, subjects were allowed to take a short break. The entire experiment took about 75 minutes, including the instructions at the beginning and the post-experiment debriefing explanation.

5.2 Results

The results of the procedure described above corroborate the idea that the more sonorous a segment is, the more difficult it is to perceive its geminacy status. First, I show that reaction

times are longer when the target segment is more sonorous. Second, I show that the identification functions are shallower for more sonorant segments.

5.2.1 Reaction time

Previous studies have shown that reaction times are generally slower for stimuli that are difficult to discriminate (e.g., Pisoni and Tash 1974; Studdert-Kennedy et al. 1963; see also Ashby et al. 1994). Therefore, the prediction in terms of reaction time of the proposal developed in §3 is that relative sonority of the stimuli should positively correlate with reaction time, because the geminacy contrast of sonorant consonants is less perceptible. The result of the experiment indeed shows that this is the case.

Superlab records the interval between the end of a stimulus and the moment the subject pushes a button. Before doing any statistical analysis, it was imperative to exclude outliers. This was particularly important because Superlab did not record a response if a listener pushed a button before a stimulus ended. In such cases, listeners tended not to notice that they pushed a button too early, and re-pushed a button much later, which often resulted in a very long reaction time. Therefore, data points larger than 3000 ms were excluded. In addition, an average and a standard deviation were calculated for each speaker, and any data point larger than the average plus two standard deviations was also excluded. This was done in order to further eliminate outliers so as to increase the power of the statistical tests. As a result, in total, 7.9 percent of the data were excluded.

We have 14 sound types (7 consonants \times 2 V1s). For each sound type, the average reaction time over 10 steps and 15 repetitions was calculated for each listener. Figure 6 illustrates the overall results, averaging over the results of all listeners.

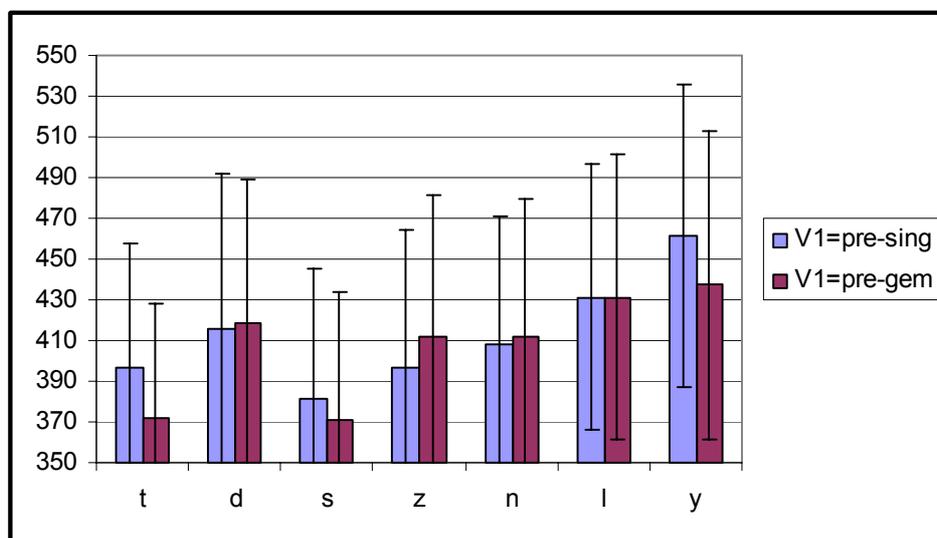


Figure 6: Average reaction time for each consonant type. Error bars represent 95 confidence intervals, based on variances over the 14 speakers.

A first look at the results shows that the reaction times for the [y]-[yy] continua were the longest; those for the [l]-[ll] continua were next. The reaction times for the [n]-[nn], [z]-[zz], and [d]-[dd] continua then cluster together. Finally, the reaction times for the [s]-[ss] and [t]-[tt] continua were the shortest.¹³ Setting aside the behavior of voiced obstruents, which is discussed below, the

¹³ One might suspect that there is a confounding factor here: the reaction times shown in Figure 6 are the intervals between the end of a stimulus and the moment the subject pushed a button. They hence do not include the time between the offset of the target consonant and the end of the stimulus, represented by \longleftrightarrow in the diagram below.

- (i) \longleftrightarrow | \longleftrightarrow RT measured by Superlab
 h a C(C) a g subject response

results generally support the idea that sonorant segments are at a disadvantage in signaling a geminacy contrast.

A within-subject ANOVA was run with V1 TYPE and SEGMENT TYPE as independent variables. The main effect of SEGMENT TYPE was largely significant ($F(6, 78)=18.474$, $MS_e=919.316$, $p<.001$), which shows that reaction times differ depending on the consonant quality. The main effect of V1 TYPE was not significant at all ($F(1, 13)=1.089$, $MS_e=679.899$, $p=.316$), which suggests that there is no systematic effect on reaction time of having pre-singleton V1 or pre-geminate V1. The interaction was marginally significant ($F(6, 78)=2.149$, $MS_e=813.508$, $p=.057$). This presumably reflects the fact that for the [t]-[tt] and [y]-[yy] continua, the reaction times were shorter for the stimuli with pre-geminate V1, whereas for [z]-[zz], the opposite pattern was observed. Finally, the effect of possible dialectal differences was checked by one-way between-subject ANOVA. The result was highly non-significant ($F(2, 11)=.729$, $MS_e=15465.314$, $p=.505$).

To ask more targeted questions, I defined the four within-subject contrasts in (27):

However, the duration of the interval shown by \longleftrightarrow in (i) is fairly constant across all of the stimulus types, and the differences among the 14 types of stimuli were negligibly small (the average=26.3ms, SD=1.3ms; cf. the reaction times shown in Figure 6 were all above 350ms).

$$(27) \quad \psi_1 = 1/4(\mu_t + \mu_d + \mu_s + \mu_z) - 1/3(\mu_n + \mu_l + \mu_y)$$

‘The difference in reaction time between the obstruents and the sonorants’

$$\psi_2 = \mu_y - \mu_l$$

‘The difference in reaction time between [y]-[yy] and [l]-[ll]’

$$\psi_3 = \mu_l - \mu_n$$

‘The difference in reaction time between [l]-[ll] and [n]-[nn]’

$$\psi_4 = \mu_n - 1/2(\mu_d + \mu_z)$$

‘The difference in reaction time between [n]-[nn] and the average of [d]-[dd] and [z]-[zz]’

where ψ is a contrast, a linear combination of weighted means in which the weights sum to zero; μ represents a population mean.

The first contrast ψ_1 tested whether there was a difference between obstruents and sonorants; the overall hypothesis of this paper predicts that this contrast would be larger than zero. ψ_2 tested whether there was a difference between the [y]-[yy] continua and the [l]-[ll] continua, and ψ_3 tested whether there was a difference between the [l]-[ll] continua and the [n]-[nn] continua. The proposed ranking *GG » *LL » *NN predicts that both of these contrasts should be larger than zero. The fourth contrast tested whether there was a difference between the [n]-[nn] continua on the one hand and the [z]-[zz] and [d]-[dd] continua on the other. This contrast was posited because Figure 6 shows that the difference, if any, is very small. Since the predictions were clear, the t-tests were one-tailed. With the four applications of the post-hoc contrast analysis, the α -level was set at $.05/4 = .0125$ by the Bonferroni adjustment.

The result is summarized in Table 3.¹⁴

	ψ_1 (obs. vs. son.)	ψ_2 ([y] vs. [l])	ψ_3 ([l] vs. [n])	ψ_4 ([n] vs. [d, z])
$\hat{\Psi}$	33.04	16.67	20.42	-1.85
$S\hat{\Psi}$	4.08	7.79	6.94	7.94
t	8.10	2.13	2.94	-0.23
p (one-tailed)	<.001	=.026	<.01	=.589

Table 3: The results of the contrast analyses on reaction time defined in (27).

The first contrast ψ_1 turned out to be highly significant, which supports the idea that a geminacy distinction is harder to discriminate for sonorants than for obstruents. ψ_2 was marginally significant, showing that the [y]-[yy] contrast is harder to distinguish than the [l]-[ll] contrast. ψ_3 was significant, showing that the [l]-[ll] contrast is harder to hear than the [n]-[nn] contrast. Therefore, overall, in terms of reaction time, the proposed correlation between sonority and difficulty in perceiving a geminacy contrast was supported.

The fourth contrast ψ_4 was not significant, which suggests that perceiving the [d]-[dd] and [z]-[zz] contrast is as hard as perceiving the [n]-[nn] contrast. This result might be explained as follows. Both the [d]-[dd] and [z]-[zz] continua are fully voiced, so that the flanking vowels are spectrally continuous because of closure voicing. Parker et al. (1986) and Kingston and Diehl (1995) have shown that, given $VC_{[+voice]}V$, when the two vowels are spectrally continuous due to

¹⁴ The values are calculated as follows:

$$\hat{\Psi} = \sum_{i=1}^n \sum_{j=1}^J \frac{w_j \bar{X}_{ij}}{n}, \quad S_{\hat{\Psi}} = \sum_{i=1}^n \sum_{j=1}^J \sqrt{\frac{(w_j \bar{X}_{ij} - w_j \bar{X}_{.j})^2}{(n-1)n}}, \quad t = \frac{\hat{\Psi}}{S_{\hat{\Psi}}} \quad \text{with df of } n-1$$

where \bar{X}_{ij} is the mean for the i -th subject of a j -type segment; w_j is the weight associated with a j -type segment such that $\sum_{j=1}^J w_j = 0$; n is the number of subjects.

low frequency energy during the consonantal closure phase, the spectral continuity causes the percept of the consonant closure duration to be shortened. Further, spectral continuity might simply make the segmental boundaries difficult to hear for voiced obstruents. These factors might make it difficult to reliably hear the constriction duration of voiced obstruents, at least as difficult as it is to hear the constriction duration of the [n]-[nn] continuum.

Voiced geminates *are* marked cross-linguistically, and their markedness has been attributed to an aerodynamic difficulty in maintaining voicing with obstruent closure (Hayes and Steriade 2004; Jaeger 1978; Ohala 1983). The results of this experiment imply that there might be an additional reason for why voiced geminates are marked—i.e., closure duration (and hence a geminacy contrast) is difficult to perceive due to their spectral continuity.

To summarize, the experiment has revealed that reaction time exhibits a hierarchy of [y] > [l] > [n], [d], [z] > [t], [s]. This nicely matches with the hypothesis that sonorancy makes a geminacy contrast difficult to hear, with an interesting additional finding that voiced obstruents might also be at a disadvantage because of their spectral continuity. These conclusions are further corroborated by the shapes of the identification functions, to which we now turn.

5.2.2 Identification functions

If geminacy contrasts are more perceptually distinct for obstruents than for sonorants, then more of the duration continuum should be consistently categorized as singletons or geminates for obstruents i.e., transition in identification function should be steeper for obstruents than for sonorants. This prediction is again borne out. Figure 7 shows the overall results.

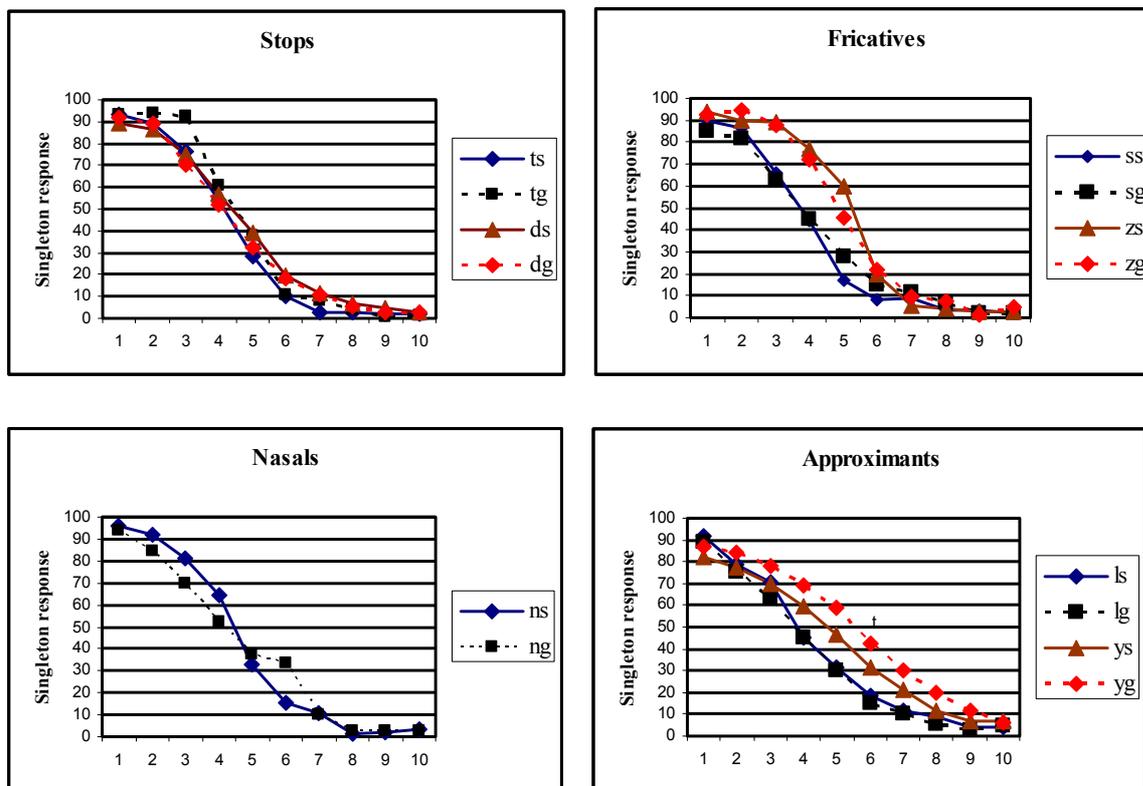


Figure 7: Identification functions for each type of consonant. The first letter in the legend represents the consonant type, and the second letter represents the V1 type.

In Figure 7, the y-axis plots the proportion of singleton responses over 15 repetitions, averaged over the results of the 14 speakers. The x-axis plots the ten steps of duration continua. A quick initial survey of the results shows that obstruents have very steep slopes, whereas approximants have a shallow slope. Nasals seem to lie in between.

To quantify the steepness of each slope, the following method was used. Consider the schematic illustration in Figure 8. The solid line represents the identification functions of the obstruents, in which the proportion of singleton responses shows a rapid fall. The dotted line, on the other hand, is the schematic illustration of the identification functions of the sonorants, in which the proportion of singleton responses steadily declines.

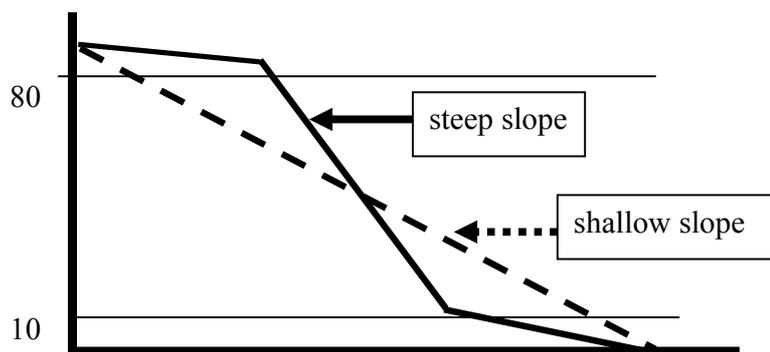


Figure 8: Schematic illustration of two types of functions.

Looking at the actual identification functions of the obstruents in Figure 7, a steep drop begins after the last point above 80, and it flattens again after the last point above 10. Thus, in order to compare the steepness of these two types of functions, we can compare the slope coefficients of the lines between the last point above 80 and the last point above 10.¹⁵ The prediction is that the lines for sonorants will show smaller coefficients within that range.

Accordingly, the slope coefficient between the last point above 80 and the last point above 10 was calculated for each segment for each speaker. Averaging over the data from the 14 listeners, the results are illustrated in Figure 9.

¹⁵ I did not use 90 as the upper cutoff point, since as seen in Figure 7, *dg* and *sg*, for example, have singleton responses lower than 90% even at their singleton endpoint. I did not use 20 as the lower cutoff point either, since especially for obstruents, the fall in identification functions goes down to a point lower than 20.

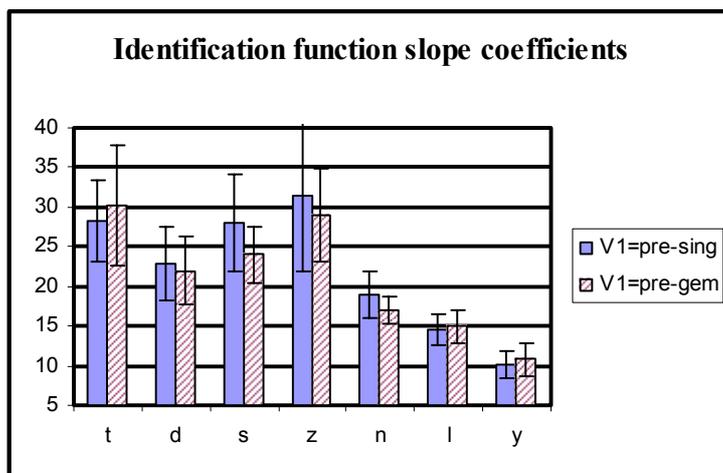


Figure 9: The slope coefficients between the last point above 80 and the last point above 10 for each type of stimuli.

Figure 9 successfully captures the observations made in Figure 7; the approximants have very shallow slopes, the obstruents have steep slopes, and the nasal stands in between. Setting the [z]-[zz] continuum aside, the slope coefficients are a mirror image of reaction time: a continuum that induced a longer reaction time had a smaller slope coefficient.

The correlation between these two measures (reaction times and slope coefficients) is in fact quite strong; even including the two [z]-[zz] continua, the Pearson coefficient r is -0.81 , $t(12)=-4.97$, $p<.001$; without the [z]-[zz] continua, $r=-0.891$, $t(10)=-6.22$, $p<.001$. This convergence suggests that reaction times and slope coefficients are reflecting the same source, which I argue is confusability of a geminacy distinction. The [z]-[zz] continuum is an exception, since it exhibits long reaction times but steep identification slopes. The reason for this exceptional behavior is not clear—explaining the idiosyncratic behavior of [z] is left for future research.

A repeated-measures ANOVA was run on the calculated coefficients with SEGMENT TYPE and V1 TYPE as independent variables. There was a main effect of SEGMENT TYPE ($F(6,$

78)=23.345, $MS_e=67.264$, $p<.001$), which shows that the slope coefficients were significantly affected by the segment type of the continua. The V1 TYPE did not show any main effect ($F(1, 13)=.814$, $MS_e=48.205$, $p=.383$). The interaction was not significant, either ($F(6, 78)=.795$, $MS_e=38.031$, $p=.577$). These results show that V1 duration/quality does not matter for the perception of geminacy, despite the apparent acoustic shortening of V1 before geminate sonorants (see §4.2.2). The effect of dialectal differences was again non-significant ($(F(2,11)=3.033$, $MS_e=16.204$, $p=.089$).

More targeted questions were asked by defining four contrasts, ones that are very similar to those used for reaction time. These contrasts are defined in (28).

- (28) $\psi_1 = 1/4(\mu_t + \mu_d + \mu_s + \mu_z) - 1/3(\mu_n + \mu_l + \mu_y)$
 ‘The difference in slope steepness between the obstruents and the sonorants’
 $\psi_2 = \mu_l - \mu_y$
 ‘The difference in slope steepness between [l]-[ll] and [y]-[yy]’
 $\psi_3 = \mu_n - \mu_l$
 ‘The difference in slope steepness between [n]-[nn] and [l]-[ll]’
 $\psi_4 = \mu_d - \mu_n$
 ‘The difference in slope steepness between [d]-[dd] and [n]-[nn]’

The first contrast, ψ_1 , tested whether there was a difference between the obstruents and the sonorants to check the validity of the overall hypothesis of this paper. ψ_2 and ψ_3 tested whether there was a difference between the [l]-[ll] continua and the [y]-[yy] continua, and a difference between the [n]-[nn] continua and the [l]-[ll] continua, respectively. The ranking *GG » *LL » *NN proposed in §2 predicts that these two contrasts should be significantly larger than zero. The fourth contrast tested whether there was a difference between the [n]-[nn] continua and the [d]-[dd] continua. This time, the [z]-[zz] continua were excluded from consideration, because the

[z]-[zz] continua clearly had steeper slopes. The results are summarized in Table 4.

	ψ_1 (obs. vs. son.)	ψ_2 ([l] vs. [y])	ψ_3 ([n] vs. [l])	ψ_4 ([d] vs. [n])
$\hat{\psi}$	12.57	4.28	3.28	4.41
$S\hat{\psi}$	1.55	0.87	0.86	1.6
t	8.11	5.06	3.81	2.75
p (one-tailed)	<.001	<.001	<.001	<.01

Table 4: The results of the contrast analyses on slope coefficients defined in (28).

All of the contrasts turned out to be significant. ψ_1 shows that, as a general theme of this paper suggests, a geminacy distinction is less perceptible for sonorants than for obstruents. ψ_2 and ψ_3 collectively show that the scale of perceptual difficulty in perceiving geminacy differences is as predicted by the hierarchy proposed in §2, *GG » *LL » *NN—i.e., Geminacy contrasts are hardest to perceive for glides, slightly easier for liquids, and easiest for nasals. The fourth contrast shows that, although we did not observe a difference in reaction time between voiced obstruents and [n], there is indeed a difference between them in terms of their slope coefficients—i.e., compared to voiced consonants, nasals are perhaps more difficult to discriminate in terms of a geminacy contrast, although the difference might have been too small to have been detected in terms of reaction time.

5.3 Summary and discussion

This section has reported an experiment that corroborates the idea that relative sonority correlates with difficulty in perceiving a geminacy contrast. Evidence was adduced from reaction time and slope steepness, which converge on the conclusion that sonorancy makes a geminacy contrast hard to perceive.

One might wonder whether lexical frequency might have caused the bias against discriminability of geminacy in sonorants. One hypothesis might be that if geminate sonorants are, due to their markedness, less frequent than geminate obstruents, then people are less used to hearing a geminacy distinction for sonorants, which would yield the kind of bias observed above. This hypothesis, however, is not viable in light of the actual data. Figure 10 illustrates the lexical frequency of consonants appearing in the second position of measure 2 verbs, which are the primary source of geminates in Arabic (based on Wehr 1971).

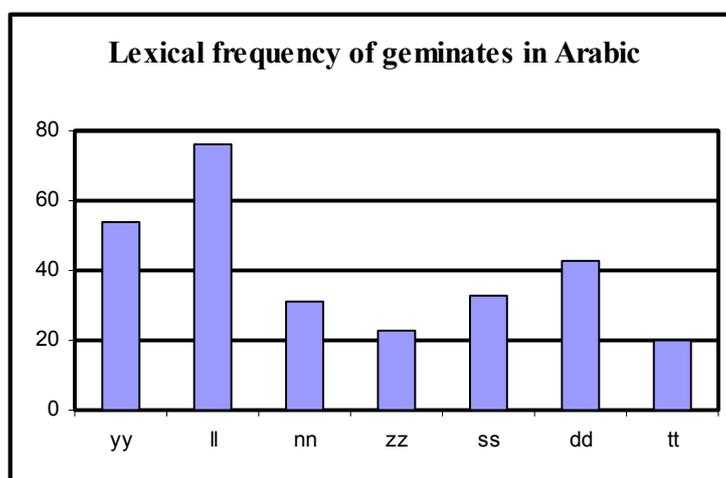


Figure 10: Frequency of the seven target consonants appearing as the second consonant in the root of measure 2 verbs.

As seen in Figure 10, [yy] and [ll] are most frequent, despite their low discriminability of geminacy contrasts. On the other hand, [tt] is least frequent, even though the [t]-[tt] continua showed the highest discriminability. Finally, in the experiment above, [t]-[tt] and [s]-[ss] pattern together, but in Figure 10, [tt] is closest to [zz], and [ss] to [nn], in terms of lexical frequency. Based on these observations, it seems unlikely that the discriminability differences observed above can be attributed to frequency differences.

6. Discussion and conclusion

6.1 On geminate fricatives

This paper has been focusing on the markedness of geminate sonorants. Some remarks on geminate fricatives are now in order. Some pieces of evidence suggest that geminate fricatives are marked. Degemination of geminate fricatives is found, e.g., in the Attic dialect of Greek (Steriade 1982: 136-139) and Klamath (Blevins 2004b). In Tamazight Berber (Saib 1976: 104-116) and Fula (Paradis 1992), fricative geminates synchronically occlusivize. Taylor (1985: 143) notes that “there are no languages with geminate fricatives but no geminate stops”.

Although the experiment reported in §5 did not show a difference in terms of geminacy discriminability between stops and fricatives, it might be that fricatives are in fact at some disadvantage in signaling geminacy contrasts. Obrecht (1965: 40) suggests that fricatives’ high frequency sounds are more susceptible to being covered by noise. Therefore, in real life situations, fricatives might be at a disadvantage in signaling their duration; hence a geminacy contrast in fricatives might be hard to perceive. This hypothesis can be tested by a perceptual experiment with stimuli covered by noise, but this is left for future research.¹⁶ See also Kirchner

¹⁶ Indeed, Obrecht (1965) ran an experiment similar to the one reported here, and found that discrimination of the [s]-[ss] continuum in Arabic is less clear-cut than for the [b]-[bb] and [n]-[nn] continua (his result is not replicated by my experiment). He suggests that “one would expect less clear-cut discrimination of stimuli which depend on the discrimination of relatively high-frequency information-bearing components, as compared with other discriminations depending on oppositions which are more reliably transmitted in speech” (p. 38). However, in his test, the [s]-[ss] continuum was placed word-initially, while the [b]-[bb] and [n]-[nn] continua

(1998) for an articulatory-based explanation for the markedness of geminate stridents.

6.2 Implications of the study

One implication of my hypothesis that merits discussion is that the avoidance of geminate sonorants derives from the difficulty in reliably perceiving the constriction duration differences between singletons and geminates. This generally supports the idea that languages avoid making contrasts that are not very perceptible. This is the main theme of the theory of Adaptive Dispersion (Liljencrants and Lindblom 1968; Lindblom 1986), which has been recently recast in the framework of OT by Flemming (1995) and Padgett (2003). Although my analysis simply makes use of constraints like *GG » *LL » *NN, not constraints on contrasts *per se*, it is certainly in the same spirit as theories of contrast dispersion that systemically prohibit contrast pairs that are difficult to discriminate perceptually (i.e., in this view, it is contrasts, not geminates *per se*, that are marked). It is also in line with a general theory of Licensing-by-Cue (Steriade 1997 *et seq.*), which claims that contrasts that are hard to perceive tend to be neutralized.

The second point addressed here is the fact that avoidance of geminate sonorants does not always result in degemination, despite the fact that geminate sonorants are likely to be marked due to their confusability with their corresponding singletons. Recall from §2 that cross-linguistically, strategies other than degemination are used to avoid geminate sonorants. The list of the alternations caused by constraints against geminate sonorants is reproduced in (29):

were intervocalic. The lower discriminability of the [s]-[ss] continuum thus might have been due to the fact that the target was not intervocalic.

(29) Heterogeneity of processes due to *SONGEM

- coda nasalization (Japanese)
- degemination (Greek, Sanskrit)
- floating mora flopping (Japanese)
- blocking of gemination (Ilokano, Selayarese)
- nasalization (Chaha, Endegeñ, Ezha)
- occlusivization (Berber, LuGanda)

A growing body of recent proposals claims that diachronic changes take place through listeners' misperceptions of ambiguous acoustic signals, and phonological processes are a direct consequence of such sound changes. In other words, when /x/ is misperceived as [y] in some context z, then this misperception is phonologized as an alternation /x/ → [y] / z (see Barnes 2002; Blevins 2004a; Blevins and Garrett 2004; Kavitskaya 2002; and Myers 2002, all of whom build upon Ohala 1981, 1991). One corollary of this approach is that most if not all phonological processes should originate from misperception. Myers (2002) makes this point quite explicit, arguing that *NC̣, a constraint that prohibits a voiceless obstruent after a nasal (Pater 1999), does not, cross-linguistically, trigger epenthesis, because there is no way in which listeners can misperceive NC̣ clusters as NVC̣.

The heterogeneity of processes in (29) remains unexplained if all phonological processes were based on misperception, however. It is conceivable that [yy], for example, would be confused with [y], and this misperception would be phonologized as a rule that replaces [yy] with [y]. Such a story is consistent with what the perceptual experiment in §5 has shown. This type of misperception would result in degemination, as in Sanskrit and Greek.

It is quite unlikely, however, that all of the processes listed in (29) can be derived from misperception; e.g., why would geminate approximants, and not singleton approximants, be misperceived as nasals (Endegeñ) or stops (LuGanda)? Further, why would geminate

approximants sound partially nasalized (Japanese)? Admittedly, I have not tested that such misperception patterns are indeed impossible, but there does not seem to be a well-motivated perceptual reason that could cause such misperception patterns.

More problematic may be the flopping of a floating mora observed in Japanese. Recall that, given reduplicative mimetic forms, a floating mora targets C_2 if C_2 is an obstruent (as in [kassa-kasa] ‘dried’), but it flops onto C_3 when C_2 is a sonorant (as in [poyopppoyo] ‘soft’) (see (11) and (12); Kawahara and Akashi 2005). It is not clear at all how a sonorant geminate in C_2 position ([poyyyo-poyo]) could be misheard as gemination in C_3 position ([poyopppoyo]). In short, most of the phenomena triggered by constraints against geminate sonorants are unlikely to stem from misperception.¹⁷ Rather, the patterns of geminate sonorants suggest that at least some phonological alternations are independent of the phonetic motivations of the constraints that trigger them (i.e., here the confusability of singletons and geminates).

Therefore, a satisfactory model of phonetics and phonology must recognize a mechanism in which the confusability of geminate sonorants with their corresponding singletons is phonologized as a prohibition against geminate sonorants. This phonologized prohibition can cause phonological alternations to eliminate geminate sonorants in a variety of ways. As shown in §2 of this paper, Optimality Theory (Prince and Smolensky 2004) is particularly suitable for modeling this idea, because the confusability of a geminacy distinction for sonorant segments can be grammatically expressed as a set of constraints, which interacts with other constraints to induce a range of phonological processes.

¹⁷ See de Lacy (2005), Hayes and Steriade (2004), Flemming (2005), Kiparsky (2004), Smith (2004), and Steriade (2001) for additional arguments against the approach of deriving phonological patterns from misperception.

6.3 Overall conclusion

In this paper, I have contended that geminate sonorants are dispreferred cross-linguistically. I have further argued that the more sonorous a segment is, the more marked a geminate it makes. I hypothesized that this is because, due to blurry transitions, small changes in amplitude, and stretched cues, the constriction duration is less perceptible for sonorants than for obstruents. As a result, sonorants provide a poor geminacy contrast. This problem is worse for more sonorous segments. This hypothesis has been supported by a perceptual experiment on Arabic both in terms of reaction times and identification function slopes. I have also argued that the perceptual difficulty in distinguishing geminacy contrasts of sonorant segments must be grammatically expressed as a set of phonological constraints, which interact with other constraints in the grammar to produce a wide range of alternations.

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