Title: Spectral continuity and the perception of duration: Implications for phonological patterns of sonorant geminates

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Abstract

This study begins with the observation that sonorant geminates are disfavored in many phonological systems. Podesva (2002) hypothesizes that the phonological dispreference against sonorant geminates exists because these geminates are easily confused with corresponding singletons. This confusability problem arises because sonorants are spectrally continuous with flanking vowels, and consequently their constriction durations are difficult to perceive. We report two perception experiments that test this hypothesis. The stimuli were non-speech sounds which mimicked the spectral properties of singleton-geminate contrasts in stops, fricatives, and sonorants. The results of a discrimination and an identification experiment show that spectral continuity in sonorants makes the singleton-geminate distinction less distinct. We conclude that the phonological dispreference against sonorant geminates has its roots in the perceptual imperative to avoid segments that are confusable with other segments.

1 Introduction

1.1 Theoretical background

Many studies have shown that speech perception plays a role in shaping phonological regularities. For example, studies within the tradition of Adaptive Dispersion Theory (Liljencrants and Lindblom, 1972; Lindblom, 1986) show that languages preferentially choose contrastive sound pairs that are perceptually distinct. For instance, languages that have three contrastive vowels have [a, i, u] rather than [ə, ɨ, ʌ], and languages that have five contrastive vowels have [a, i, u, ɛ, ɔ] rather than [ə, ɨ, ʌ, ɤ, ɪ]. This cross-linguistic observation follows from the principle that speakers deploy contrastive pairs that are perceptually non-confusable (see e.g. Boersma 1998; Diehl et al. 2004; Engstrand and Krull 1994; Flemming 1995; Padgett 2002; Schwartz et al. 1997a,b). The current study offers a case study within this tradition focusing on the perceptibility of singleton-geminate distinctions.

1.2 Synopsis

This study starts with the observation that many phonological systems disfavor sonorant geminates, at least in inter-sonorantal positions. Podesva (2000, 2002) argues that the dispreference against sonorant geminates exists because these geminates are highly confusable with corresponding singletons. This confusability problem arises because sonorants are spectrally continuous with surrounding vowels, and consequently their consonantal durations are difficult to perceive. Since a singleton-geminate contrast primarily relies on the difference in consonantal durations, sonorant geminates are more confusable with corresponding singletons than obstruent geminates are with corresponding singletons. This paper reports two perception experiments that test this hypothesis.

The stimuli were non-speech sounds, which mimicked the spectral properties of geminate contrasts in stops, fricatives, and sonorants. The results show that spectral continuity in sonorants makes the singleton-geminate distinction both harder to discriminate and harder to learn. We conclude that the phonological dispreference against sonorant geminates may have its roots in the perceptual imperative to avoid segments that are confusable with other segments.

2 The phonological observation

We begin this paper with the observation that many languages avoid a singleton-geminate contrast in sonorants.

2.1 Restrictions on segmental inventories

The first evidence comes from inventory restrictions. In many languages with a singleton-geminate contrast, the contrast is limited to a subset of their inventories. In particular, Podesva (2002) argues that cross-linguistically, singleton-geminate contrasts are more common for obstruents than for sonorants. Taylor (1985: 122), based on her cross-linguistic survey of geminate inventories, makes a similar observation: "[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".

The claim by Podesva and Taylor was checked against the P-base (Mielke, 2007), a database which contains several thousand sound patterns from more than 500 languages.[1] We find languages which are consistent with the claim that sonorant geminates are likely to be missing from the geminate inventories, as listed in (2) and (3).[2]

(1) Languages in which any manner of consonants can geminate

  a. Af Tunni Somali (Tosco, 1997)
  b. Arbore (Hayward, 1984)
  c. Lama (Ourso, 1989)
  d. Tuvaluan (Besnier, 1987)

(2) Languages in which only obstruents can geminate

  a. Brahui (Andronov, 1980)
  b. Bribri (Constenla, 1981)
  c. Ngura (Holmer, 1988)

[1] Our much thanks to Jeff Mielke for his help.

[2] There are some exceptions to this generalization as well. For example, in Nangikurrunggurr, the only geminates are [nn] and [ll] (Hoddinott and Kofod, 1988); in Yir-Yorot, the only geminate consonants are rhotics, and one each of the nasals, glides, and laterals (Alpher, 1991). These examples show that sonorant geminates are not the only kinds of geminates that are disprefered, and that the claim by Taylor is too strong. See section 3.2 for discussion.

d. Pech/Paya (Holt, 1999)

e. Nuuchahnulth (Stonham, 1999)

(3) Languages in which some sonorant geminates are missing

a. Japanese (Geminate approximants are missing) (Vance, 1987)

b. Kalenjin (Geminate glides are missing) (Toweett, 1979)

c. Pengo (Rhotics, laterals and glides do not geminate) (Burrow and Bhattachrya, 1970)

d. Afar (All consonants appear as geminates, but glide geminates are fricated) (Bliese, 1981)

2.2 Selayarese gemination blockage

In addition to the inventory restrictions against sonorant geminates, there are phonological alternations that actively eliminate or avoid sonorant geminates. One example, which was discussed by Podesva (2000, 2002) in relation to gaps in the geminate inventories, comes from gemination blocking in Selayarese. 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 (4) (Mithun and Basri 1986: 243):

(4) Gemination when root-initial consonants are voiceless obstruents

a. /ta**ʔ-p**elaʔ/ → [ta**pp**elaʔ] ‘get lost’

b. /ta**ʔ-t**uda/ → [ta**tt**uda] ‘bump against’

c. /ta**ʔ-k**apula/ → [ta**kk**alupa] ‘faint’

d. /ta**ʔ-s**ambaŋ/ → [ta**ss**ambaŋ] ‘stumble, trip’

This gemination fails when root-initial consonants are sonorants, as in (5) (Mithun and Basri 1986: 244). There are no glides in Selayarese, so we cannot tell whether glides undergo gemination or not.[3]

(5) Gemination is blocked when root-initial consonants are sonorants

a. /ta**ʔ-m**uri/ → [ta**ʔm**uri] ‘smile’

b. /ta**ʔ-n**oʔnoso/ → [ta**ʔn**oʔnoso] ‘to be shaken’

c. /ta**ʔ-ŋ**oaʔ/ → [ta**ʔŋ**oaʔ] ‘to yawn’

[3]Gemination also fails when root-initial consonants are voiced stops. The dispreference against voiced stop geminates is well motivated phonetically: stop closure raises intraoral airpressure and therefore it is difficult to maintain transglottal airpressure drop to sustain voicing during obstruent closure. This aerodynamic problem is particularly challenging for geminates because of their long constriction (Hayes and Steriade, 2004; Ohala, 1983; Westbury, 1979). However, this aerodynamic challenge does not explain the dispreference against sonorant geminates, because the airway is not significantly occluded in sonorants.

d. /ta**ʔ-l**esaŋ/ → [ta**ʔl**esaŋ] 'to be removed'

e. /ta**ʔ-r**iŋriŋ/ → [ta**ʔr**iŋriŋ] 'to be walled'

2.3 Ilokano gemination blockage

Another example of gemination blockage is found in Ilokano (Hayes 1989: 270-271). Ilokano resolves hiatus by gliding a first vowel, and this formation of a glide causes compensatory lengthening—or gemination—of the preceding consonant. This gemination process usually applies to obstruents as in (6). In the same environment, gemination is marginally possible for nasals and [l], as in (7). Hayes states that gemination of these consonants is optional, possibly with lexical variation. Gemination never applies to [r, w, y], as in (8).

(6) Obstruents usually geminate after gliding of vowels

a. /lú**t**o-én/ → [lu**tt**wén] 'cook GOAL-FOCUS'

b. /pag-ʔá**s**o-án/ → [pagʔa**ss**wán] 'place where dogs are raised'

c. /kina-ʔa**p**ó-án/ → [kinaʔa**pp**wán] 'leadership qualities'

d. /bá**g**i-én/ → [ba**gg**yén] 'to have as one's own'

e. /pag-ʔatá**k**e-án/ → [pagʔatá**kk**yán] 'place where an attack takes place'

(7) Nasals and [l] sporadically geminate

a. /dá**m**o-én/ → [da**m**wén], ?[da**mm**wén] 'to be new to something'

b. /na-ʔali**n**o-án/ → [naʔali**n**wán], ?[naʔali**nn**wán] 'to become sensitive'

c. /pag-ʔali**ŋ**ó-án/ → [pagʔali**ŋ**ẃán], ?[pagʔali**ŋŋ**ẃán] 'place where boars are found'

d. /bá**l**e-án/ → [ba**ly**án], ?[ba**ll**yán] 'to change'

(8) [r, w, y] never geminate

a. /pag-ʔá**r**i-an/ → [pagʔa**r**yán] 'place of leadership'

b. /ká**r**o-án/ → [ka**r**wán] 'to intensify'

c. /ʔá**y**o-én/ → [ʔa**y**wén] 'cheer-up GOAL-FOCUS'

d. /babá**w**i-én/ → [baba**w**yén] 'regret GOAL-FOCUS'

2.4 Berber occlusivization

Another type of phonological alternation that avoids sonorant geminates comes from Beber. In Berber, to derive incomplete forms, medial consonants become geminates, as shown in (9). However, when medial consonants are [R] or [w], they become stop geminates, as in (10) (Elmedlaoui 1995: 194-195).

(9) Gemination in incomplete form

a. /n**k**r-μ/ → [n**kk**r] ‘to get up’

b. /l**d**i-μ/ → [l**dd**i] ‘to pull’

c. /n**g**i-μ/ → [n**gg**i] ‘to crash into’

d. /n**s**a-μ/ → [n**ss**a] ‘to pass the night’

e. /n**z**l-μ/ → [n**zz**l] ‘to spur’

f. /n**z**a-μ/ → [n**zz**a] ‘to be sold’

(10) Stopping of sonorant geminates

a. /n**R**a-μ/ → [n**qq**a] ‘to kill’

b. /ṛ**R**a-μ/ → [ṛ**qq**a] ‘to get warm’

c. /r**w**l-μ/ → [r**ggʷ**l] ‘to run away’

d. /n**w**a-μ/ → [n**ggʷ**a] ‘to cook’

[l] becomes a geminate without hardening in this position (e.g. [jllu] ‘to lose’). The reason for the difference between [l] and [w] may be that [l] is less sonorous than [w] (Parker, 2008). This and the Ilokano examples in section 2.3 therefore show that there may be a distinction among sonorant geminates such that the more sonorous geminates are disfavored more strongly. See section 3.2 for an additional phonetic problem of rhotic geminates, which may explain why Berber disfavors [RR] more than [ll].

2.5 Japanese nasal insertion

Two more examples of phonological patterns that avoid (some) sonorant geminates come from Japanese. Japanese has geminates of voiceless obstruents and nasals ([katta] ‘bought,’ [sassuru] ‘guess,’ [sonna] ‘such’), but lacks approximant geminates from the inventory. One phonological process actively avoids creating them.

Japanese has many onomatopoetic, mimetic forms, whose function is primarily sound symbolic (Hamano, 1986). Many mimetic roots have the CVCV shape, and often appear reduplicated. The suffix /-ri/ can attach to a bare mimetic root, and can cause gemination of root-final consonants, as in (11). When the root-final consonants are glides, an archiphonemic nasal /N/ is inserted instead of gemination, as in (12) (Kuroda 1965: 201-208).[4] When the root-final consonant is [r], neither gemination nor nasal insertion occurs, as in (13). The nasal insertion in (12) and blockage of gemination in (13) show that Japanese actively avoids creating approximant geminates. The example in (13) in addition shows that Japanese avoids a [Nr] sequence as well.

(11) /-ri/ causes gemination of root-final consonants

[4] In pre-continuant position, this archiphonemic nasal is phonetically realized as [ɰ̃ː], a nasalized long high back unrounded approximant (Vance 2008: pp. 96-99).

a. /ba**t**a-μ-ri/ → [ba**tt**ari] cf. [bata-bata] 'accidentally'

b. /po**k**a-μ-ri/ → [po**kk**ari] cf. [poka-poka] 'absent-mindedly'

(12) Nasal insertion occurs instead of gemination of glides

a. /hu**w**a-μ-ri/ → [hu**Nw**ari] cf. [huwa-huwa] 'fluffy'

b. /bo**y**a-μ-ri/ → [bo**Ny**ari] cf. [boya-boya] 'spacing out'

(13) Neither gemination nor nasal insertion occurs when the final consonant is [r]

a. /ki**r**a-μ-ri/ → [ki**r**ari] cf. [kira-kira] 'shining'

b. /hi**r**a-μ-ri/ → [hi**r**ari] cf. [hira-hira] 'flying'

2.6 Japanese gemination flopping

Another phonological process from Japanese shows that this language avoids creating nasal geminates as well. The evidence is again observed in the phonology of mimetic forms. Nasu (1999) points out that given reduplicated C_1VC_2V-C_3VC_4V forms, to create their emphatic forms, Japanese speakers predominantly geminate the second consonant when the consonant is a stop, as in (14) (Kawahara, 2006; Nasu, 1999). However, when C_2 is a nasal and C_3 is a stop, speakers prefer to target C_3, as in (15).

Kawahara (2007a) has shown this dispreference against creating nasal geminates using an audio-based, forced-choice wug-test. In this test, C_3 was fixed as [p] or [k], and C_2 was systematically varied among stops, fricatives and nasals (8 items per each C_2 * C_3 combination). When asked to create emphatic forms of nonce mimetic words, when C_2 is a stop, Japanese speakers chose C_2-gemination about 80% of the time, supporting the preference in (14). However, when C_2 is a nasal and C_3 is a stop, they chose C_2-gemination only about 35% of the time and instead resort to C_3-gemination, as schematized in (15).

(14) Emphatic forms via gemination of C_2 when C_2 is a stop

a. /pa**t**a-pata-μ/ → [pa**tt**apata] 'running'

b. /pi**k**a-pika μ/ → [pi**kk**apika] 'shining'

(15) When C_2 is a nasal and C_3 is a stop, speakers prefer C_3-gemination

a. /ka**n**o-kano-μ/ → [kano**kk**ano] (nonce word)

b. /ki**n**a-kina-μ/ → [kina**kk**ina] (nonce word)

2.7 A summary

To summarize, many languages lack sonorant geminates from their inventory (Podesva, 2002). Moreover, not only are sonorant geminates likely to be gaps in the inventories, they are also resolved by a variety of phonological processes: gemination blockage in Salayarese and Ilokano, stopping in Berber, nasal insertion in Japanese, and gemination flopping in Japanese. A question that arises is, why do so many languages avoid sonorant geminates? The rest of this paper addresses this question.

3 The phonetic grounding of the dispreference against sonorant geminates

3.1 The hypothesis

Podesva (2002) proposes that sonorant geminates are dispreferred because they are perceptually confusable with corresponding singletons. The logic goes as follows: sonorants have blurry transitions into and out of flanking vowels, because sonorants are spectrally continuous with surrounding vowels. (By "spectrally continuous", we mean "continuation of periodic energy into and out of surrounding intervals", which would exclude fricatives). It is thus hard to pin down where sonorants begin and where they end (Turk et al., 2006). As a result, their constriction durations are hard to perceive. Since a difference in constriction duration serves as a primary cue for singleton-geminate contrasts (e.g. Engstrand and Krull 1994; Esposito and Di Benedetto 1999; Hankamer et al. 1989; Ham 2001; Idemaru and Guion 2008; Kingston et al. 2009; Krähenmann 2003; Lahiri and Hankamer 1988; Rochet and Rochet 1995), singleton-geminate distinctions are hard to distinguish for sonorants.

For the sake of illustration, we provide waveforms of real singleton-geminate contrasts in stops and glides from Egyptian Arabic in Figure 1 and 2. Kawahara (2007b) recorded several types of geminates in Arabic in the word frame [haC(C)ag], which are all nonce words. We observe that while stops have clear boundaries with the surrounding vowels, glides have very blurry boundaries. It is therefore difficult to know where the glides begin and where they end. Then, it is expected that the constriction durations are harder to accurately perceive for sonorants than for obstruents.

Besides the acoustic blurriness of segmental boundaries of sonorants, another factor that may work against the accurate perception of duration of sonorants is that changes in amplitudes—or changes in perceived loudness—facilitate the detection of segmental boundaries (Kato et al., 1997). Because sonorantal boundaries with spectral continuity involve less amplitude/loudness changes than obstruent boundaries (Kawahara, 2007b), sonorants have yet another disadvantage in signaling their boundaries.

As summarized here, Podesva (2002) offers an interesting and plausible story about the grounding of the dispreference against sonorant geminates. However, no perception experiments are reported to test this hypothesis. Partly to address this problem, Kawahara (2007b) created continua from geminates to singletons for each type of geminates in Arabic, and presented them to Arabic speakers for an identification task. The results show that the identification functions were steeper

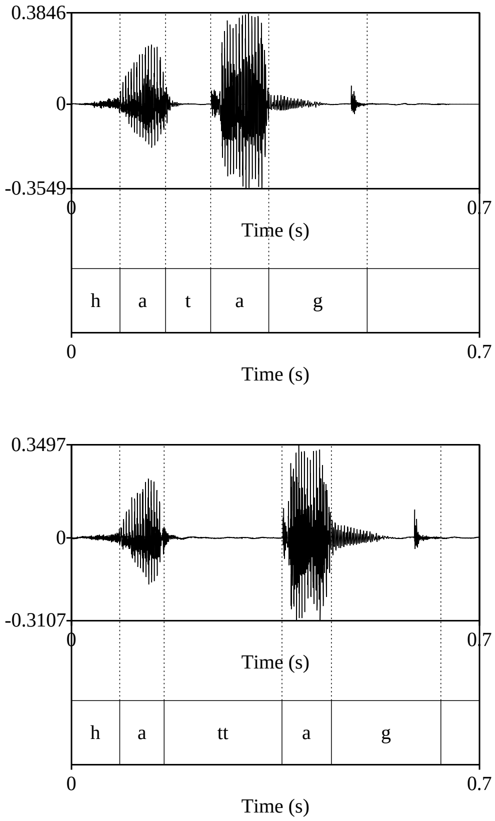

Figure 1: Arabic [t]-[tt] pair.

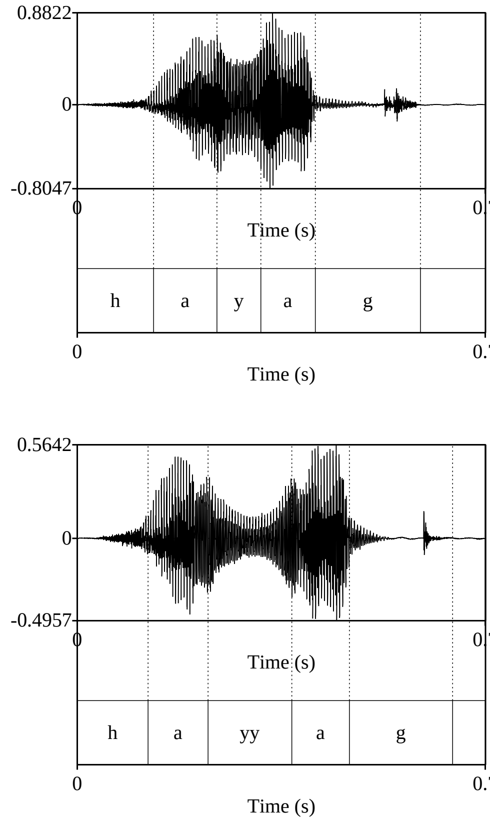

Figure 2: Arabic [y]-[yy] pair.

for obstruents than for sonorants—more of the continuum was consistently categorized for obstruents than for sonorants. However, the relationship between the steepness of identification functions and the distinctiveness of singleton-geminate contrasts does not seem straightforward to interpret. Moreover, the experiment used speech sounds of Arabic as stimuli and Arabic listeners as participants. Therefore, the effect of factors other than sonority—such as lexical frequencies of each type of geminates or transitional probabilities from preceding consonant to each of singletons and geminates—remained unclear, and possibly worked as confounds.

This paper therefore builds on Kawahara (2007b) and reports two non-speech experiments, which more directly test the relative non-distinctiveness of singleton-geminate contrasts in sonorants. To control for phonetic factors other than spectral continuity, we made use of non-speech sounds that mimicked singleton-geminate contrasts in obstruents and sonorants.

3.2 Some caveats

A few remarks are in order before we proceed to the description of our experiments, first on our theoretical context. Podesva's general idea is couched within the general framework of Adaptive Dispersion Theory (Liljencrants and Lindblom, 1972; Lindblom, 1986), which is incorporated into generative phonology (Boersma, 1998; Flemming, 1995; Padgett, 2002) via Optimality Theory (Prince and Smolensky, 2004). Within this framework sonorant singleton-geminate pairs can be marked because they are not perceptually distinct. In this theory, it is the singleton-geminate contrasts in sonorants, not the sonorant geminates *per se*, that are marked; see the references cited above for formal implementations of this idea. Our aim is to test the assumption behind Podesva's (2002) hypothesis—the non-distinctiveness of sonorant singleton-geminate pairs—but we do not commit ourselves to any particular theoretical implementation of this idea.

Second, Podesva's (2002) hypothesis concerns the perceptual problem of sonorant geminates in intervocalic or inter-sonorantal positions. Since most geminates in the world's languages appear in such positions (Ladefoged and Maddieson 1996: 92),[5] his hypothesis applies to most cases of geminates. In most of the cases we discussed in section 2, avoidance of sonorant geminates occurs in inter-vocalic positions; in Berber, it occurs in inter-sonorantal positions. We should bear in mind, however, that there are cases in which geminates appear at word-edges (e.g. Leti: Hume et al. 1997). Since geminate contrasts at word-edges rely on non-durational cues (as well as durational cues) (Abramson, 1991, 1999; Muller, 2001), we do not commit ourselves to the perceptibility differences of singleton-geminate contrasts in such positions.

Third, we also observe that some languages avoid a subset of sonorant geminates, and the dis-

[5]This positional restriction on geminates holds in Bengali (Hankamer et al., 1989), Fula (Paradis, 1992), Japanese (at the lexical level) (Vance, 1987), Koya (Sherer, 1994) and Turkish (Hankamer et al., 1989), among others. In Swiss German an underlying singleton-geminate distinction at word-edges is maintained only in inter-sonorantal environments (Krähenmann, 2003).

preference seems stronger for more sonorant consonants (as in Berber and Ilokano). This tendency is also observed in the inventory restrictions we discussed in (3), although we do find a counterexample in the P-base, e.g., Sema which allows /ww/ and /ll/ but not nasal geminates (Sreedhar, 1980). In this paper we will set aside further distinctions among sonorant geminates, and focus on the difference between sonorants and obstruents, while noting that Podesva's hypothesis does offer an explanation. The more sonorous a consonant is, the blurrier the boundaries, and consequently the harder it is to perceive the constriction duration.

Finally, we do not assume that the confusability problem between singletons and geminates is the only source of the avoidance of sonorant geminates. For example, given intervocalic geminate glides (e.g. [iyyi]), it is conceivable that the first part of the geminate can be confused as a part of a preceding (long) vowel. Also concerning rhotic geminates, it would be impossible to prolong the duration of a tap or a flap, and they would instead have to turn into a trill in order to become a geminate while keeping its rhoticity. However, a trill requires a very precise articulatory coordination (Ladefoged and Maddieson, 1996; Solé, 2002). In short, low distinctiveness of singleton-geminate pairs is not the only phonetic problem for sonorant geminates.

Neither do we assume that sonorant geminates are the only kinds of geminates that are avoided for a phonetic reason. For example, voiced obstruents geminates are known to be avoided in many languages because it is difficult to maintain voicing during obstruents for a long stretch of time for an aerodynamic reason (Hayes and Steriade 2004; Ohala 1983; Westbury 1979, see also footnote 3).[6]

To summarize then, the focus of this paper is on sonorant geminates in inter-sonorantal—or intervocalic in most cases—positions, which are spectrally continuous with surrounding environments. The observation is that some phonological systems avoid such geminates, and the hypothesis is that at least a part of the reason why such geminates are avoided is because their constriction duration is hard to perceive. The following two experiments test this hypothesis.

4 Experiment I: Discrimination experiment

4.1 Introduction

This experiment aimed to test whether sonorantal spectral continuity makes a short-long pair difficult to distinguish. The stimuli were non-speech analogues mimicking singleton-geminate pairs of stops, fricatives, and sonorants. We used non-speech stimuli so as to control for acoustic parameters other than spectral continuity, such as preceding vowel duration, intensity of surrounding vowels, and, most importantly, duration of consonant intervals themselves. In experiments using

[6]It may as well be the case that spectral continuity in low frequency range in voiced stops makes the perception of duration harder for voiced stops than for voiceless stops. However, we set this hypothesis aside, because the aerodynamic challenge of voiced stops geminates is well-established.

real speech, on the other hand, it is difficult to control for the duration of consonant intervals because the duration of glides is difficult to measure, for reasons stated in section 3 (see also Turk et al. 2006). By using non-speech sounds as the stimuli, we also avoided perceptual bias effects, such as lexical bias (Ganong, 1980), lexical frequency bias (Connine et al., 1993) or transitional probability bias (McQueen and Pitt, 1996).

4.2 Method

4.2.1 Stimuli

The three conditions were non-speech analogues of stops, fricatives, and sonorants. The first two conditions were baselines and the third condition is the target. All the stimuli had VCV structure in which the duration of C was varied.

To create non-speech analogues of vowels, we used anharmonic complexes of sine waves (Kingston et al., 2009). They consist of 50 sine waves ranging from 100Hz to 16kHz and separated by equal natural log intervals. The amplitude of each sine wave negatively correlated with its frequency. More specifically, for each sine wave component, its amplitude ratio to the base sine wave was: $1/(2 * ComponentNumber^2 - 1)$ (i.e. 1/3, 1/9, 1/19, etc.). The peak amplitude of the anharmonic complexes was set to 0.8 by Praat (Boersma, 2001; Boersma and Weenink, 2011).

For consonant intervals, we used the acoustic intervals that mimicked the acoustic properties of stops, fricatives and sonorants; i.e., silence for stops, white noise filtered between 2kHz and 22kHz for fricatives, and the same interval as the vocalic interval with half of its peak energy for sonorants. Figure 3 and Figure 4 illustrate the parallels between the non-speech stimuli and the corresponding speech forms. To create short-long pairs, we set the duration of the short consonants to 100ms and that of long consonants to 150ms. These two values were chosen because the short-long contrasts based on these values were neither too easy or too difficult to discriminate in a pilot study. The vocalic intervals were set to be 100ms. For the discrimination experiment, two VCV sequences were concatenated with 400ms ISI.

4.2.2 Procedure

The task was a same-different discrimination experiment. We prepared four pairs of combinations of S(hort) and L(ong) stimuli—SS (same), LL (same), SL (different), LS (different)—for each condition. Participants went through all the stimuli once in the practice block while receiving feedback. An experimenter stayed with the participants during the practice run so that if the participants had remaining questions, they could be answered.

The main session presented 25 repetitions of all the stimuli, thus a total of 300 pairs (25 repetitions * 4 same-different pairs * 3 conditions). The participants kept receiving feedback during the main session in the form of the correct answer (i.e. Same or Different). Superlab (ver 4.0) was

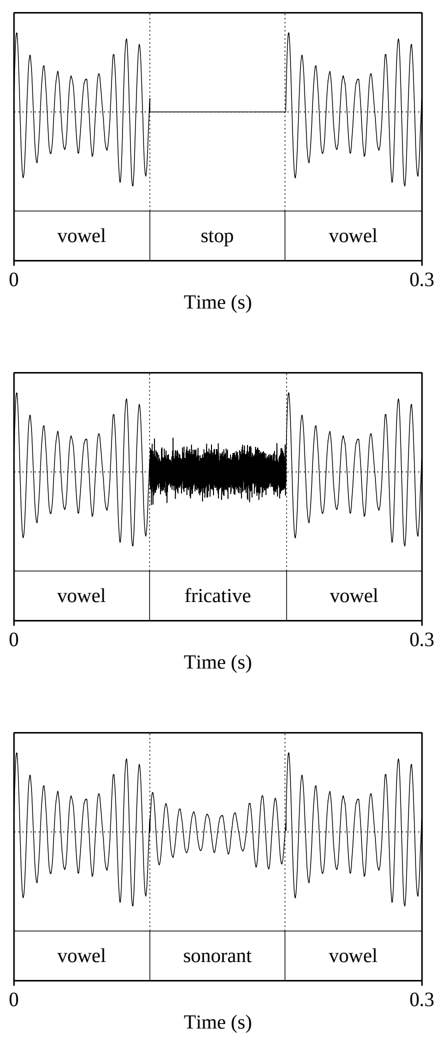

Figure 3: The stimuli. Top=stop; middle=fricative; bottom=nasal.

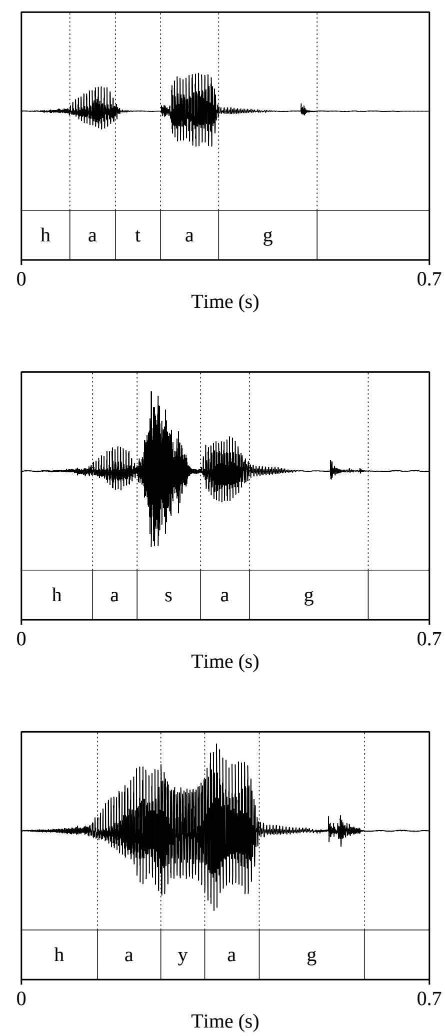

Figure 4: Corresponding speech forms (in Arabic).

used to present the stimuli and feedback. The order of the stimuli was randomized. All the participants wore high quality headphones (Sennheiser HD 280 Pro), and registered their responses using an RB-730 response box (Cedrus). The experiment took place in a sound-attenuated laboratory at Rutgers University.

4.2.3 Participants

Twenty-five native speakers of English participated in this experiment. They received (extra) course credit for their classes. English does not have singleton-geminate contrasts, so their native language knowledge should not make one particular singleton-geminate contrast easier to discriminate than the other contrasts.

4.2.4 Analysis

We used d'-values as a measure of discriminatbility. Given the roving mode of the experiment in which different types of pairs were presented in one session, we assumed a differentiating mode of discrimination (Macmillan and Creelman 2005: 221-225). d'-values were calculated using `psyphy` package (Knoblauch, 2009) of R (R Development Core Team, 2011). In a few cases, hit rates were lower than false alarm rates. In that case we assumed that the d'-value is zero. Two listeners showed lower hit rates than false alarm rates in two out of three conditions, so their data was excluded. d'-values across three conditions were compared using a within-subject t-test. The alpha level was Bonferroni-adjusted according to the number of comparisons (.05/3=.017).

4.3 Result

Figure 5 illustrates the results of the discrimination experiment. Each scatterplot compares d'-values in two different conditions. Each point within a scatterplot shows a pair of d'-values for each participant. Any point that is to the left of the diagonal axis shows that the listener had a higher d'-value for the condition represented in the y-axis; any point that is to the right of the diagonal axis shows that the listener showed a higher d'-value for the condition that is represented in the x-axis.

We observe that in the stop-fricative comparisons, some listeners showed higher d'-values in the stop condition while others showed the opposite pattern. The stop condition and the fricative condition thus did not differ significantly (the averages: stop 2.63 vs. fricative 2.25; $t(22) = 1.95, n.s.$). In the other two panels, we observe that most, if not all, listeners showed lower d'-values in the sonorant condition than in the stop or the fricative conditions (the average for the sonorant condition=1.38). Statistically, the sonorant condition was different from the stop condition ($t(22) = 5.71, p < .001$), and the fricative condition ($t(22) = 3.56, p < .01$).

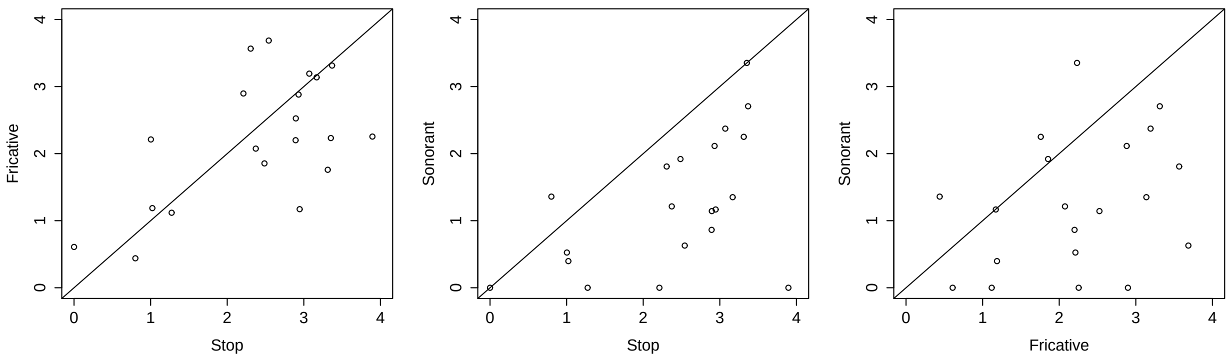

Figure 5: The distributions of d'-values in each condition in the discrimination experiment.

4.4 Discussion

The result shows that sonorantal spectral continuity does make the short-long pair less discriminable. This result supports Podesva's (2002) hypothesis that sonorantal spectral continuity makes the duration of the consonantal intervals hard to distinguish, and hence make the short-long pair harder to discriminate.

Admittedly we cannot prove the causality relationship between the low discriminability of a durational contrast of spectrally continuous intervals and the fact that many languages avoid sonorant geminates. However, the experiment does show the correlation between the two observations. It therefore seems reasonable to speculate that the avoidance of sonorant geminates in some phonological systems may have its root in the discriminiability problem of the singleton-geminate contrasts.

5 Experiment II: Identification experiment

5.1 Introduction

The previous discrimination experiment shows that it is hard to distinguish a short-long pair when the consonant interval is spectrally continuous with surrounding vocalic intervals. In the second experiment, we followed up on this result with an identification experiment, which addressed whether spectral continuity makes it hard to learn the short and long category. Although a discrimination experiment has an advantage for experimental participants in that they do not need to learn two categories, an identification experiment may emulate the language acquisition situation more closely. During the course of acquisition, language learners need to learn the short and long categories based on tokens presented in isolation.

5.2 Method

5.2.1 Stimuli and procedure

For the identification experiment, we used the same set of stimuli as the discrimination experiment. Listeners learned two categories in the practice phase, and were tested on how well they learned each category in three different conditions. Listeners were not told that the two categories were based on durational differences; instead the short category was labeled as A and the long category was labeled as B.

Since a pilot experiment showed that it is difficult to learn the two categories for three types of non-speech sounds at the same time, each type of stimuli (stop, fricative, and sonorant) was blocked into small, separate sessions, each with its own practice phase and testing phase. We expected that the order of learning these three categories might influence their performance. Therefore, the order of the presentation of the three blocks was controlled by a Latin Square design. Group 1 went through the experiments in the order of stop, fricative, and sonorant; Group 2 in the order of fricative, sonorant, and stop; Group 3 in the order of sonorant, stop, fricative.

The practice session consisted of three phases. The first phase presented five repetitions of A-B chains, followed by five repetitions of B-A chains. The second phase presented five repetitions of A in isolation and five repetitions of B in isolation. In the final practice phase, the participants were tested on 15 tokens of each with feedback. A main session contained 60 tokens of each of the short and long stimuli. The order of stimuli was randomized during the main sessions. We provided feedback in the main session as well, because a pilot experiment without feedback resulted in performances near chance.

As with the discrimination experiment, Superlab (ver 4.0) was used to present the stimuli and feedback. All the participants wore high quality headphones (Sennheiser HD 280 Pro), and registered their responses using an RB-730 response box (Cedrus). The experiment took place in a sound-attenuated laboratory at Rutgers University.

5.2.2 Participants

Eight native English speakers participated in each Latin Square order (a total of twenty-four speakers.). They all received extra credit for their class. There is no overlap between the participants of Experiment I and those of Experiment II.

5.2.3 Analysis

As with the discrimination experiment, we used d'-value as a measure of sensitivity. Three listeners showed a negative d'-value in one of the three conditions; these values were replaced by 0. One listener showed negative d'-values for two out of the three conditions, and this person's data was therefore thrown out. Another listener was run to compensate for the gap.

d'-values in three conditions were compared using a within-subject t-tests. Since the predictions were clear from the results of the previous experiment, the alpha-level was not adjusted.

5.3 Results

Figure 6 illustrates the distribution of d'-value for each listener in the identification experiment.

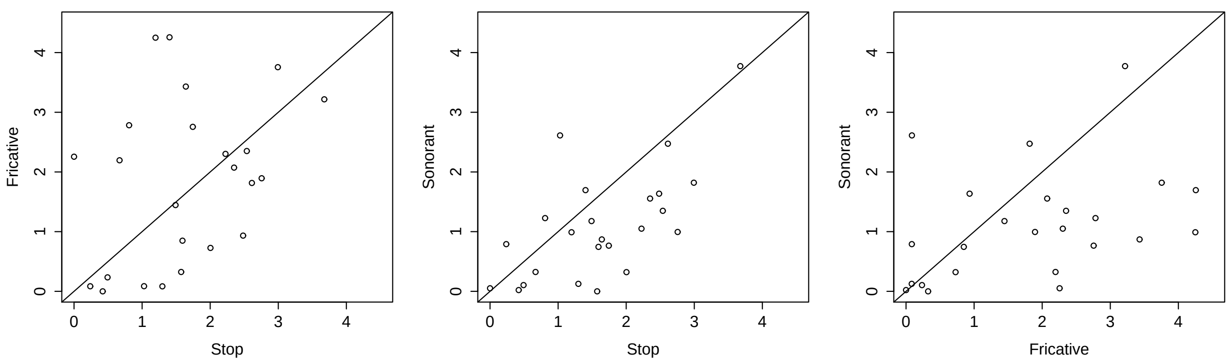

Figure 6: The distributions of d'-values in each condition in the identification experiment

As with the discrimination results, listeners differed in whether the stop contrast or the fricative contrast was more perceptible (the averages: stop=1.63 vs. fricative: 1.84; $t(23) = -0.73, n.s.$). On the other hand, d'-values for the sonorant condition were generally lower than those for the stop condition ($t(23) = 3.29, p < .01$) or those for the fricative condition ($t(23) = 2.68, p < .05$) (the average for the sonorant condition=1.10). In terms of the order effect, the average d'-values increase in successive blocks (1st block: 1.35; 2nd block: 1.47; 3rd block: 1.71), although this correlation did not reach significance ($\rho = .14, n.s.$).

5.4 Discussion

The results show that the short and long categories are generally harder to learn for the sonorant condition than the obstruent conditions. There was one listener who showed a very high d'-value in the sonorant condition (2.61) compared to the stop (1.03) or the fricative condition (0.09). This listener took the sonorant condition in the third block; therefore, it may be that this listener got used to identifying non-speech stimuli after the first two blocks.[7] All other listeners showed a d'-value for the sonorant condition that is lower than or comparable to the d' values for the other two conditions. These results show that a duration contrast that is spectrally continuous with surrounding

[7] Recall that the order effect did not reach statistical significance. Therefore, this learning effect must have been strong specifically for this participant.

intervals is harder to learn than contrasts that are spectrally not continuous.

6 General discussion

6.1 Summary

The first contribution of this paper is phonological: we have shown that many languages avoid sonorant geminates. Not only do we observe inventory gaps (Podesva, 2002), we also observe that various phonological patterns actively eliminate sonorant geminates: gemination blockage in Selayarese (Podesva, 2000) and Ilokano (Hayes, 1989), stopping in Berber (Elmedlaoui, 1995), nasal insertion in Japanese (Kuroda, 1965), gemination flopping in Japanese (Kawahara, 2007a). These observations show that languages avoid making geminate contrasts in sonorants; i.e. sonorant geminates are crosslinguistically marked.

Second, the current experiments show that a duration contrast that relies on consonant intervals that are spectrally continuous with surrounding vowels is both difficult to discriminate (Experiment I) and difficult to learn (Experiment II). Taken together with the phonological observation just summarized above, these results support the hypothesis that phonological dispreference against sonorant geminates has its roots in the confusability of singleton-geminate contrasts in sonorant consonants.

6.2 Further implications

To the extent that this correlation holds, the current study offers some insight into how phonetics and phonology interact. First of all, the results support the thesis that languages avoid contrasts that are not well perceived, as proposed by Adaptive Dispersion Theory as well as by its Optimality Theoretic version (Boersma 1998; Diehl et al. 2004; Engstrand and Krull 1994; Flemming 1995; Liljencrants and Lindblom 1972; Lindblom 1986; Padgett 2002; Schwartz et al. 1997a,b).

Second, the results show that the structure [A] can be marked because [A] is confusable with [B], but it is not necessarily the case that [A] becomes [B]; in other words, the phonetic problem presented by [A] is independent of how it is resolved in phonology (Boersma, 2005; Dinnsen, 1980; Kawahara, 2006; Keating, 1985). For example, Berber turns sonorant geminates into stops, as shown in (10). Japanese speakers avoid creating nasal geminates whey they make emphatic forms, and seek for another locus for gemination, as in (15). Therefore, phonetics may determine what is avoided in phonology, but the phonetic problem of a phonological structure may not determine how it is resolved in phonology.

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