GEMINATE TYPOLOGY AND THE PERCEPTION OF CONSONANT DURATION

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Abstract

The crosslinguistic typology of geminate consonants demonstrates several prominent tendencies: geminates are typically found in intervocalic positions, often after stressed vowels, but are avoided in adjacency to other consonants and on word boundaries, more so word-initially than word-finally; sonorant geminates are more infrequent than obstruent geminates. This dissertation investigates the effect that the contextual environment (vocalic or consonantal neighbors, position with respect to the edges of the word, and stressed vowels) as well as the phonetic properties of the consonants themselves (sonority, continuancy, and voicing) has on the perception of the contrast between short and long consonants. The primary goal of the perceptual experiment with speakers of Russian, American English, and Italian as participants was to demonstrate that perception of the durational distinction in consonant was context-dependent. In particular, it was hypothesized that listeners would have greater difficulties in categorizing the consonants as short and long in contexts where geminates are rarely found across languages, which would provide an explanation for the typological patterns.

The experimental results established that perceptual contrast distinctiveness was higher in the intervocalic than in the preconsonantal environment, and in the word-initial than in the word-final position. These generalizations are based on the facts that the perception of the distinction was less categorical in the preconsonantal and word-final conditions: consonants were less consistently categorized as either short or long, while a greater portion of a durational continuum caused indecision about the category membership of the consonant. In addition, perception of durational distinctions in the preconsonantal and word-final conditions was affected by singleton-bias: listeners were more reluctant to categorize consonants in these environments as

long.

Distinctiveness-based explanation for the crosslinguistic preference for post-tonic and obstruent geminates was not supported by the experimental results. It was found that stress did not affect perception of consonant duration. However, a survey of several languages for which a stress-geminacy connection was reported showed a striking correlation between weight-sensitivity and tendency to geminate in the post-stress position. Thus, an alternative account for this typological pattern is proposed, which states that gemination is used in the weight-sensitive languages to repair light stressed syllables, creating a typological connection between geminate consonants and stress.

Results concerning the perception of consonant duration as a function of the phonetic properties of the consonant showed that the durational distinction was easiest to perceive in sonorant consonants (liquids and nasals) and alveolar voiceless fricatives. Both voiced and voiceless alveolar stops conditioned a less well-defined perceptual contrast. These results contradict typological observations and some previous experimental data, thus warranting further research in this domain.

The dissertation also develops an optimality-theoretic account of typological asymmetries in the distribution of duration contrasts, focusing on the effects of segmental environment (intervocalic and preconsonantal) and word-position (word-initial and word-final). The proposed model is based on contrast dispersion theory and incorporates phonetically-based constraints on the minimal perceptual distinctiveness that the contrast needs to satisfy in order to be included into the phonological inventory of the language. The model which incorporates contrast perceptibility and syllable weight constraints generates most of the geminating languages in the typological survey.

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Chapter 1

Introduction

1.1 Overview

This dissertation addresses the question of why geminate consonants across languages are frequently found in certain phonetic environments and avoided in others; and likewise, why consonants with certain manners of articulation appear more often as geminates in crosslinguistic inventories than consonants of other manners.

It has been noticed by linguists that phonemic consonant duration contrast across languages is often limited to certain contextual environments and types of consonants. In particular, based on typological observations, the intervocalic, especially post-tonic, environment has been proposed as optimal for geminate consonants (Thurgood, 1993). Geminates at the edges of words, or next to other consonants, appear to be avoided (Blevins, 2004a; Kraehenmann, 2001). In terms of the comparison between word-initial and word-final positions, it has been believed for some time that word-initial consonant duration contrasts were extremely rare, while word-final ones were more easily found. Some recent research (Muller, 2001) suggests that word-initial geminates may not be as uncommon as previously assumed.

With respect to the type of consonant, voiced obstruents are found to geminate less frequently than voiceless obstruents (Jaeger, 1978; Ohala, 1983; Taylor, 1985); in addition, sonorants in general do not contrast in length as often as obstruents do (Kawahara, 2006; Podesva, 2000, 2002). A natural question that follows from these

observations concerns the causes of these asymmetries and the underlying factors that govern the distribution and inventories of geminate consonants across languages.

Phonological neutralization of length contrasts has often been observed in positions such as word-final and consonant-adjacent, both in synchronic and diachronic dimensions. For example, in some dialects of Arabic consonant-adjacent and word-final geminates are subject to neutralization and surface as singletons (Cowell, 1964; Erwin, 1963). In Russian, variable degemination occurs with higher probability in word-initial and consonant-adjacent environments and is virtually exceptionless word-finally (Kasatkin and Choj 1999). Historical neutralization of word-final gemination is also attested (Jastrow, 1997).

As Ohala (1983) convincingly argues, a phenomenon that manifests itself in unrelated languages through sound change, as differences in phonological inventories, and as morphophonological alternations, is likely to be functionally motivated. A variety of phonetically-based explanations for the asymmetries in geminate typology has been offered in the literature but few of them have been tested experimentally or verified rigorously against typological data. Moreover, focus on the phonetic side of the story may have caused some to overlook possibly useful phonological and historical factors (although see Blevins (2004a, 2008) for an approach primarily based on historical sound change, and Spaelti (2002) for a moraicity-based account of geminate distribution).

In this dissertation I am offering a comprehensive overview of phonetic, phonological, and typological data relevant to the crosslinguistic patterns of gemination. The central proposal is that positional and manner preferences for geminates are based on a perceptually-driven contrast dispersion effect: a contrast between singletons and geminates is more perceptible in some contexts and for some manners of articulation, and it is in those cases that gemination is found most often crosslinguistically. For example, it is easier for listeners to tell the difference between *tonna* and *tona* (intervocalic environment) than between *tonnka* and *tonka* (preconsonantal environment). I tested this hypothesis in three case studies with speakers of Russian, American English, and Italian, supplemented with typological data from over 50 languages for which consonant duration contrast was reported. Among the types of

evidence I considered were attested and unattested patterns of gemination, diachronic and synchronic processes resulting in the evolution of geminates or neutralization of the contrast, and phonological conditions under which geminates arose or avoided neutralization.

The results demonstrate that in a number of contextual environments observed crosslinguistic tendencies can be attributed to perceptual factors: in particular, the preference for intervocalic over preconsonantal and word-edge geminates. The experimental results also indicated that, at least for the types of consonants included in the experiment, word-initial duration contrast was in the perceptually privileged position compared to word-final contrast. Stress-related gemination, on the other hand, is better explained by phonological factors: more specifically, the role of gemination in optimizing the phonological weight of stressed syllables. Crosslinguistic gemination preferences based on the manner or sonority of the consonant proved the most controversial issue. Conflicting typological and experimental evidence warrants further inquiry into the nature of the factors behind manner-based crosslinguistic patterns in geminate typology.

The acoustic duration data collected in the course of the investigation also allowed me to evaluate a number of additional hypotheses proposed in the literature. In addition, these findings contribute to the body of data on prosodically conditioned effects on segmental duration. The results provide evidence against the proposal that post-tonic gemination is simply a phonologization of the allophonic increase in duration conditioned by stress (Blevins, 2004a; Taylor, 1985; Thurgood, 1993). Durational increase in stressed syllables was found to be mostly limited to the onset position and did not extend to post-tonic consonants[1]. The hypothesis that differences in geminate-to-singleton durational ratio (Aoyama and Reid, 2006; Pajak, 2009a) are responsible for the crosslinguistic patterns was only partially supported in this study, which raises questions about the language-independence of this effect.

The established generalizations were formalized in an optimality-theoretic model of grammar, designed to account for the asymmetries in the typology of durational

[1]Apart from phonetic consonant lengthening in weight-sensitive languages conditioned by preceding light stressed syllables, as in Dogrib (Jaker, 2011).

contrast in consonants, in particular, with respect to the word-edge and immediate segmental environment effects. A theory of contrast dispersion (Flemming, 1995, 2004; Liljencrants and Lindblom, 1972; Lindblom, 1986) served as the foundation for the formal approach developed here.

Methods for modeling quantitative between-language variation in the distribution of the geminate-singleton contrast are also explored. In addition, I address the issue of contrast preservation in word-initial position and on the morphological boundaries, as well as the connection between syllable weight, stress, and gemination.

In the following section I will briefly discuss advances in the area of perceptually-driven phonology as a motivation for the primary hypothesis of this study. I will then review some of the background literature on geminate consonants organized into three major categories: phonetic, phonological, and typological studies. In this dissertation, I consider evidence from all three lines of research. A major advantage of this approach is that typological patterns resulting from phonetic effects can be distinguished from typological patterns related to phonological or historical factors.

Following the review of studies on geminates I will introduce a number of explanations for geminate typology proposed in the previous literature. I will advance my own proposal and formulate the hypotheses to be tested in this dissertation. An outline of the dissertation is provided at the end of the chapter.

1.2 Perceptually driven phonology

A large amount of work that has been done in recent years in the fields of laboratory phonology and speech perception demonstrates that it is not just the articulatory considerations and physics of sound production that affect patterns of sounds across languages - perceptual factors are equally important. In particular, the phonological organization of languages has been shown to have properties aimed at minimizing the likelihood of perceptual confusion between sounds. Situations where two (or more) sounds are relatively similar to each other acoustically and perceptually, for instance, due to effects of the contextual environment, are avoided by resorting to a number of repair strategies. As Flemming (2004) notes, perceptual optimization is relevant for

phonology only when considered as a quality of the phonological contrast, that is, a quality of the distinction between contrasting sounds. Insufficient distinction, on the one hand, can be attended to by contrast neutralization, which removes the necessity to deal with perceptually confusing sounds altogether. On the other hand, phonetic enhancement can magnify the acoustic distance between the sounds and repair the perceptually misleading situation.

Although typically considered distinct pathways of repairing perceptually disadvantaged contrasts, neutralization and enhancement are closely related in at least two ways. First, depending on the actual acoustic cue chosen to enhance a particular phonological distinction, enhancement of one contrast may involve neutralization of another one. For example, rounding back vowels to increase their acoustic distinctiveness from front vowels (Stevens et al., 1986) presupposes a neutralization of the contrast between back rounded and back unrounded vowels. Second, neutralization can be used to enhance the overall distinctiveness of the inventory. For example, to increase the acoustic distance between vowels in the inventory, certain vocalic contrasts may be neutralized, bringing the overall number of members down. This is believed to be a driving force behind the crosslinguistically common reduction in vowel inventories in unstressed syllables (Crosswhite, 2004; Flemming, 2004).

Among the phonological domains where perceptual factors were shown to play a role in forming inventories of phonemes and determining the directionality of phonological processes, some of the best studied cases involve vowel inventories and assimilation in consonant clusters. Languages are generally believed to make optimal use of the available "vowel space" in constructing their vocalic inventories: depending on the number of vowels in the inventory they are typically dispersed towards the extremal points of articulation, providing each individual pair of vowels with a maximal possible acoustic distance. Languages which crowd all their vowels into one portion of the available space, reducing the distance between the members of the inventory, are rare or unattested (Flemming, 2004; Liljencrants and Lindblom, 1972; Lindblom, 1986). Similar behavior has been reported for consonantal inventories as well. Padgett (2001) argues that Russian, where consonant palatalization is phonemic, uses

velarized consonants as an opposing member of the inventory since the acoustic distance between palatalized and velarized consonants is greater than between plain and palatalized consonants (see also Ni Chiosáin and Padgett, 2001). Padgett and Zygis (2003) argue on similar grounds for the perceptual motivation of historical changes in the inventories of the sibilant consonants in Polish and Russian.

Asymmetries in neutralization processes involving consonant clusters have attracted a fair amount of attention as well. In particular, it has been noticed that consonantal assimilation is typically regressive in VCCV configurations. The explanation usually has to do with acoustic cues to the identity of the consonant (e.g., place of articulation) and their distribution across neighboring sounds. Stops in particular rely heavily on vowel transitions in cueing their phonological features. Moreover, CV transitions have been shown to be rather more useful perceptually than VC transitions (Ohala, 1981, 1990; Steriade, 1999). Thus, in VC_1C_2V clusters C_2 is more perceptible and less confusable, unlike C_1, which becomes the target of neutralization where the features of a more robustly cued C_2 are appropriated: [anpa] → [ampa], not [anta] or [akta] → [atta], not [akka].

Steriade (2001) further justified a perceptual account of this type of neutralization by showing that the direction of place assimilation can be contrast-specific: retroflex consonants are more perceptible in postvocalic environment, thus in such clusters assimilation is progressive.

Related to this discussion is the observation that CV syllables are generally more common crosslinguistically than VC syllables for similar reasons (Fujimura et al., 1978; Wright, 2001). A common pattern of stop-sibilant metathesis can also be understood as an alternative to neutralization in perceptually dangerous positions — a maneuver which relocates stops to the position where they can take advantage of the CV transitions, with sibilants being relatively immune to the perceptual troubles of stops thanks to their internal acoustic cues: Hebrew /it-saper/ → [istaper] "get a haircut" (2sg. masc.).

A common theme that runs through many of the investigations in perceptual phonology is that the perceptual "quality" of the contrast - its distinctiveness - is not

context-independent, just as acoustic cues to phonological contrasts are not context-independent. Selective implementation of the contrast in particular phonetic environments and prosodic positions is then a straightforward prediction of this approach, which suggests that perceptual distinctiveness is a very likely place to look for explanations for the contextually-conditioned asymmetries in typological patterns. This leads us to the principal goal of this dissertation: to examine contextual effects on the perception of consonant duration in order to determine whether there is a connection between the perceptibility of durational contrasts in various contextual positions and crosslinguistic tendencies in geminate inventories and distribution.

1.3 Background on geminates

Geminates, or long consonants (both are used here interchangeably), in some languages contrast phonologically with singletons, or short consonants, and phonetically this opposition is expressed mainly as a difference in length or duration: geminates are acoustically longer than singletons. Geminates are also sometimes referred to as double consonants, although this definition is more closely related to the spelling tradition of using two identical consonantal graphemes to indicate a geminate.

Although an increase in duration is implied in the definition of geminate consonants, the degree of lengthening varies across languages. For example, Ladefoged and Maddieson (1996) report that geminate stops can be between one and a half to three times longer than singletons, in careful speech.

Not as frequently found as long vowels, geminates are nevertheless not uncommon in the world's languages and are included in the inventories of Finnish, Hungarian, Estonian, Japanese, Russian, Arabic, Italian, and Polish, among others. Example 1.1 shows a geminate-singleton minimal pair in Italian.

(1.1) Italian: *sette* [sette] "seven" - *sete* [sete] "thirst"

Geminates are clearly less wide-spread than plain short consonants which suggests their marked nature compared to singletons: Maddieson (1984) reports 11 languages with consonant length contrast in a database of 317 languages. This imbalance is

likely to find an explanation in an articulatory effort-based approach. For example, in Kirchner (1998)'s effort-based hierarchy of segments geminates are ranked lower than singletons.

Geminates are traditionally divided into lexical (underlying, "true") geminates, a category into which assimilated geminates, resulting from a total assimilation in consonantal clusters, are typically included, and concatenated ("fake") geminates - formed as a combination of two identical consonants at the juncture of morphemes or words. Examples of underlying, concatenated, and assimilated geminates in Bengali are shown in 1.2-1.4 (from Lahiri and Hankamer, 1988).

(1.2) Underlying: /pa̪t̪t̪a/ [pa̪t̪t̪a] "whereabouts"

(1.3) Concatenated: /pa̪t̪+t̪e/ [pa̪t̪t̪e] "spread out" infinitive

(1.4) Assimilated: /kor+t̪e/ [ko̪t̪t̪e] "do" infinitive

Three major types of inquiries into the nature of geminate consonants have been made in the literature: phonetic, phonological, and typological. The following sections address each of them in turn.

1.3.1 Phonetic studies of geminates

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Ham (2001) provides an overview of a number of phonetic studies of geminates and points out that most of them are directed at establishing the acoustic correlates of gemination, agreeing for the most part that duration is the major phonetic cue to gemination. A perceptual component of these studies is usually focused on determining the perceptual boundary between single and geminate consonant, i.e. the durational value that corresponds to the categorical shift in perception. Another question frequently addressed in the phonetic literature on geminates is whether any phonetic differences can be found between geminates of various origins: lexical, concatenated, and assimilated. Here I will briefly summarize several representative studies, although many more of a similar structure are available for a variety of languages.

Lahiri and Hankamer (1988) examined the acoustic correlates of geminate consonants in Turkish and found that although both Voice Onset Time (VOT) and closure duration systematically varied with gemination, only duration played a significant role in the perception of the contrast. They also addressed the issue of possible phonetic differences between underlying, concatenated, and assimilated geminates using material from Bengali and concluded that such differences could not be determined.

Hankamer et al. (1989) further investigated the perception of consonant duration contrast in Turkish and Bengali. They established that if stimuli were created by shortening geminated consonants a perceptual shift from singletons to geminates was observed on average 8 ms earlier than for stimuli created by lengthening singleton consonants. This effect was observed mainly in the medial duration range, where consonants were not obviously short or long and the durational cue was not very informative. They hypothesized that acoustic cues other than increased duration are involved in production and perception of geminate consonants. Listeners rely predominantly on the primary cue when its contribution is most revealing (e.g., at the extremes of the durational continuum), while secondary cues affect perception of durational categories when duration of the target consonant is ambiguous. However, none of the eight additional acoustic measurements showed a correlation with the perceived geminacy.

A similar shift of the perceptual boundary between singletons and geminates, conditioned by the nature of experimental stimuli was observed in an earlier study by Lisker (1985). Stimuli created on the basis of Marathi words with geminates were identified as long at a shorter duration than stimuli created on the basis of words with singletons. This effect was observed only for the listener who was a native speaker of Marathi but not for American English listeners, which suggests a language-specific basis of this effect. It appears that only native speakers are sensitive to secondary cues to the phonological contrast present in their language.

Ridouane (2010) established that duration was the main acoustic correlate for geminacy in Tashlhiyt Berber[2], although duration of the preceding vowel, as well as release duration and F0 perturbations for some types of consonants and Root

[2]Several alternative names are in use, including Tashelhit/Tachelhit and Tashelhait/Tachelhait

Mean Square (RMS) amplitude for some speakers also co-varied with gemination. Ridouane (2010) also compared underlying, concatenated, and assimilated geminates in Tashlhiyt Berber and found they they did not differ in terms of duration, although underlying and assimilated geminates as opposed to concatenated ones were further characterized by shorter preceding vowels and higher RMS amplitude, which Ridouane (2010) attributed to the"tense" mode of their articulation.

Similar studies were conducted for a variety of languages with geminate consonants, including Cypriot Greek (Arvaniti, 1999; Arvaniti and Tserdanelis, 2000; Muller, 2001), the Austronesian languages Buginese, Madurese, and Toba Batak (Cohn et al., 1999), Finnish (Doty et al., 2007), Malayalam (Local and Simpson, 1999), Hindi (Ohala, 2007; Samudravijaya, 2003), Swiss German (Kraehenmann, 2001; Kraehenmann and Lahiri, 2008), Kentani Malay (Hamzah, 2010), Pattani Malay (Abramson, 1986, 1987, 1991, 1999a,b, 2003), Italian (Esposito and Di Benedetto, 1999; Faluschi and Di Benedetto, 2001; Farnetani and Kori, 1986; Giovanardi and Di Benedetto, 1998; Mattei and Di Benedetto, 2000; Payne, 2005; Pickett et al., 1999) (phonetic studies of geminates in Italian are discussed in greater detail in chapter 5). Linguistic uses of consonant length in English are addressed in detail in chapter 4. Most of these studies arrive at similar conclusions: although sometimes acoustic features other than duration correlate with geminacy, in perceptual experiments they generally do not have an effect on categorization of consonants length, with possible exception of preceding vowel length (see Pickett et al. (1999) and Esposito and Di Benedetto (1999) on Italian) and word-initial contrasts in languages like Pattani Malay (Abramson, 2003).

These studies, although providing valuable descriptive information on the acoustic implementation of durational contrast in various languages, do not make systematic comparisons between the production and perception of geminate consonants. They also do not directly address the question of the possible connection between the phonetic properties of the durational contrast and the typology of geminate consonants. Few compare phonetic or perceptual properties of geminates and singletons across different contextual environments.

Figure 1.1: Geminate representations.

1.3.2 Phonological studies of geminates

The interest of phonologists in geminate consonants has usually been motivated by representational issues. The two main approaches to geminate representation debated in the literature include the length analysis and the moraic analysis. The length approach is represented by two related views of geminates: according to one, geminates are linked to two slots on the skeletal tier (Leben, 1980; McCarthy, 1979), another one connects them to two root nodes (Selkirk, 1991). This representation is exemplified in 1.1a, where X is a slot on the skeletal tier or a root node. This representation encodes the length of the geminates and allows their parts to behave independently under some phonological conditions.

A body of research on geminate *integrity* and *inalterability* (Hayes, 1986a,b; Kenstowicz, 1973; Kirchner, 2000; Schein and Steriade, 1986) advocates a multiply-linked representation of geminates adopted in the skeletal approach. *Integrity* refers to the resistance of geminate consonants to phonological processes that violate the unity of the segment, for instance, epenthesis, supporting the view of geminates as single units on the segmental tier. In Arabic, vowel epenthesis affecting certain consonant clusters, including concatenated geminates, does not apply to underlying geminates (example in 1.5 from Palestinian Arabic, from Hayes (1986a), originally in Abu-Salim, 1980).

(1.5) /sitt/ *[sitit] “grandmother” (monomorphemic)
/fut+t/ [futit] “entered” l p. sg. (concatenated)

Inalterability refers to the resistance geminate consonants show to certain phonological processes that normally affect singletons in identical environments. This resistance is generally explained as the blocking of a rule that would otherwise affect only one half of the geminate. For example, in varieties of Italian spoken in the northern parts of the country intervocalic alveolar fricatives become voiced but geminates resist this process, as shown in 1.6.

(1.6) *casa* /kasa/ [kaza] "house"
cassa /kassa/ [kassa] "cash register"

In Tigrinya post-vocalic spirantization fails to apply to underlying geminates:

(1.7) [kʌlbi] "dog" - [ʔaxalɨb] "dogs"
but: [fʌkkʌrʌ] "he boasted"

Alternative explanations for these blocking effects have been proposed as well (Kenstowicz, 1994). Kirchner (1998, 2004) argues that geminates are immune to spirantization because long fricatives involve a greater amount of articulatory effort due to the high articulatory precision required in their production. There is other evidence that geminate inalterability may be process-specific, in particular, it may be limited to processes modifying the stricture features, or lenition processes (Kirchner, 2000).

The moraic approach represents geminates as underlyingly moraic or heavy (Davis, 1994, 2011; Hayes, 1989), thus, they are always linked to a mora, as shown in 1.1b. The moraic view of geminates relies on evidence from a variety of languages where geminates participate in phenomena which refer to syllable weight, such as stress assignment, reduplication, and word-minima requirements. Such evidence includes geminates' contribution to the minimal word effect; divergent behavior with respect to weight of geminates on one hand and consonant clusters, or single consonant codas on the other; avoidance of long vowels followed by geminate consonants, attraction of stress to syllables with geminates, and gemination as a repair strategy for light stressed syllables. For an excellent summary of representative cases see Davis (2011).

Although moraic theory is generally believed to be superior to the skeletal approach in accounting for a number of prosodic phenomena, it faces certain issues when it comes to geminates. A view of geminates as inherently moraic (unlike syllable-final consonants that may or may not be moraic, depending on the language) has difficulty accounting for initial geminates: on the one hand onsets typically do not contribute to syllable weight, on the other hand geminates are viewed as inherently moraic (Hajek and Boedemans, 2003; Spaelti, 2002). In search of reconciliation between these conflicting predictions Davis (1999) and Topintzi (2008) present data from a number of languages where initial geminates are moraic.

Another prediction of the moraic approach is that CVC syllables are expected to always pattern as heavy if the coda consonant is part of an underlying geminate, even in languages where CVC syllables closed by singletons are normally light. Tranel (1991) holds that this is not always the case and points to weightless geminates in languages like Selkup. Tranel (1991) concludes that geminate codas tend to behave with respect to weight the same way other consonants do in a language and proposes a principle of equal weight for codas. These observations suggest that the question of geminate representation may require a more complex treatment involving features of both moraic and skeletal models. Examples of such *composite* or *hybrid* models can be found in Curtis (2003) and Muller (2001).

Although representational views of geminates are not in the focus of this dissertation, the fact that the moraic component plays a prominent role in the phonology of geminates in many languages is important. This connection between geminacy and weight, however, has not been capitalized on in the typological literature on geminates, for instance, in the studies that explored the link between geminates and post-tonic position. I will come back to the issues of the inherent moraicity of geminate consonants in Chapter 7 to explore the interaction between perceptibility-related constraints on contrast and weight-related constraints on stressed syllable well-formedness, and to account for the crosslinguistic preference for post-tonic geminates reported in the typological literature and some cases of word-final gemination.

1.3.3 Typological studies of geminates

Typological studies of patterns of gemination across languages are not as numerous as phonetic and phonological works focusing on evidence from individual languages. Jaeger (1978) used the Stanford Phonology Archive (Crothers et al., 1979) to draw a sample of geminating languages. He established that voiceless obstruent geminates were significantly more frequent than voiced ones and offered an explanation based on the aerodynamics of voicing. He also noticed that nasals constituted the most frequent class of geminate consonants across languages, with 16 languages that allowed only nasal geminates.

Almost a decade later Taylor (1985) examined patterns of gemination in the same database (Crothers et al., 1979) and drew several generalizations concerning the types of consonants and positions preferred for gemination. It was observed that the presence of geminate sonorants frequently implied a presence of geminate obstruents, with the addition that whenever sonorant consonants were found in the language they were quite likely to be allowed as geminates. A general preference for voiceless over voiced obstruent geminates was also confirmed and a preference for stop geminates over fricative geminates was pointed out. In terms of position, it was concluded that while medial geminates were the most common (several languages in the sample restricted geminates to intervocalic position), word-final ones were also often allowed, while word-initial ones were categorized as rare. It was also noticed that gemination could be triggered by stress (in Somali, Spanish, and Icelandic). Taylor (1985) writes: "the probable explanation here is that phonetic length is often a correlate of stress and that length gets extended or transferred onto the following consonant".

Thurgood (1993) once again based his survey of gemination on the languages included in the Stanford Phonology Archive, supplemented by some original sources. He found that geminates were preferred in intervocalic position, especially after short stressed vowels. Thurgood (1993) discussed the phonetic correlates of stress and concluded that stress-related lengthening may be realized on vowels as well as consonants, suggesting that post-tonic gemination is connected to the lengthening effect of stress. He also noted that higher pitch, another frequent correlate of stressed syllables, had also been shown to cause consonant lengthening (Pike, 1974), and may be regarded

as the factor triggering consonant lengthening after stress: "the correlation between stress and consonant length has to do with pitch <...> Since stress often has high pitch as an important characteristic, it is not surprising that consonant length is connected to stress".[3]

Podesva (2002) was mostly interested in sonority as a driving force of the geminate typology. He hypothesized that the more sonorant consonants were avoided as geminates due to their acoustic similarity to vowels, especially in terms of intensity. He based this hypothesis on the finding by Kato et al. (1997), who showed that large jumps in intensity were beneficial to the perception of duration. Podesva (2002) constructed his own database of 52 languages using original sources and found general support for the claims that voiceless obstruent geminates were preferred over voiced ones, that geminate stops were preferred over geminate fricatives, and that geminates of lower sonority were preferred over geminates of higher sonority.

Maddieson (2008) conducted a survey of over 40 languages focusing on the types of consonants allowable as geminates. He confirmed the findings of Podesva (2002) that stops were commonly found as geminates. He also observed that nasals were probably as common as stops, although one language in his sample, Noon (Soukka, 2000), excludes nasal geminates from its inventory. Maddieson (2008) also agreed with Podesva (2000) that fricatives, liquids, glides and [h] were increasingly less frequent as geminates than stops and nasals. This especially applies to [h], and as Podesva (2000) stated, to all "guttural" consonants, which usually include uvular, pharyngeal, and glottal consonants, which are routinely prevented from gemination in a variety of languages.

Muller (2001) focused on word-initial gemination and compiled a database of 29 languages with word-initial consonant length contrast. Among other things, this survey demonstrated that languages with word-initial geminates were not as uncommon as previously believed. The survey includes information about types of geminates and distributional restrictions on geminates present in the languages. The general pattern

[3] As far as I can tell, Pike (1974) made no explicit connection between *high pitch* and consonant lengthening; rather he suggested that stressed syllables, often characterized by raised pitch compared to unstressed syllables, sometimes condition consonant lengthening.

that emerged was that in almost all languages with initial geminates medial geminates were also found, with only a few exceptions (Ngada, Nhaneun, Pattani Malay, Sa'aban). In addition, word-initial gemination appeared less common than word-final gemination on the basis of this investigation. Or, as Taylor (1985) put it, word-initial geminates are possibly avoided in conjunction with word-final geminates: "to avoid a difficult question of what to do when a word ending in a geminate is adjacent to a word beginning in the same or even another geminate". Both Taylor (1985) and Muller (2001) agree that while word-final geminates may presuppose the existence of word-medial geminates in the language, word-initial geminates may or may not be independent of word-medial ones. Geminates in adjacency to other consonants were also found to be quite rare, and in a majority of cases imply the presence of word-medial geminates.

In terms of the types of geminates the general pattern suggested by Podesva (2002) and Maddieson (2008) was supported by Taylor (1985): stops and nasals were among the most common, followed in decreasing order by liquids, fricatives, glides, and affricates.

Thus, the picture that seems to emerge is that intervocalic geminates are undoubtedly more common than geminates in all other positions, including word-edge and consonant-adjacent; with the post-tonic position having a special attraction for geminate consonants. In terms of possible differences between word-initial and word-final contexts, word-final geminates are reported to be more common than word-final ones. With respect to the nature of the consonant itself, the general consensus is that sonorants make worse geminates than obstruents. Among obstruents fricatives geminate less often than stops, and among stops voicing is avoided in geminates. Nasals seem different: despite being sonorants they are often geminated and some languages limit their geminate inventories to nasals.

1.4 Proposed explanations of typological patterns

1.4.1 Types of explanations

In the introduction to the volume, Good (2008) distinguished three approaches to explaining linguistic patterns: structural, historical, and external. The structural approach attributes universal patterns in linguistics to the universal properties of the grammar (Kiparsky, 2008b). The historical approach views linguistic patterns as consequences of widely attested patterns of sound change (Blevins, 2004a). The external approach explains patterns in linguistics by referring to constraints on production and perception of speech, general properties of human cognition, physiology, and psychology (Hayes et al., 2004; Ohala, 1981, 1983).

In this section I will review the proposed explanations for the typological patterns of geminate consonants, focusing on investigations of the third type (for examples of structural approaches to geminate typology see Morén (2001), Spaelti (2002)), and will then advance my proposal.

1.4.2 Aerodynamics

Jaeger (1978) and Ohala (1983) discuss aerodynamic constraints on sustaining voicing in consonants with full obstruction in the oral cavity, such as stops. They point out that for voicing to be present throughout the articulation a difference between subglottal and supraglottal pressure must be maintained to allow for the airflow from the lungs to the vocal tract and vocal fold vibration. With a complete closure in the vocal tract the difference in pressure is soon equalized and voicing can no longer be sustained. They attribute the crosslinguistic rarity of voiced stops and a well-attested tendency of voiced geminate stops to devoice to this aerodynamic constraint. This is perhaps the most well-documented and well-explained tendency in geminate typology. All of the typological surveys discussed above agree that voiced geminate stops are less frequent across languages than voiceless geminate stops.

1.4.3 Effort

In Kirchner (1998, 2000, 2004), the aerodynamic explanation for the avoidance of voiced geminate stops is reformulated as the avoidance of additional articulatory effort involved in production of voicing in long stops. He also proposed that more effort is required to produce geminate fricative consonants due to the "precision involved in maintaining a steady-state partial constriction for a prolonged interval" (Kirchner, 2000). This effort-based explanation is formalized as the optimality-theoretic constraint LAZY which is proposed to be responsible for multiple facts related to geminates' resistance to lenition processes, such as spirantization and voicing. Podesva (2002) adopted Kirchner (2000)'s effort-based explanation to motivate the crosslinguistic tendency to avoid geminate fricatives, compared to geminate stops, and formalized it as a segmental constraint prohibiting fricative geminates: **SS*.

1.4.4 Perceptibility

It has also been proposed that perceptual considerations play a role in defining geminate typology. Most of the perceptually-based explanations stem from the general idea that the perception of segmental length contrasts relies on the ability of the listener to correctly identify the boundaries between the target segment and adjacent sounds. Podesva (2002) pointed out that sonorant consonants are acoustically more similar to vowels especially in terms of formant structure and levels of intensity. Since geminates are normally found in the intervocalic environment this acoustic similarity is predicted to complicate the identification of the geminates' boundaries and the evaluation of their duration. Similarity in intensity levels may be particulary relevant since Kato et al. (1997) showed that larger jumps in intensity facilitate the perception of duration.

Perceptual difficulties associated with the estimation of segmental duration are unavoidably detrimental to the quality of the contrast based on duration and, according to Podesva (2000, 2002), are responsible for the fact that crosslinguistically sonorant geminates are less frequently attested than obstruent geminates. This tendency was formalized as a general segmental constraint prohibiting sonorant geminates: **RR*.

Kawahara (2006) confirmed Podesva's predictions in an experiment on the perception of geminate-singleton contrast for different manners of articulation by Arabic listeners. In the identification task reaction times were significantly longer for sonorants than for obstruents. In addition, the slopes of the identification curves were steeper for obstruents. Kawahara (2006) interpreted these results as evidence that difference between geminates and singletons is less perceptible in sonorant consonants and a motivation for the phonetically grounded OT constraint **GeminateSonorant*, an analogue of Podesva's **RR*.

Hansen (2012) conducted a similar investigation of the perceptibility of the durational contrast in consonants as a function of consonant's sonority. He performed the experiments with speakers of Persian as participants and established that sonorant consonants were more difficult to categorize into long and short than obstruents; while the glottal fricative [h] proved the most difficult.

In line with the same reasoning, Padgett (2003) suggested that intervocalic position in general is preferred for all duration-based contrasts, including tap-trill contrast and singleton-geminate contrast. Surrounding vowels provide clear beginning and end points to the target consonant facilitating the perceptual estimation of its duration. This proposal can be adopted to explain the crosslinguistic preference for intervocalic geminates as opposed to consonant-adjacent geminates, word-initial, and word-final geminates. Pajak (2009b) also used vowel-adjacency as a motivating factor behind the selective preservation/neutralization of the consonant duration contrast in Polish. Vowel-adjacency may be especially relevant for voiceless stops which in absolute utterance-initial position lack any acoustic cues to the onset of the closure, since a stop closure is essentially a period of silence, clearly discernable only in context. Kraehenmann (2001) demonstrated that the contrast between word-initial geminate and singleton stops in the Swiss German dialect of Thurgovian is not perceptible when utterance-initial. Blevins (2004a) maintains that scarcity of perceptual cues to gemination in word-initial and word-final positions may lead to the neutralization of contrast or its strengthening through the reinterpretation of the geminates as fortis or aspirated consonants (which seems to happen exclusively in word-initial but not in word-final position).

1.4.5 Geminate to singleton ratio

A special case of perceptually-based explanations for geminate typology refers to the idea that the perceptual salience of the durational contrast depends on the degree of durational difference between the two contrasting phonemes, which can be quantified as a ratio between the average geminate duration and the average singleton duration. A more acoustically distinct contrast based on a higher ratio is hypothesized to be crosslinguistically preferred in comparison to the contrasts based on a lower ratio.

Aoyama and Reid (2006) examined geminate consonants in Guinaang Botok, a language with geminate consonants of all manners of articulation. They established that glides, the crosslinguistically least frequent geminates (also see Maddieson (2008) on geminate glides), have the smallest durational ratio between average geminate and average singleton duration, compared to stops and nasals.

Blevins (2004b) used similar reasoning to motivate a recent *ss > s sound change in Klamath and the overall crosslinguistic avoidance of geminate sibilants. She suggested that since singleton sibilants are generally longer than any other type of consonant they may be closer in duration to geminates, i.e. have a smaller geminate to singleton ratio.

Other ratio-related findings contradict the observed tendencies in geminate inventories: geminate to singleton ratios are found to be *higher* for presumably inferior types of geminates - sonorants and voiced consonants. Hamzah (2010) reports that in Kelantan Malay geminate to singleton ratio is higher for sonorants, nasals, [l], and voiced stops than for voiceless stops (this sample did not include glides). Cohn et al. (1999) also established that in three languages of Indonesia, Madurese, Buginese, and Toba Batak, geminate to singleton ratio was generally higher for voiced than voiceless consonants, with exceptionally large ratios observed for rhotics (geminates being on average four to six time longer than singletons).

Thus, the ratio differences can be interpreted in two ways: on the one hand, lower ratio in some types of consonants, caused by unknown aerodynamic or articulatory factors of production, may lead to the crosslinguistic rarity of geminates of this type. On the other hand, ratio, as a feature under deliberate control of the speakers, may

be used to boost the perceptual distinctiveness of the tokens that are otherwise sub-optimal candidates for the singleton-geminate contrast, such as sonorants.

Pajak (2009a) adopted the ratio approach to address the typological patterns in geminate distribution over various contextual positions and to my knowledge was the first to test the effect of ratio differences on perception. She compared word-medial and word-initial geminates and singletons in vowel-adjacent and consonant-adjacent positions in Moroccan Arabic and found that the ratio between geminates and singletons increased in the following order: #ttC < VttC < #ttV < VttV. To verify whether this difference affected the perceptibility of the contrast she tested speakers of American English in a "same-different" discrimination task and established that listeners' sensitivity to the contrast increased together with the ratio between geminates and singletons. This finding offers an explanation for crosslinguistic preference for intervocalic consonant duration contrast, provided the order of duration ratios can be shown to be universal across languages.

Ridouane (2007) reports production data on the duration of singletons and geminates in Tashlhiyt Berber in a variety of contextual positions which can be used to calculate the corresponding ratios. Calculations based on Ridouane (2007)'s data demonstrate that the duration ratio in this language is higher in word-initial and word-final than in intervocalic position: Intervocalic < Initial < Final (for fricatives) and Intervocalic < Final (for stops - not measured in word-initial position).

Thus, the ratio components cannot be shown to possess universal characteristics across different languages. While some studies provide evidence for smaller geminate-to-singleton ratios in positions or types of consonants generally avoided in duration contrast across languages, others bring forth higher ratios for the same positions, which could result from a strategy aimed at repairing the perceptual distinctiveness of the contrast in an otherwise disadvantaged position. One thing seems clear - typological avoidance of geminates in certain contexts cannot be attributed to the universally lower ratios of geminate to singleton duration in these environments.

1.4.6 Allophonic duration

The gist of this approach is that allophonic increase in segmental duration under certain conditions, such as lexical or emphatic stress, or prosodic boundary lengthening, can be phonologized as gemination, resulting in eventual cross-linguistic increase of geminate-singleton contrasts in certain contexts. This reasoning has been mainly applied to justify the crosslinguistic preference for geminates in post-tonic environment. Thurgood (1993) lists duration as one of the most common correlates of stress and attributes gemination in post-stress position to the general tendency for durational increase in stressed syllables. He also noticed that stressed vowels preceding geminate consonants are often short and suggested that "in those instances, the stress is manifested in the consonantal rather than in the vowel quantity".

Blevins (2004a) also explores the tendency of segments to lengthen allophonically under stress as a source of stress-related gemination: "the simplest explanation of lengthening under stress is that length is a direct phonetic manifestation of stress" and "length differences in stressed syllables are great enough to give rise to geminate/singleton contrast" (Blevins, 2004a, p. 173); "syllables are longer under stress, and the phonetic length of consonants is reinterpreted as contrastive". Blevins (2004a) cites a number of examples where gemination was conditioned by post-tonic position, which often, it seems, happened when the quality of the preceding (stressed) vowel was incompatible with lengthening. For example, post-schwa gemination in Kelabit, Madurese, Sangir, Buginese, Isnag, and Konjo; gemination after stressed voiceless vowels in Southern Paiute, and gemination after stressed schwa in open syllables of Norton-Sound Unaliq. Blevins (2004a) also proposes that articulatory and durational strengthening on the edges of prosodic domain can too get phonologized as gemination.

1.4.7 Historical

Blevins (2004a) proposes that there is no need to posit explicit formal constraints in the synchronic grammars against certain types of rarely attested geminates since (1) none of the attested patterns are exceptionless and (2) historical pathways of geminate

evolution together with some phonetically motivated pressures can account for the majority of geminate types and distributional patterns. She distinguishes seven ways in which geminates are believed to arise diachronically including

1. Assimilation in consonant clusters
2. Assimilation between consonants and adjacent vowels or glides
3. Vowel syncope
4. Lengthening under stress (including expressive lengthening)
5. Boundary lengthening
6. Reinterpretation of a voicing contrast (t → [tt], d → [t])
7. Reanalysis of identical C+C clusters

While it is undeniably true that many of these processes lead to the evolution of geminates, some more often than others, Blevins (2004a) does not fully address the question of the quantitative asymmetries between certain types of geminates and geminates in various contextual positions. It appears that her proposal, instead of motivating statistical patterns, provides an explanation for the *diversity* of geminate types, since without additional constrains on the typology of these processes or the typology of their outcomes, most of them predict that any consonant in any context can evolve into a geminate, with equal probability.

To summarize, a variety of explanations have been proposed in the literature for the patterns in the typology of geminate consonants. Some appear to be more plausible than others and only a few were tested experimentally. This dissertation offers a more comprehensive look at the possible sources of asymmetries in geminate typology. I will report experimental findings for the hypothesis laid out below, and supplement it with a typological survey, including an analysis of the phonological conditions under which gemination occurs.

1.5 Proposal

There are four main domains where asymmetries in the distribution of geminate-singleton contrasts across languages can be observed: immediate phonetic environment (vocalic or consonantal), position in the word (medial, initial, final), stress-related positions (post-stress, pre-stress, not adjacent to stress), and the nature of the geminate itself, in particular its manner of articulation or sonority. The following research questions are based on the tendencies reported in the typological literature:

1. Why do we find more geminates intervocalically than in adjacency to consonants?

2. Why do we find more word-final than word-initial geminates?

3. Why do we find more voiceless stop and fricative geminates than voiced and sonorant geminates?

4. Why do we find more geminates across languages in post-stress position than in pre-stress or not-adjacent-to-stress positions?

One major and two minor hypotheses are tested experimentally in this study. The study was designed to test the major hypothesis, but the data collected also allow us to evaluate two additional, minor hypotheses.

PERCEPTUAL HYPOTHESIS (major)
Crosslinguistic tendencies in geminate typology are due to the fact that the contrast between singletons and geminates is more perceptually salient in some types of consonants/contexts.

(a) Ratio hypothesis (minor)
The differences in perceptual robustness of the contrast is due to the fact that geminate to singleton duration ratio is higher for some consonants and in some contextual environments.

(b) Allophonic duration hypothesis (minor)
Crosslinguistic tendencies in geminate typology are due to the fact that the consonants

are allophonically longer in some contexts. This allophonic duration increase gets phonologized as gemination.

The perceptual basis for the asymmetries in the typology of the geminate-singleton contrast is well motivated, especially in the view of the growing body of evidence which shows that perceptual factors affect the distribution of phonological contrasts. With relation to the durational contrasts in particular, Padgett (2003)'s proposal that intervocalic position provides the optimal environment for the perceptual discrimination of the contrast is a plausible hypothesis, which has not been tested experimentally. Perceptual reasons for avoiding word-initial contrast between short and long voiceless stops and word-final contrast between short and long stops, especially unreleased, are obvious, and have been experimentally confirmed (Kraehenmann, 2001). However, stops are not the only geminates avoided in these positions. Here I will test perceptual differences between short and long voiceless *fricatives* in word-initial and word-final position, which do not have the acoustic disadvantages of stop consonants, such as absence of cues to the beginning of the consonant in absolute phrase-initial position, and possible absence of cues to the end of the consonant in absolute phrase-final position. The goal is to determine where there are universal perceptual advantages that correlate with the order of crosslinguistic preferences.

Podesva (2002) and Kawahara (2006) argue for the superior status of non-sonorant geminates on perceptual grounds. Kawahara (2006) supports this claim with experimental evidence. However, the data are available from one experiment on one language: Arabic (although see also a recent study by Hansen (2012) on Persian). Here I will attempt to replicate and extend these findings in a similar experiment with three additional languages.

Finally, although perceptual reasons have not been proposed as a cause of the crosslinguistic preference for geminates in post-tonic position, it is a possibility. For example, if we adopt the assumption that jumps in intensity facilitate perception of duration (Kato et al., 1997), adjacency to stressed vowels, which often are more acoustically intense that other vowels, should prove an advantage to the perception of the duration contrast in consonants.

1.6 Outline of the dissertation

Chapter 2 provides information about the general methodology and statistical analysis used in the experimental study. Chapters 3, 4, and 5 discuss the experimental results for Russian, American English, and Italian groups of participants. Chapter 6 combines the data from all three groups of participants in one analysis and discusses the effects of language experience on the perception of the duration contrast. Chapter 7 reviews the typological data and introduces the Optimality Theoretic model of the typological patterns.

Chapter 2

Methodology

2.1 The steepness of the identification curve

The first question that needs to be addressed concerns the property that can be evaluated experimentally as an indication of the perceptual salience of the contrast. I propose that the relative *certainty* of the listeners about the category membership of the perceived stimulus can be used as such an indication. The next question that arises, thus, is how to quantify the certainty on the part of the perceiver with respect to the phonological identity of the target. Two quantitative measures are used here as a reflection of the degree of perceptual certainty: the relative steepness of the identification curve, addressed in this section, and the relative location of the perceptual boundary, addressed in the following section.

The relative *steepness* of the identification curve was obtained using a forced-choice identification experiment, where listeners were required to label each perceived token as belonging to the category of "long" or "short" consonants (Kawahara, 2006). The assumption is that in an acoustically well-cued contrast each token is perceived relatively unambiguously as a member of one or another category and across listeners only a small number of tokens will show variation due to being categorized as "long" by some participants, and as "short" by others. The result of this scenario will be an S-like curve characteristic of "categorical" perception of phonological contrast, with a fairly steep transition from the lower plateau, corresponding to 100% "long"

responses, to the upper plateau, corresponding to the 100% "short" responses. An example of such a response curve is demonstrated in figure 2.1 (reproduced with permission from the Internet Speech Dictionary (http://blogjam.name/sid/) illustrating the categorical perception of consonant voicing as function of VOT duration (the stimuli represent a voicing continuum from *ba* to *pa*).

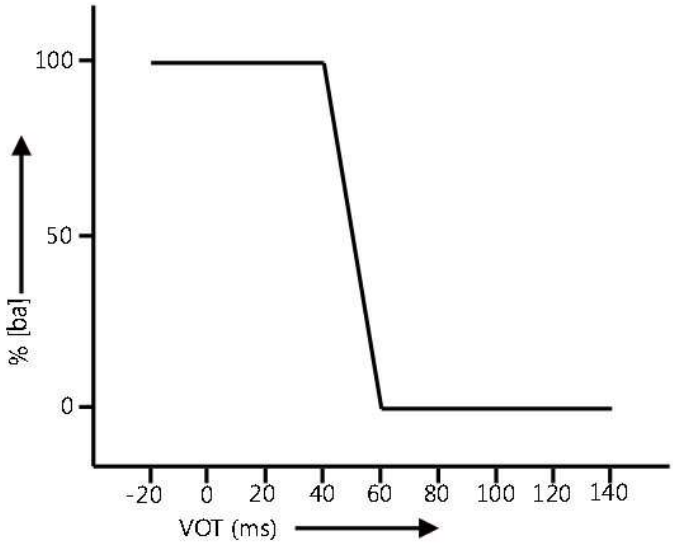

Figure 2.1: A categorical identification curve.

This figure shows that all consonants with VOT up to 40 ms are categorized as voiced, all consonants with VOT of 60 ms and above are categorized as voiceless, and only a small portion of the durational continuum - consonants with VOT between 40 and 60 ms correspond to the area of relative indecision about the category membership of the consonant.

The value at the x-axis at which 50% of the responses (y-axis) categorize it as category A (e.g., [ba]) and 50% of responses categorize it as category B (e.g., [pa]) is generally considered the perceptual boundary between the two categories. In figure 2.1 this values is 50 ms: all consonants with a VOT less than 50 ms are more likely to be categorized as voiced, all consonants with a VOT greater than 50 ms are more likely to be categorized as voiceless, while consonants with a VOT of 50 ms have a 50% chance to be categorized as either voiced or voiceless.

The identification curve is not always quite as steep as shown on this graph and

a less steep, more gradual transition between the two plateaus can be interpreted as an indication of a greater indecision on the part of the listeners about the category of the perceived stimuli. A shallower curve would include a greater portion of the continuum plotted on the x-axis as an indecision area - where participants alternate between category 1 and category 2 in their responses, suggesting that they are not as sure about the category membership as they are at the extreme values of the continuum.

Such a situation is potentially detrimental to the communicative function of the language realized through a system of meaning-differentiating phonological contrasts. In the noisy and variable conditions in which real language is produced it is unrealistic to expect that all the tokens along a given phonological dimension will come from the two extreme points of the acoustic correlate which cues the contrast. Some tokens are likely to fall within the middle range and, if the perceptual distinction in this area is not reliable enough, not be perceived as an intended category 1 or category 2, resulting in a break-down of the communication. Contrasts with a shallower identification function invoke a greater probability of such a break-down.

Thus, a **prediction** generated by the major perceptual hypothesis of this study, states that an identification function will be steeper for the geminate-singleton contrasts that are more robust perceptually, which are expected to correspond to the contrasts more frequently found across languages. In particular, it is expected that:

1. The identification function will be steeper for intervocalic than consonant-adjacent contrast (or word-edge contrasts).

2. The identification function will be steeper for word-final than word-initial contrast

3. The identification function will be steeper for stress-adjacent (especially post-stress) than for non-stress adjacent contrast

4. The identification function will be steeper for obstruent than for sonorant consonants

2.2 Location of the perceptual boundary

A second quantitative measure of the perceptual certainty is the location of the perceptual boundary between the two categories defined as a value of the acoustic correlate (in this case, duration) at which the identification of the two categories is at 50%. For example, when a 150 ms target is perceived half the time as "short" and half the time as "long" it is considered to be the perceptual boundary between short and long consonants. The null hypothesis is that the perceptual boundary reflects the distribution of the durational values in production: roughly, if single consonants are on average 100 ms long and geminate consonants are on average 200 ms long, the perceptual boundary may be expected at around 150 ms.

The location of the perceptual boundary that is not in agreement with the production values is indicative of a 'geminate' or a 'singleton' bias in the perception of length. For example, if the perceptual boundary was at 190 ms in the scenario outlined above there is a clear singleton bias in perception: the participants are reluctant to label the perceived segments as long even at a duration that is typically associated with geminacy in production. My proposal is that such a singleton bias may result from a higher degree of uncertainty of the listeners about the category membership of the stimuli. They cope with this uncertainty by reverting to the "default category" - singletons. In other words, when the listeners are uncertain whether the consonant they are identifying is short or long they prefer to label it as "short" because it is a *safer* choice.

Singletons, considerably more frequent across as well as within languages, can be viewed as the "default" category, the one listeners come to expect. In a situation of a greater uncertainty, when the nature of the stimulus with respect to a given phonological dimension is ambiguous, it is probable that one of the coping strategies would be to "fall back" on the default category. Probabilistically, any token is more likely to be a singleton than a geminate and categorizing it as such in unclear cases increases the chance of success (a correct guess). Thus, one would expect a singleton bias in the perception of the less salient contrasts, resulting in the category boundary shift towards the higher end of the durational continuum (a consonant needs to be

relatively *longer* to be categorized as "long").

This effect is represented schematically in figure 2.2. This is a one-dimensional representation of the consonantal length contrast, where the x-axis corresponds to the *duration* of the consonant. S and G stand for an average singleton and geminate in the two contextual environments considered. A vertical line indicates the perceptual boundary between the two categories. The lower portion of this representation corresponds to the environment where a higher degree of uncertainty about the phonological status of the stimuli in the middle portion of the durational continuum leads to a singleton bias and a category boundary shift towards the geminate end of the scale. A greater portion of the durational continuum is perceived as corresponding to the "short" consonants.

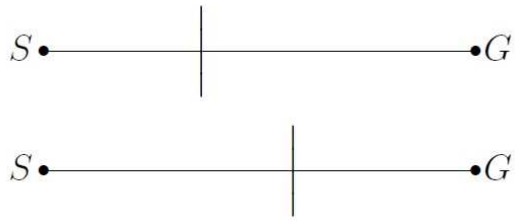

Figure 2.2: Schematic representation of singleton bias.

It is obvious that to evaluate the perceptual boundary shift one needs information about the average duration of short and long consonants in each case under consideration. In figure 2.2 the two contexts condition the same duration of the consonants. This is not always the case, especially if contrasts are compared across various contextual environments. It is a well known fact that segmental duration is subject to variation under the effect of prosodic factors, such as domain boundary conditions. An expected effect of this well-established variability is perceptual compensation. Listeners being aware of the allophonic differences in duration compensate for them perceptually: for example, voiceless stops are generally longer than voiced stops, and as a result they continue to be perceived as singletons at a greater duration, when voiced stops may already be assigned a geminate status. A perceptual boundary between singletons and geminates will accommodate allophonic differences by shifting

to a greater duration for consonants that are phonetically longer in production. This effect is schematically represented in 2.3.

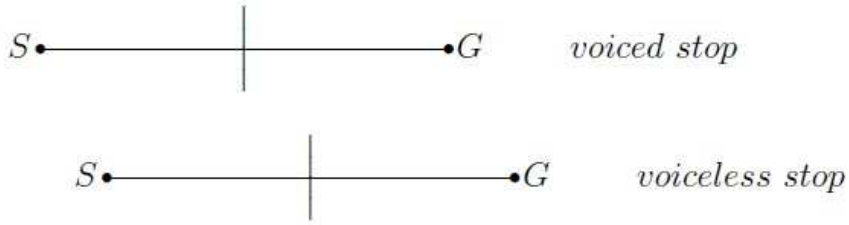

Figure 2.3: Perceptual accommodation.

The area between the two vertical lines indicating the perceptual category boundary between singletons and geminates in voiced and voiceless stops corresponds to the portion of the durational continuum which is perceived as "long" in voiced stops but "short" in voiceless stops. Such a displacement of the perceptual boundary is an expected consequence of perceptual compensation, and has been shown to occur with a change in the rate of speech (Pickett et al., 1999). To ensure that the boundary displacement effect that we observe in the experiment is not due to such perceptual compensation, data needs to be collected on phonetic consonant duration for all consonant types and contextual environments considered in the study. The possible types of boundary displacement that are not justified by the allophonic differences in production are exemplified in figures 2.4-2.6.

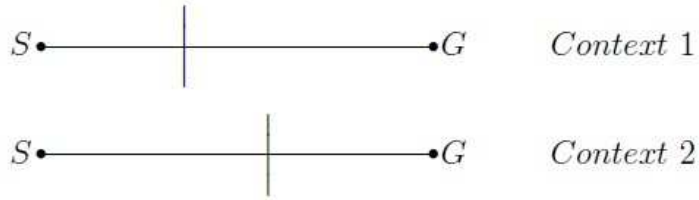

Figure 2.4: Perceptual boundary displacement type 1.

In figure 2.4 duration of singletons and geminates is the same across two contexts but the perceptual boundary is displaced towards geminates in Context 2. This is

a case of a greater uncertainty about the phonemic status of the stimulus. This uncertainty is expressed as a singleton bias.

In figure 2.5 both singletons and geminates are shorter in Context 1 than in Context 2 but perceptual boundary is not significantly different between the two contexts. Here, the contrast in Context 1 is affected by the singleton bias.

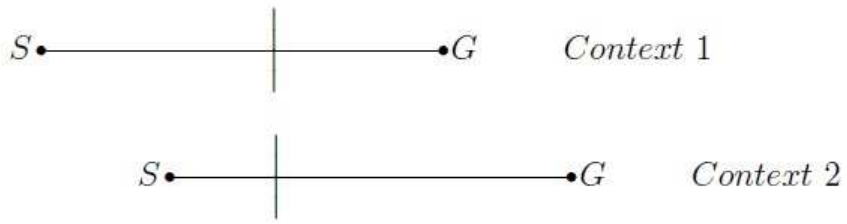

Figure 2.5: Perceptual boundary displacement type 2.

In figure 2.6 both singletons and geminates are shorter in Context 1 but the perceptual boundary is shifted towards the geminate compared to the contrast represented in the lower part of the graph. Here, Context 1 is affected by the singleton bias.

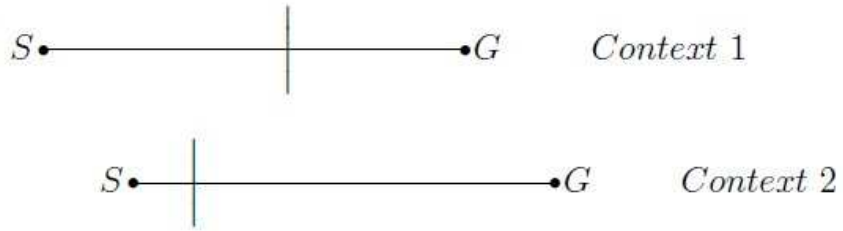

Figure 2.6: Perceptual boundary displacement type 3.

Thus, a prediction concerning the location of the perceptual boundary between short and long consonants, generated by the perceptual hypothesis, is that a singleton bias will be observed in cases where the contrast is of a relatively lower perceptibility. In particular, it is predicted that:

1. There will be a singleton bias in the perception of length in consonant-adjacent compared to intervocalic position.

2. There will be a singleton bias in the perception of length in word-initial compared to word-final position.

3. There will be a singleton bias in the perception of length in non-stress adjacent compared to stress-adjacent (especially post-stress) positions.

4. There will be a singleton bias in the perception of length in sonorants compared to obstruents.

Production data will also allow us to evaluate the Ratio Hypothesis (Aoyama and Reid, 2006; Pajak, 2009a) and the Allophonic Duration Hypothesis (Blevins, 2004a; Thurgood, 1993). The Ratio Hypothesis states that durational contrasts are preferred across languages in certain contexts/for certain types of consonants because they condition a higher durational difference between geminates and singletons. This predicts that the geminate-singleton duration ratio will be higher in contexts where the contrast is frequently found crosslinguistically. For example, if intervocalic singletons are on average 100 ms long and intervocalic geminates are on average 200 ms long (a G/S ratio of 2), while consonant adjacent singletons are 70 ms long and geminates are 105 ms long (a G/S ratio of 1.5) the crosslinguistic preference for intervocalic geminate-singleton contrast may be explained by this difference. A higher durational difference (ratio) makes the contrast more easily perceptible, protecting it from the perceptually driven neutralization. The concrete predictions generated by this hypothesis are the following:

1. The geminate/singleton ratio will be higher for intervocalic than consonant-adjacent contrasts (or word-edge contrasts).

2. The geminate/singleton ratio will be higher for word-final than word-initial contrasts.

3. The geminate/singleton ratio will be higher for stress-adjacent (especially post-stress) than non-stress adjacent contrasts.

4. The geminate/singleton ratio will be higher for obstruents than for sonorants.

The Allophonic duration hypothesis predicts that consonants that are allophonically longer in some context are reanalyzed as geminates and give rise to the geminate-singleton contrast in the corresponding positions. The prediction is that longer average duration will be established for consonants in those contextual environments where geminate-singleton contrasts are typically found crosslinguistically. This hypothesis has been proposed mainly for the stress-induced gemination. For example Thurgood (1993) and Blevins (2004a) suggested that gemination in post-tonic position is related to the phonetic increase in consonant duration under stress. Blevins (2004a) also notes that gemination may arise as a consequence of the prosodic boundary lengthening, such as word-final lengthening. Thus, the prediction of the Allophonic duration hypothesis is the following:

1. Consonants in stress-adjacent (especially post-stress) will be longer than in non-stress adjacent positions.

2.3 Languages

The three languages chosen for the experimental part of this dissertation are Russian, American English, and Italian. These three languages represent a range of options with respect to the phonological treatment of the consonant duration contrast.

Russian has long consonants both on the boundaries of morphemes (so called "fake" geminates) and morpheme-internally, although the latter occur mostly in assimilated loanwords and native vocabulary with obliterated morphemic boundaries. Minimal pairs exist, however few, and long pronunciation alternates with degemination according to a number of gradient morphophonological constraints. A number of Russian linguists analyze double consonants in Russian as positional combinations of two identical phonemes rather than a single long unit (Matusevich, 1976; Panov, 1967, 1979), while others consider them "facultative" phonemes or quasi-phonemes with restricted distribution (Ardentov, 1979).

In English allophonic consonant length has a number of important linguistic uses (Klatt, 1976), including cuing of consonant voicing, boundaries of prosodic domains, and stress (Kaye, 2005), but is not implemented as a phonological contrast.

Italian is a well-known example of a language with phonemic consonant length. In Italian geminates occur morpheme-internally and participate in meaning differentiation. Geminates are allowed intervocalically and before liquids for stop and [f] length contrasts, e.g., *soffrire* "to suffer", *applicato* "applied".

2.4 Participants

Twenty five native speakers of Russian participated in the perception experiment. Production data were collected from five speakers of Russian. Russian participants were recruited on the Stanford campus and in the neighboring communities through word of mouth and electronic fliers distributed to the subscribers of Stanford Russian Students Association and Center for Russian, East European, and Eurasian Studies mailing lists.

Thirty one native speakers of American English participated in the perception experiment. Production data were collected from five monolingual speakers of the Midwestern dialect of American English. Participants for the perception experiment were recruited on the campus of Stanford University from the subject pool of the linguistics department. They were students enrolled in undergraduate linguistics classes and were given course credit for their participation. Only perception data from participants who reported no significant exposure to any foreign language were included in the analysis. Participants for the production experiment were recruited through fliers on the campus of Purdue University and were paid for their participation.

Thirty two native speakers of Italian participated in the perception experiment (five were tested at Stanford, four at Purdue, and 23 in Italy). Participants were recruited through word of mouth and fliers on the campuses of Stanford University and Purdue University, and within the community of the town of Varazze, Italy.

Production data were collected from eight native speakers of Italian (two were recorded at Purdue and six in Italy). Participants of the production experiment were a subset of the participants in the perception experiment. The number of participants in each language group who took part in the experiment is summarized in table 2.1.

All of the Italian participants were young adults in their early 30s who were born

Language group	Perception	Production
Russian	25	5
American English	31	5
Italian	32	8

Table 2.1: Participants.

and raised in Italy. With the exception of three persons who came from Milan, Venice, and Modena, the majority of Italian participants were from Liguria, a region of Italy situated on the coast of the Ligurian Sea in the North-West of the country, bordering with France to the west. The capital of the region is Genoa and one of the commonly spoken dialects is Genovese (Zeneize), which is characterized by a strong French influence on its phonology. The Genovese dialect, like other northern Italian dialects, lost its geminates in the course of its historical development (Ghini, 1995). All the participants in the experiment speak a local variety of Standard Italian and have only a passive knowledge of the Ligurian dialects. Italians who participated in the experiment belong to the generation who grew up when the prestige of Standard Italian was high and speaking local dialects was regarded as a sign of lack of education. Speaking dialect was discouraged in the public school system and parents often restrained themselves from speaking dialect to their children and used only Standard Italian when addressing them to ensure that children acquired Standard Italian only (Cremona and Bates, 1977; Lepschy and Lepschy, 1998). Thus, for the purposes of this experiment the participants are considered native speakers of the local variety of Standard Italian.

None of the participants reported speech or hearing disorders.

2.5 Procedures

2.5.1 Perceptual experiment

All three groups of participants were subjected to an identical procedure during the perceptual experiment, although the location of testing varied. Russian and American participants were tested in the Linguistics laboratory of Stanford University, using a desktop computer and a response box. The majority of Italian participants were tested in a quiet room in a residence in Liguria, Italy, using a laptop computer, Sony MDR-NC7 noise canceling headphones, and a keyboard as an input device. The procedure is described below.

A forced-choice identification experiment was designed using the E-Prime software. Participants were seated in front of the computer screen wearing headphones. Instructions were presented in the native language of the participant (Russian, English, or Italian) on the screen. Participants were instructed to listen to each word and answer as quickly as possible whether the target consonant was short or long by pressing one of the two buttons on the button box or the keyboard. The corresponding buttons (buttons “1” and “5” on the button box or buttons “F” and “J” on the keyboard) were labeled “short” and ”long” in the native language of the participant. Buttons “2” and “4” on the button box, or “D”, “G”, “H”, and “K” on the keyboard were also accepted as valid responses, since these were the buttons immediately adjacent to the response buttons on either side and could be pressed by accident instead of the intended one.

Audio stimuli were presented through the headphones. Each audio presentation of the stimulus was preceded by its visual presentation on the screen, where target consonant was substituted by a question mark “?”, e.g., *ko?apu*. Stimulus presentation was followed by a 2.5-second interval, during which the participant was expected to give an answer. If no answer was received the experiment automatically moved on to the next stimulus.

The experiment started with a short practice session, which consisted of 10 items similar to those used in the experiment. The practice session was designed to familiarize the participants with the task and present them with the types of stimuli

they were going to encounter in the experiment. Durations of the consonants in the practice session were selected from the extremes of the durational range rather than the middle portion to make the task more understandable.

Once the practice session was over, experimental stimuli were presented to the participants. Stimuli were randomized and arranged in three blocks. After each experimental block participants had an option to take a five minute break or move on to the next block immediately. The experiment took approximately 40 minutes to complete. Perception experiment always preceded the production experiment. The stimuli are discussed in more detail in section 2.6.

2.5.2 Production experiment

During the production experiment participants were asked to read through a list of stimuli several times at a pace comfortable for them. Participants were encouraged to pronounce the stimuli as naturally as possible and to assign stress according to the notations provided in the list. Russian spelling in particular allows an indication of stress in ambiguous cases and Russian participants are reasonably accustomed to follow these notations. Russian participants were also asked to make sure that double consonants were pronounced as long so as to avoid degemination common in colloquial speech. English production experiment did not include long consonants.

Russian participants were recorded in a sound-attenuated booth in the Linguistics laboratory of Stanford university, using a Tascam US-144 solid-state recorder and a sampling rate of 44.1 kHz. American participants were recorded in a sound attenuated booth in the Audiology Clinic of Purdue University, using a Marantz PMD660 solid state recorder and a Shure BG 1.1 unidirectional dynamic microphone, at a sampling rate of 44.1 kHz. The majority of Italian participants were recorded in a quiet room in a residence in Liguria, Italy, using a Marantz PMD660 solid state recorder and a Marantz Lavalier electret condenser microphone.

The first three readings of the word list were used for the analysis. The fourth or (for American participants) fifth repetitions were used to provided substitutions for

items that were mispronounced or otherwise corrupted during the first three repetitions.

Measurements were made for the duration of the target consonant. The measurement and segmentation criteria are described in section 2.7.

2.6 Stimuli

Non-word stimuli were designed to test the perception of consonant length as a function of:

1. Immediate phonetic environment (intervocalic and preconsonantal environments were compared)
2. Position in the word (word-initial and word-final position were compared)
3. Position with respect to the stressed vowel (preceded by a stressed vowel, followed by a stressed vowel, or not adjacent to stressed vowels)
4. Manner of articulation (voiceless stop [t], voiced stop [d], voiceless fricative [s], nasal [n], and liquid [l] were compared)

Only the voiceless alveolar fricative [s] was used in the first two conditions (phonetic environment and position in the word).

Non-words for the intervocalic and the preconsonantal condition were of the shape (C)VCC(C)VC, all with a final stress: e.g., *issék - isslék*. Perception of the length of fricative [s] in intervocalic position was compared to preconsonantal positions, where [s] was followed by sonorants, [l] or [m]: *bissík - bissmík*. Four non-words were used in this condition.

Items contrasting word-initial and word-final fricatives were represented by pairs of words of the shape CV-CCVCV(C) where the target fricative was either a final segment in the first word or an initial segment in the second word: *poss ʌvap - po ssʌváp, diss ipa - di ssipá*. All disyllabic words had final stress. Four non-words were used in this condition.

Environment	Position	Stress x Manner
issék - isslék	*poss ʌváp - po ssʌváp*	*kóttapu - kottápu - kottapú*
bissɨ́k - bissmɨ́k	*diss ipá - di ssipá*	*kóddapu - koddápu - koddapú*
		kóssapu - kossápu - kossapú
		kónnapu - konnápu - konnapú
		kóllapu - kollápu - kollapú

Table 2.2: General perceptual stimuli and production stimuli for Russian participants.

Items contrasting target consonants in pre-stress, post-stress, and non-stress adjacent position were of the form *koCCapu* with stress on the initial, penultimate, or antepenultimate vowel. The second consonant in these stimuli was a voiceless stop [t], voiced stop [d], voiceless fricative [s] , nasal [n], or liquid [l]: *kottapu, koddapu, kossapu, konnapu, kollapu*. Fifteen non-words were used in this condition (five manners of articulation x three levels of stress). The stimuli used in the perceptual experiment are summarized in table 2.2.

These stimuli, with a target consonant pronounced as a geminate, were recorded by the author (a native speaker of Russian) and instrumentally manipulated to create a range of durations for each non-word, from 50 to 410 ms in 20 ms steps. A Praat (Boersma and Weenink, 2010) script was used for precise manipulation of duration. As a result, 19 stimuli were created on the basis of each originally recorded non-word with a geminate as a target consonant, which summed up to a total of 437 experimental stimuli ($(4 + 4 + 15) = 23 * 19$) for presentation in the perceptual experiment.

The same stimuli were used for the production experiment with Russian participants. Two versions of each non-word were presented to the participants for pronunciation: one with a singleton as a target consonant and one with a corresponding geminate, e.g., *isék - issék*. The stimuli were arranged in three columns in a pseudo-random order on one sheet of paper, with fillers added at the top and bottom of each column to avoid intonational effects associated with the beginning and end of the list and in several locations within the list to break the repetitiveness: 57 items in total,

Environment	Position	Stress x Manner
desout - destout	*fandis ebair - fandy sebair*	*cápavan - capávan - capaván*
desay - desmay	*blace equire - blay sequire*	*cábavan - cabávan - cabaván*
beseek - besleek	*brice emote - bry semote*	*cánavan - canávan - canaván*
esair - espair	*kase epout - kay sepout*	*cálavan - calávan - calaván*
		cásavan - casávan - casaván

Table 2.3: Production stimuli - American English.

including 46 experimental stimuli and 11 fillers. A total of 138 tokens (46 stimuli x 3 repetitions) were recorded by each Russian participant.

The production word list for American participants did not include any geminate consonants.

Non-words for the intervocalic and the preconsonantal condition were of the shape (C)VCVVC - (C)VCCVVC, e.g., *desout - destout; esair - espair*, with stress always on the final syllable. Duration of the fricative [s] was measured in the intervocalic position and in clusters: [sp], [st], [sm], or [sl]. A total of eight experimental stimuli were used in this condition.

Items contrasting word-initial and word-final fricatives were represented by pairs of words where the target fricative was either a final segment in the first word or an initial segment in the second word: *fandis ebair - fandy sebair; kase epout - kay sepout*. There were eight experimental stimuli in this condition.

Non-words for the stress condition were of the shape *CaCaCVn* where the stress fell on the initial, penultimate, or antepenultimate vowel: e.g., *cápavan - capádin - rapadán*. Consonants used in this condition included voiced and voiceless bilabial stops [p-b], voiceless fricative [s], nasal [n], and liquid [l]. Bilabial stops were used here instead of coronal stops since in American English voiceless coronal stop [t] behaves differently depending on the stress environment: post-stress [t] becomes a tap or a flap - a sound acoustically quite different from the voiceless stop. There were 15 experimental stimuli in this condition. American English production stimuli are summarized in table 2.3.

The words were arranged in pseudo-random order in two columns on one sheet of paper: 46 items total, including 31 experimental stimuli and 15 fillers. To assist the speakers with the stress patterns in the non-words a real word with the same stress pattern was provided in parentheses next to the experimental word: e.g., *caládin (as in Aláddin); cápavan (as in cáravan); rapadán (as in Ramadán).* A total of 93 tokens (31 x 3 repetitions) were recorded by each American participant.

The production word list for Italian participants contained geminates only in stress-related contexts, since this condition contained target consonants in intervocalic positions where geminates are normally found in Italian.

All preconsonantal fricatives were in word-initial positions, as their prevocalic counterparts, and were of the shape CVC(C)V - CCVC(C)V: e.g., *solzi - scolzi; sape - scape.* In Northern Italian intervocalic [s] voices to [z]; placing the sC-sV comparison in word-initial position eliminates this issue. In this condition duration of [s] was measured in prevocalic position and in [sk] clusters. Eight stimuli were used in this condition.

All items contrasting word-initial and word-final fricatives were of the shape CVCV - (s) - VCVCV where the medial [s] was either a final segment in the first word or an initial segment in the second word: e.g., *lucus atora - lucu satora.* Since Italian does not normally allow word-final consonants these stimuli were created to sound like pseudo-Latin words. There were eight stimuli in this condition.

Non-words implementing the stress condition were of the shape *CaC(C)iCano* where the stress fell on the initial, penultimate, or antepenultimate vowel: e.g., *cátitano/cáttitano - catitáno/cattitáno - ratínano/rattínano.* Consonants used in this condition included voiced and voiceless coronal stops [t-d], fricative [s], nasal [n], and liquid [l]. There were 30 stimuli in this condition since in each stimulus occurred twice in the list; once with a target singleton and once with a target geminate. The Italian production stimuli are summarized in table 2.4 (the stimuli in the stress condition are listed only with singletons).

The words were arranged in a pseudo-random order in one column on three sheets of paper: 72 items, including 46 experimental stimuli and 26 fillers. To assist the speakers with the stress patterns in the non-words a sentence containing a real word

Environment	Position	Stress x Manner
sella - schella	*lucus atora - lucu satora*	*cátitano - ratínano - catitáno*
sammo - scammo	*fumus opalo - fumu sopalo*	*cáditano - radínano - caditáno*
solzi - scolzi	*calos itota - calo sitota*	*cánitano - ranínano - canitáno*
sape - scape	*butas emeto - buta semeto*	*cálitano - ralínano - calitáno*
		cásitan - rasínano - casitáno

Table 2.4: Production stimuli - Italian.

	Stress		Manner		Envrnmt		Position	
	S	G	S	G	S	G	S	G
Russian	yes	yes	yes	yes	yes	yes	yes	yes
Italian	yes	yes	yes	yes	yes		yes	
English	yes		yes		yes		yes	

Table 2.5: Production data for the three groups of participants.

with an equivalent stress pattern was provided: e.g., *cátitano - Queste cose cápitano spesso* "These things happen often". Sentences instead of individual words were used in this case to disambiguate two of the real words used as examples, which differed only in the stress pattern: *capitáno* "captain" and *cápitano* "to happen". A total of 138 tokens (46 x 3 repetitions) were recorded by each Italian participant.

Table 2.5 summarizes the conditions that were represented in the production data recorded by the three groups of participants. Preconsonantal and intervocalic contexts are grouped under the category Environment. Category Position includes word-initial and word-final contexts. We can see that Russians recorded target consonants in each conditions, as both singletons and geminates. Italians did not pronounce geminates in the Environment and Word-position conditions. Americans did not record any geminates at all.

2.7 Measurements and segmentation

Recordings of the stimuli collected during the production experiment were analyzed acoustically to measure the duration of the target consonant, singleton or geminate. Measurements were made from the waveforms and the spectrograms displayed by the speech analysis software Praat (Boersma and Weenink, 2010).

The following segmentation criteria were used when determining the boundaries of the target consonants:

Intervocalic voiceless stops were measured from the onset of the stop closure (a silent portion on the spectrogram) which coincided with the offset of the periodic vowel signal, to the point where periodic signal resumed, as shown in 2.7

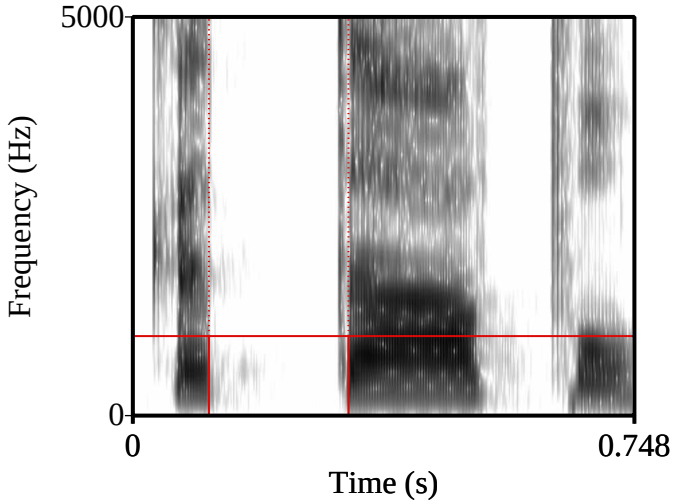

Figure 2.7: Segmentation for [*tt*] in *kottápu*.

Intervocalic voiced stops were measured from the onset of the voiced stop closure, marked by a sudden drop in the amplitude of the periodic signal and absence of the high frequency components on the spectrogram, to the onset of the following vowel, indicated by an onset of a high intensity periodic signal, including high frequency components and the formant structure (shown in 2.8). Release portion of the stop consonants, including burst and aspiration, was measured as part of the total stop duration (Turk, 1992).

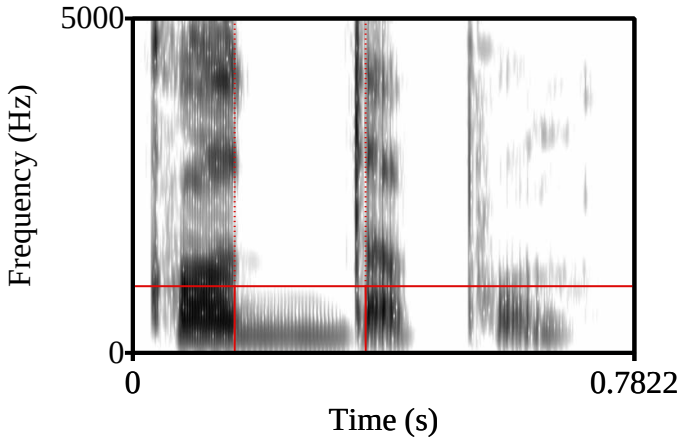

Figure 2.8: Segmentation for [*dd*] in *kóddapu*.

Duration of the *intervocalic voiceless fricatives* was measured from the onset of the aperiodic noise with a pronounced high frequency component to the onset of the periodic vowel signal (2.9).

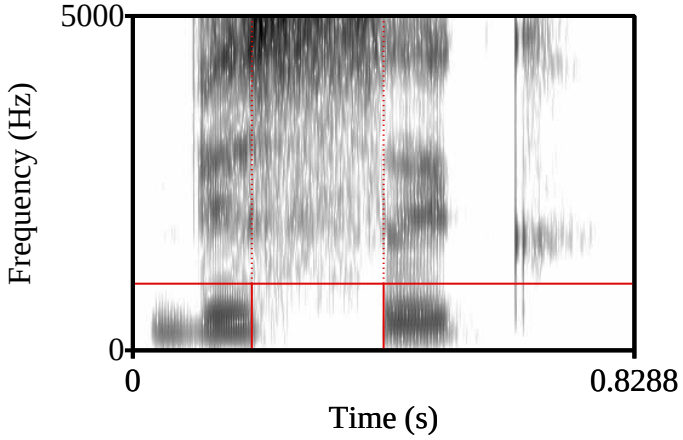

Figure 2.9: Segmentation for [*ss*] in *bissík*.

Intervocalic nasals were measured as a portion of the signal between two points of

the sudden drop in signal intensity, also characterized by the presence of antiformants (white horizontal bands on the spectrogram) as shown in 2.10. These spectrographic events were also accompanied by a change in the amplitude and the shape of the waveforms.

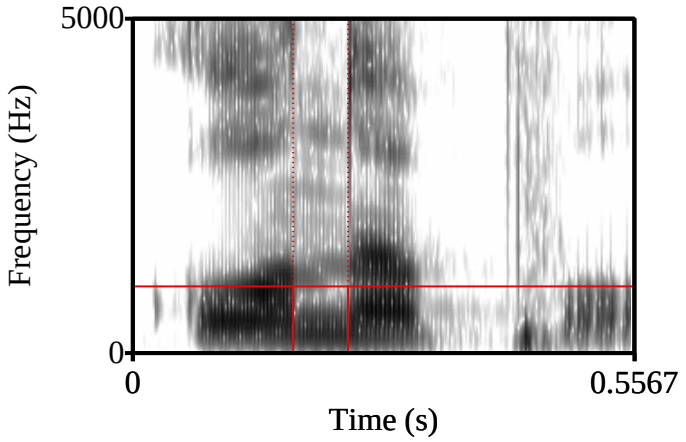

Figure 2.10: Segmentation for [*n*] in *kónapu*.

Intervocalic liquids were measured as a portion of the signal between abrupt changes in the waveform frequency, shape, and amplitude, usually corresponding to a decrease in signal intensity and less visible formant structure (2.11). The onset of the lateral liquids was also sometimes marked by a pronounced drop in the frequency of the first formant.

The offset of the *preconsonantal fricatives* was defined as the point where aperiodic noise was replaced by the periodic signal of the following sonorant or by the silent closure portion of the following voiceless stop (2.12).

Word-initial and *word-final fricatives* were measured from the onset/offset of the aperiodic noise with a pronounced high frequency component on the spectrogram to the onset/offset of the pause (if followed by pause) or onset/offset of the vowel, marked by a periodic waveform and formant structure on the spectrogram.

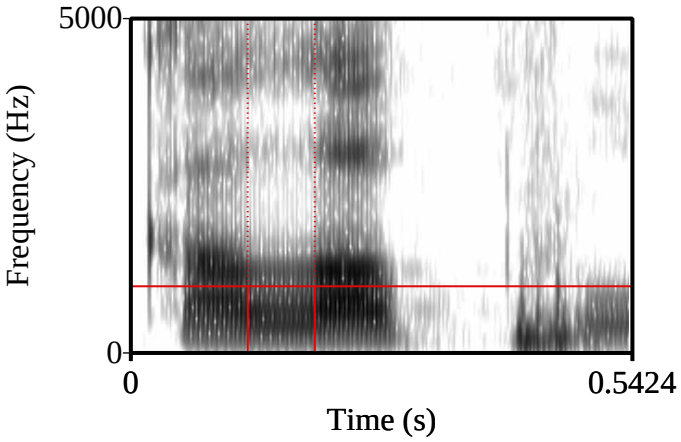

Figure 2.11: Segmentation for [*l*] in *kolapú*.

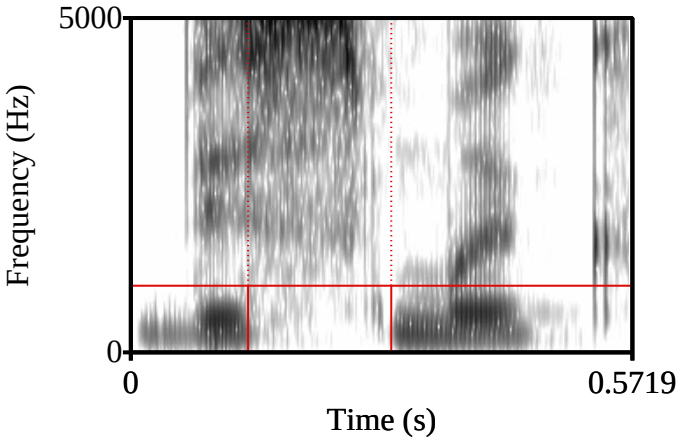

Figure 2.12: Segmentation for [*s*] in *bismík*.

2.8 Analysis

2.8.1 Overview

The analysis method described below is motivated by the need to estimate the distinctiveness of the contrast in each of the conditions, as expressed by the relative steepness of the identification curve and the relative singleton bias of the identification functions. The method for analyzing the steepness of the curves is described in section 2.8.3.

Singleton bias requires a more complex analysis. The data needed to establish the presence of a relative singleton bias are (a) location of the category boundary in production, (b) location of the category boundary in perception. The null hypothesis is that these two values will coincide for every given environment, or that, at least, if there is some amount of separation between these two values (as an experimental artifact), the degree of separation will be *the same across conditions* that are being compared. That is, if participants decide that consonants are long at a slightly greater durational value than the one that optimally separates the two distributions in production, the amount by which that value is *greater* is not expected to differ as function of the contextual environment (e.g., intervocalic and preconsonantal) under the null hypothesis. If the degree of separation is different, the condition where the perceptual boundary is relatively closer to the geminate category is affected by a relative singleton bias.

The method for establishing the category boundary in production is described in section 2.8.2. The method for establishing the category boundary in perception is described in section 2.8.3. The method for analyzing these two groups of data together in order to detect the relative singleton bias is described in section 2.8.4.

2.8.2 Production data

Durational measurements were analyzed statistically to determine whether the consonants differed in duration across contextual environments. The data were analyzed with a series of repeated measures ANOVAs (analysis of variance). A separate ANOVA for each independent variable. Separate ANOVAs are justified for this dataset because Position (word-initial and word-final) and Environment (intervocalic and preconsonantal) condition were implemented as two separate sets of stimuli. Stress and Manner factors were combined in a factorial design in the same set of stimuli but each cell was represented by a single token. That is, there was only one stimulus for each level of stress combined with each level of manner. In cases like this a two-way ANOVA is not possible and each factor has to be analyzed in a separate one-way ANOVA.

Therefore, for each language group four separate one-way repeated measures ANOVAs were conducted. In each one duration of the target consonant was used as a dependent variable and either Stress, Manner, Position, or Environment was used as an independent variable. In cases where consonants were measured as singletons and geminates an additional independent variable, Geminacy, was introduced. Geminacy in itself is not a very interesting factor, since geminates, as expected, were invariably produced as significantly longer than singletons. However, potential interactions of Geminacy with other independent variables were indicative of the significant difference in the geminate/singleton duration ratio across contexts. In other words, these interactions showed that the difference in duration between singletons and geminates was significantly greater at one level of the independent variable (e.g,. word-initial) than at another level (e.g., word-final). Thus, a significant interaction of this type can be used as evidence for the Ratio hypothesis.

A second type of statistical analysis applied to production data was the Discriminant function analysis (DFA). Discriminant analysis is used to predict group membership from a set of predictor variables. If there are two groups and p predictor variables the linear discriminant equation for each group will look like this:

$$D_i = a + b_1x_1 + b_2x_2 + ... + b_px_p \tag{2.1}$$

Since in our case there is only one predictor variable - duration, the equations for two groups (singletons and geminates) will be the following:

$$D_i = a_i + b_ix \tag{2.2}$$

$$D_j = a_j + b_jx$$

where

- D is a classification score for groups i and j.
- b is a classification function coefficient
- a is a constant

Thus, the classification score is found by multiplying the raw score on each predictor, x, by its associated classification function coefficient, b (summing over all predictors), and adding a constant, a. The linear discriminant equations are constructed such that the two groups differ as much as possible on D.

Here, I am using discriminant analysis to establish the exact boundary (in production) between the two distributions of data: singletons and geminates, in order to compare this value with the perceptual boundary, determined by the perceptual experiments.

For each data point, if $D_i - D_j$ is positive then the data point is classified into group i (e.g., singletons). If $D_i - D_j$ is negative then the data point is classified into group j (e.g., geminates). There exist a hypothetical data point for which $D_i - D_j = 0$, so its probability of belonging to group i or group j is 50%. In other words, it is the *category boundary* between the two groups. This precise data point can be calculated using the transformation of the following equation:

$$D_i - D_j = 0 \tag{2.3}$$

$$a_i + b_i x - (a_j + b_j x) = 0$$

$$a_i - a_j = (b_j - b_i)x$$

If we divide both sides of the equation by x we get:

$$\frac{a_i - a_j}{x} = b_j - b_i \tag{2.4}$$

Now we can express x as:

$$x = \frac{a_1 - a_j}{b_j - b_i} \tag{2.5}$$

Discriminant analysis, for obvious reasons, was used only for those subsets of data where both singletons and geminates were recorded (Russian and portions of Italian production data).

Discriminant analysis was performed for each subject and each level of each condition separately, to obtain the classification coefficients and constants for singletons and geminates. Then the category boundary was calculated using the formula above. As a result, it was possible to obtain a value of "best separation" between short and long consonants in each condition. For example, we could see what the boundary between singletons and geminates was in word-initial position, which corresponded to the durational value from which all the short consonants on one side, and all the long consonants on the other side, were the most distant.

Discriminant analysis was performed on the data not averaged across repetitions (three repetitions for each subject) to increase the number of data points available for categorization.

Category boundary values for each participant, obtained with the discriminant analysis, were then submitted to a repeated measures ANOVA to establish whether there was a significant difference in the location of the boundary between contextual environments.

2.8.3 Perception data

A logistic regression function was fitted to each subject's responses collected in the perceptual experiment, with duration of the stimulus (19 steps) as a predictor variable variable and response as a dependent variable. This analysis was performed separately for each level of each condition (as for discriminant analysis).

Logistic regression is a statistical model used to model binary response variables. In a model with a single predictor variable X the probability of a binary response variable Y (1 or 0) to equal 1 at predictor value x is $\pi(x)$. The logistic regression model has linear form for the logit of this probability (Agresti, 2007):

$$\text{logit}[\pi(x)] = \log\left(\frac{\pi(x)}{1-\pi(x)}\right) = \alpha + \beta x \tag{2.6}$$

Probability $\pi(x)$ increases or decreases as an S-shaped function of x. Logit increases by β for each 1-unit increase in the predictor variable X. Thus, parameter β in the equation determines the *rate of increase* (if β is positive) of the S-shaped curve for $\pi(x)$. It is also related to the slope of the linear function tangent to the curve at each particular x value: a slope of the linear function describes the rate of change of the logistic function at this point and is equal to $\beta\pi(x)[1-\pi(x)]$ (see figure 4.1 in Agresti 2007, p. 100). For example, if $\pi(x) = 0.5$ the slope of the linear function at this point equals $\beta(0.5)(0.5) = 0.25\beta$. This is the point of the highest slope for the logistic function: as $\pi(x)$ approaches 1 or 0, the slope approaches 0 (near-horizontal tails of the S-shaped curve).

The value of x at which $\pi(x) = 0.5$ is related to the logistic regression parameters by $x = -\alpha/\beta$. This can be shown by the following transformation of the logistic regression equation:

$$\log\left(\frac{\pi(x)}{1-\pi(x)}\right) = \alpha + \beta x \tag{2.7}$$

$$\log\left(\frac{0.5}{1-0.5}\right) - \alpha - \beta x = 0$$

Since $\log[(0.5)/(1-0.5)] = 0$:

$$-\alpha = \beta x \tag{2.8}$$

And:

$$x = \frac{-\alpha}{\beta} \tag{2.9}$$

This x value, called the *median effective level* and denoted as EL_{50}, represents the value at which each outcome has a 50% chance. In other words, it represents the perceptual boundary between two categories.

The logistic regression was used here to collect two values: the value of the β coefficient for each individual regression model and the Median level value of x, calculated from the logistic equation using the formula above. The β coefficient is interpreted as an indication of the *steepness* of the logistic curve and can be used to evaluate the relative perceptual distinctiveness of the contrast in each particular condition. The Median level is interpreted as a perceptual boundary between the two categories and can be used to establish whether the perceptual boundary between singletons and geminates was different for consonants in one position (e.g., word-initial) than for consonants in another position (e.g., word-final).

To establish whether the differences in β coefficients and Medial levels across contextual positions were statistically significant the values of β coefficient and median levels were submitted to a series of repeated measures ANOVAs as dependent variables with Stress, Manner, Position, and Environment as independent variables. Since the perceptual task was identical for each language group, this analysis could be applied within, as well as across language groups - with Language as an additional independent variable (before submitting to the ANOVA analysis a reciprocal transformation was applied to the β coefficients of the logistic functions: $1/\beta$)[1].

A similar approach to the analysis of categorical response data was adopted among

[1]While it is true that the slope of the average function is the average of the slopes of the individual functions, the β coefficient of the average function is *not* the average of the β coefficients of the individual functions. The reason for this discrepancy is that β is not linearly related to the slope of the S-curve. On the other hand, it is reasonable to assume that the average of the *inverse* of the β coefficients of each individual function equals the β coefficient of the average function. Thus, to be able to apply in a meaningful way an analysis like ANOVA, which relies on data

others by Pind (1986), and more recently Holt et al. (2004), Kondaurova and Friancis (2008), see also Morrison and Kondaurova (2009).

A significant effect on β coefficient would signify that the rate of increase of the regression function was higher for one level of the independent factor than the other (e.g., word-initial vs. word-final within a Position factor). The interpretation of this result is that the perceptual distinction between short and long consonants is more categorial with a higher β coefficient (steeper slope). This means that the stimuli were more consistently categorized into short and long by the listeners, while the "grey area", i.e., the portion of the durational continuum not consistently associated with the perception of singletons or geminates, was smaller. In other, words, the distinctiveness of the contrast is higher because fewer stimuli are "undecided" - neither short nor long.

A significant effect on the Median level would signify that the functions were displaced with respect to each other along the duration axis. That is, consonants in one context (e.g., word-initial) were perceived as long at a shorter duration (lower median level value) compared to consonants in another context (e.g., word-final).

2.8.4 Joint analysis of production and perception data

Discriminant analysis provided values for the category boundary between singletons and geminates in production while logistic regression provided values for the category boundary between singletons and geminates in perception. These two sets of values can now be evaluated in conjunction to determine whether there are any discrepancies between the production and perception boundaries that would be indicative of the relative singleton bias in one of the conditions, not justified by the allophonic differences in production. The values for the production and perception boundary between singletons and geminates for each participant in each condition were entered into a series of repeated measures ANOVAs with Modality (Production or Perception) as a between-subject independent variable and Stress, Manner, Position, or Environment

averaging, a reciprocal transformation is preferred. In addition, β coefficients are typically non-normally distributed, thus a reciprocal transformation is recommended as one of the methods to make the data distribution more normal.

as a within-subject independent variable.

Of a particular interest in this analysis would be an interaction between Modality and contextual factors. Such an interaction would indicate that perception does not mirror production in terms of the boundary between two categories; that is, if there is no difference between the production boundaries there should be no difference between the perception boundaries. If there is such a difference in perception it may be indicative of the singleton bias in the perception of the category distinction in a particular contextual environment, due to a higher uncertainty about the category membership of the stimuli in this condition. This scenario is represented schematically in figure 2.13, a one-dimensional representation with consonant *duration* on the x-axis. The lower part of the figure corresponds to the environment where the singleton bias in perception is detected: the production boundary (solid vertical line) is the same as in the case presented in the top part of the figure, but the perceptual boundary (dotted vertical line) is shifted to the right, demonstrating a reluctance of the listeners to categorize the stimuli as geminates.

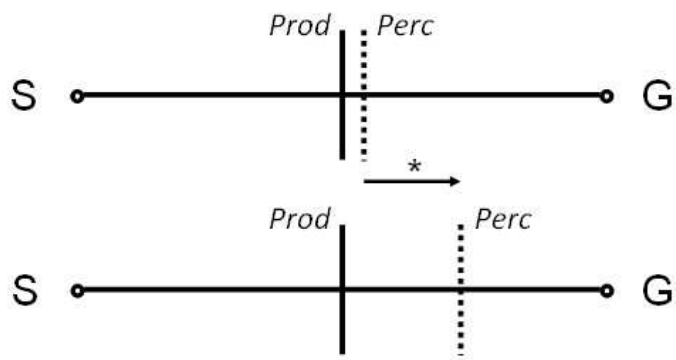

Figure 2.13: Singleton bias in perception.

If production boundaries differ due to the allophonic differences in consonant duration, the default expectation is that perception will accommodate for production: as consonants become longer or shorter due to contextual factors and the production boundary between two categories shifts accordingly, so will the perception boundary. If this perceptual accommodation does not happen, or it is incomplete, it may be an indication of the singleton bias in perception of the distinction in one of the contextual

environments. This scenario is schematically represented in figure 2.14.

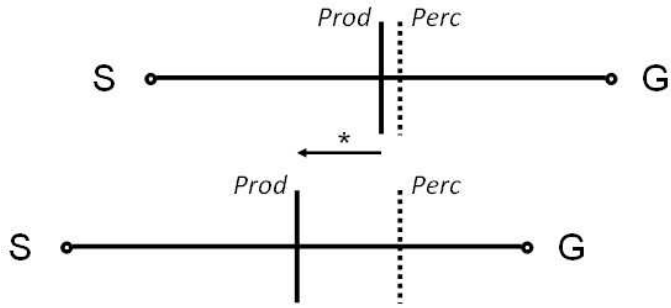

Figure 2.14: Singleton bias in perception.

Thus, this type of a joint analysis of the perceptual and production data allows us to detect a shift in the perceptual boundary not justified by the conditioning shift in the allophonic duration of the consonants. A comparison between the categorization of the data produced by the Discriminant Analysis and the categorization of the data done by human listeners was used for example in Port and Crawford (1989), who focused on the percent correct categorization rather than category boundaries.

To summarize, analysis of the production data allows us to evaluate the Allophonic Duration and Ratio Hypotheses. Analysis of the perceptual data allows us to evaluate the Perceptual Hypothesis by comparing the β coefficients of the logistic functions across various contextual environments. A joint analysis of the perception and production data allows us to add another piece of evidence for the Perceptual Hypothesis by comparing the perceptual boundaries (Median levels of the logistic functions) across various contextual environments, while adjusting for the possibility that a shift in perception could be caused by differences in production (category boundaries in production calculated by the Discriminant Analysis).

Chapter 3

Experiment 1: Russian

3.1 Overview

In this chapter, I will begin by discussing the status and the history of the short-long consonantal distinction in Russian and the findings of the relevant literature, including the studies of the prosodic effect on segment duration in Russian. Section 3.4 presents the results of the analysis of the production and perception data collected in the course of two experiments with speakers of Russian. Section 3.5 offers a summary, interpretation, and discussion of the results.

3.2 The short-long distinction in Russian consonants

Consonant length is a controversial issue in Russian linguistics. The source of the controversy is in the history of geminates in Russian and their questionable phonemic status in contemporary Russian.

In Proto-Slavic and proto-Russian consonant length was not used contrastively (Churganova, 1973; Makarov, 1979; Panov, 1990) but in the course of language development clusters of identical consonants emerged as a result of certain phonological processes. The majority of geminate consonants in the native Russian lexicon are

due to the loss of yers, reduced centralized vowels, which disappeared in prosodically weak positions sometime between the 12th and the 14th centuries (Carlton, 1991). In many cases the loss of yers created double consonants on the morpheme boundary, which was later obliterated. Examples from Fasmer (2004) are shown in 3.1

(3.1) */sъsora/ → /ssora/ "quarrel, fight"
*/sъsuda/ → /ssuda/ "loan"

Assimilation also played a role in creating long consonants across historical morpheme boundaries, as shown in 3.2.

(3.2) Proto-Slavic */drozga/, */drozska/ → /droʒʒɨ/ "yeast" (Fasmer, 2004)

Alongside the native Russian words with long consonants, which were largely limited to morpheme boundaries, foreign borrowings served as a major source of the "true", non-concatenated geminates. Panov (1990) offers a detailed account of the history of geminate consonants in the Russian language, supplied with evidence from literary writing, poetry, and letters of the past centuries. He established that the history of words with double consonants in Russian can be described as a gradual movement towards increased acceptability of both double spelling and long pronunciation.

During the second half of the 18th century changes in the political and economical situation in Russia led to an influx of lexical borrowings from foreign languages. During this period a tendency to avoid long pronunciation of double consonants in speech was very strong for both borrowed and native vocabulary. Some of the loanwords lost double consonants in spelling as well as pronunciation. For example, /arest/ from German /arrest/ (Kolesnikov, 1990).

In the first half of the 19th century geminate consonants were attested in colloquial speech but still avoided in formal and higher styles of speech. Between the second half of the 19th century and the first half of the 20th century geminate consonants became more common, although morpheme-internal geminates were still regarded as a sign of a foreign word not yet fully assimilated by Russian.

The mid-20th century was characterized by a broad acceptability of long consonants both morpheme-internally and across morpheme boundaries.

In present-day Russian any consonant can be geminated (and pronounced as phonetically long) with an exception of the palatal glide [j]. Palatalized [ʃ] is usually described as inherently long.

Morpheme-internally, native Russian words may contain only long [s] and long [ʒ]. The majority of native geminates are concatenated: on the boundary of prefixes and stems or on the boundary of stems and suffixes. Since affixes are a closed class the number of geminates that can arise in this manner is limited. They include geminated [t], [d], [v], [s], [z], [ʃ], and [n]. Several very productive suffixes are [n]-initial, which contributes to a high frequency of geminated [n] in Russian. Regressive voicing and place assimilation also lead to surface gemination:

(3.3) /pod+teret^{j}/ [potteret^{j}] "to wipe out"
/ras+ʃit^{j}/ [raʃʃit^{j}] "to embroider"

Loan words contribute a greater variety of geminate consonants, which in addition to the already mentioned ones include [p], [b], [k], [g], [f], [m], [l], [r], [ʦ], [ʧ], and [x]. Several languages served as sources for borrowed vocabulary with geminate consonants, including English, German, French, Italian, Greek, and Latin:

(3.4) English: [ballast] "ballast"
Greek: [gamma]"scale, spectrum, letter of Greek alphabet"
Latin: [discussija] "discussion"
French: [tonnel] "tunnel"
Italian: [barokko] "baroque"

Kolesnikov (1995) reports the relative frequencies of double consonants in Russian orthography, summarized in table 3.1.

The table shows that voiced fricatives and stops are clustered near the bottom of the frequency range, followed only by the affricates and velar fricatives. The top is occupied by nasals, liquids, voiceless stops, and [s].

nn	*ll, ss*	*mm, rr, tt*	*kk, pp, ff*	*dd, zz, vv, gg, bb*	*ʃʃ, ʧʧ, xx*
62%	11%	2-3%	<2%	1-2%	>0.1%

Table 3.1: Frequency of double consonants in Russian orthography.

This frequency count relies on the orthography and does not include, for example, assimilated geminates (this would raise among other things, the frequency of geminated [ʃ]). However, if we assume that orthography reflects to some degree the tendencies in pronunciation, it appears that manner-based gemination preferences in Russian follow at least in some respects the crosslinguistic patterns. We see a general avoidance of voiced geminated obstruents compared to voiceless ones, and a preference for nasal geminates (*nn* in particular).

Geminate consonants in Russian can participate in meaning differentiation, which suggests that they are, at least partially, phonologized. However, minimal pairs are few and mostly involve gemination on the boundary of morphemes:

(3.5) /voz/ "cart" - /v-voz/ "import"
/spin-oj/ "back"(Instr. sing.) - /spin-noj/ "spinal"

In borrowed and especially professional vocabulary minimal pairs can be found for morpheme-internal geminates and singletons although these contrasts are not likely to have a high functional load:

(3.6) /pas/ "to pass, to let go" - /pass/ "the movement of the hypnotist's hands"
/dalija/ "georgina" - /dallija/ "blackfish"

The scarcity of minimal pairs, a low number of morpheme-internal or "true" geminates in the native lexicon, and the fact that double consonants are not always realized as phonetically long in speech warrants doubts concerning the phonemic status of Russian gemination. Some researchers prefer to classify Russian geminates

as positional combinations of two identical phonemes rather than a single unit (Matusevich, 1976; Panov, 1967, 1979), others propose a status of the "facultative" or quasi-phonemes with restricted distribution (Ardentov, 1979).

The Russian prescriptive tradition acknowledges the variability in the pronunciation of double consonants and provides a set of rules which define environments where long or short pronunciation is recommended. Long pronunciation of double consonants is prescribed for all concatenated geminates in general (Avanesov, 1984; Matusevich, 1976) and on the boundary of prefixes and stems in particular (Panov, 1979). Long pronunciation is also advised in intervocalic position (Kolesnikov, 1990; Panov, 1979) and after stressed vowels (Avanesov, 1984; Kalenchuk and Kasatkina, 1997; Kolesnikov, 1990; Matusevich, 1976). Some sources suggest that long pronunciation is justified in adjacency to stressed vowels on either side, whether before or after the consonant (Panov, 1979).

Prescriptive literature warns against long pronunciation in preconsonantal positions (Avanesov, 1984; Cubberley, 2002; Kalenchuk and Kasatkina, 1997; Panov, 1967, 1979), word-finally (Avanesov, 1984; Cubberley, 2002; Kalenchuk and Kasatkina, 1997; Panov, 1967, 1979), and when not adjacent to stressed vowels (Sazonova, 1998). Thus, long pronunciation is favored intervocalically and next to stressed vowels, while short pronunciation is favored in adjacency to consonants, at the end of the word, and intervocalically when not preceded or followed by stressed vowels. Once again, we can see that these prescriptive generalizations follow the pattern of the crosslinguistic preferences. They show similarities in terms of the tendency to avoid geminates in adjacency to other consonants and at word-edges (word-finally in particular); we can also see signs of the connection between geminacy and stress, just as in the crosslinguistic literature.

Kasatkin and Choj (1999) showed that natural patterns of degemination in speech are governed by the same factors that are appealed to in prescriptive literature. They analyzed a corpus of television programs and college lectures and established that speakers degeminated long consonants more frequently in preconsonantal and word-final positions than in intervocalic and word-initial positions; intervocalic long consonants were degeminated more often if neither of the surrounding vowels was stressed.

Long pronunciation was particulary favored in post-stress position.

Kasatkin and Choj (1999) also report that sonorant geminates, nasals and liquids, degeminated in speech more easily than fricatives, affricates, and stops. Degemination happened more often in fast and spontaneous speech as opposed to slower, prepared speech, and in reading.

Thus, the short-long consonantal distinction in Russian, although not uncontroversially phonemic, does play a functional role, is familiar to speakers of Russian, who produce and perceive it without difficulties, and is realized phonetically as a function of a number of contextual factors, which appear to follow the pattern of crosslinguistic tendencies in the distribution of geminate consonants across contextual positions.

3.3 Prosodic effects on consonant duration in Russian

Effects of prosodic factors on segmental duration in Russian, such as lengthening at the edges of prosodic domains and stress-related duration enhancement, are not as well studied as in some other languages, for example English. Oller (1973) mentions that syllable-final lengthening was reported for Russian by Zlatoustova (1954) (I was unable to locate the original source). Kochetov (2006) examined syllable position effects on gestural timing and magnitude in Russian. It was established that syllable-initial articulatory gestures were more sequential; they showed less overlap and a greater magnitude than syllable-final articulatory gestures, which were characterized by a greater articulatory overlap, reduction in magnitude and duration, and higher variability. Indirectly, this data implies a higher likelihood of durational reduction rather than lengthening in syllable-final position in Russian.

Zlatoustova (1962) reported that Russian consonants were longer in onsets of stressed syllables than in unstressed syllables when measured in disyllabic words of the CVCV structure. She also observed that consonants were shorter in clusters than in intervocalic position. The available equipment did allow a reliable analysis of word-initial consonants' duration in this study although data on vowels demonstrate that

both word-initial and word-final positions produce a consistent lengthening effect, at least for stressed vowels. Initial stressed vowels, as in [ˈoda] "ode" (Nom. sing.) were longer than non-initial stressed vowels, as in [ˈkoda] "code" (Gen. sing.)

Davidson and Roon (2008) examined the duration of consonant sequences in Russian across word-boundaries (C#C), in word-initial position (#CC), and separated by a schwa (#CvC). Their findings demonstrate some evidence for a durational reduction of consonants in clusters, and a durational increase in word-initial consonants.

Overall, this sparse experimental evidence suggests that we may expect (1) shorter consonants in adjacency to other consonants compared to intervocalic consonants, (2) longer consonants in the onsets of stressed syllables than in the onsets of unstressed syllables, and possibly (3) longer consonants word-initially than word-finally.

3.4 Experimental Results

3.4.1 Summary

I will begin this section by briefly summarizing the main findings for each comparison of the contextual environments. The following few sections provide a more detailed overview of the results of the statistical analysis. The final section offers the conclusion and some speculations concerning the causes of the observed effects.

The comparison of the intervocalic and preconsonantal environments showed that the perceptual distinctiveness of the contrast between short and long consonants was *higher* in the *intervocalic* environment. A higher degree of uncertainty of the listeners about the category membership in the preconsonantal environment manifested itself as a singleton bias in the perception of length in this condition.

Results of the statistical analysis are summarized in table 3.2. The first column lists the parameters that were compared across the two environments. The second column indicates the direction of the difference (if any). The third column notes whether the observed difference was statistically significant (a statistically significant difference is indicated by a star "*"). The fourth column specifies whether the observed difference along a certain parameter was in the expected direction (whether

PARAMETER	DIRECTION	SIGNIFICANCE	EXPECTATION
Steepness	no difference	—	V_V > _C
Singleton bias	_C	*	As expected
Ratio	V_V > _C	near-sign.	As expected

Table 3.2: Effect of Environment: Russian.

Analysis	DIRECTION	SIGNIFICANCE	EXPECTATION
Steepness	W-I > W-F	non-sign.	Against
Singleton bias	W-F	*	Against
Ratio	W-I > W-F	non-sign.	Against

Table 3.3: Effect of Position: Russian.

significant or not). The expected direction is based on the predictions of the study, detailed in Chapter 2.

We can see that a singleton bias in the preconsonantal environment was significant, and that an increase in the geminate/singleton ratio in the intervocalic environment was near-significant.

A comparison of the word-initial and word-final geminate-singleton contrasts revealed that distinctiveness of the contrast was *higher* in the *word-initial* position, evidenced by a significant singleton bias in the perception of consonant length in the word-final position. As table 3.3 shows, the difference in terms of the steepness of the identification curves was in the direction opposite to predicted and indicative, as well, of a higher contrast distinctiveness in the word-initial position. This difference, however, did not reach significance.

An analysis of the amount of durational increase in gemination also showed a difference in the same direction: a greater increase in the word-initial than in the word-final position, although non-significantly.

A comparison of durational contrasts across the three stress conditions (preceding stress, following stress, no stress) revealed virtually no differences. As table 3.4

Analysis	DIRECTION	SIGNIFICANCE	EXPECTATION
Steepness	no difference	—	_V́, V́_ > V_V
Singleton bias	V_V	a trend	As expected
Ratio	V́_, V_V > _V́	non-sign.	Against

Table 3.4: Effect of Stress: Russian.

Analysis	DIRECTION	SIGNIFICANCE	EXPECTATION
Steepness	[n,l] > [t,d]	*	Against:
	[s] > [t]		[t, s] > [d, n, l]
Singleton bias	no effect	—	[n, l]
Ratio	s > l > d > n > t	non-sign.	Against

Table 3.5: Effect of Manner: Russian.

shows, there was a non-significant trend in the expected direction in the singleton bias analysis: a singleton bias was observed in the perception of length in the non-stress adjacent consonants. This suggests that contrast distinctiveness may be lower between two unstressed vowels than in adjacency to stressed vowels. The durational difference between geminates and singletons was somewhat higher in the preceding stress and, unexpectedly, in the no stress conditions. The lowest difference was observed in the following stress condition. If ratio differences were to explain crosslinguistic tendencies we would expect greater durational difference in the stress adjacent, most importantly in the preceding stress condition, but not in the adjacency to unstressed vowels. However, these differences were non-significant.

Comparison of the quality of the durational contrast across consonants of various manners of articulation revealed some significant differences but not in the predicted direction. Slopes of the identification functions were steepest for nasals, liquids, and voiceless fricatives, suggesting that the geminate-singleton contrast was the most perceptually distinct for these consonants (table 3.5).

A more detailed overview of the statistical analysis follows.

3.4.2 The effect of the immediate phonetic environment: intervocalic vs. preconsonantal

Production

An analysis of consonant duration in intervocalic and preconsonantal environments established that consonants (both geminates and singletons) in Russian were on average longer in the intervocalic than in the preconsonantal environment. This effect appears to be driven partly by the fact that lengthening under gemination is more pronounced in the intervocalic than the preconsonantal environment, as evidenced by a higher geminate/singleton ratio and a near-significant Geminacy-Environment interaction (statistical effects are summarized in table 3.6).

Figure 3.1 illustrates the average differences in duration between geminates and singletons in the intervocalic and the preconsonantal environments. Table 3.7 summarizes mean durations and geminate/singleton ratios.

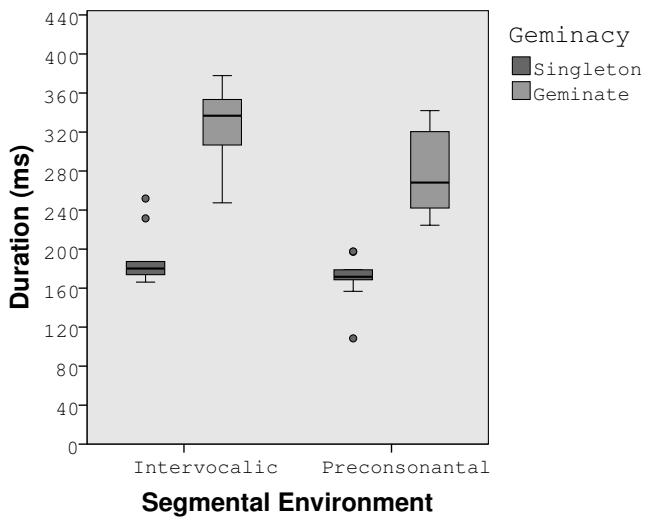

Figure 3.1: Duration of Russian consonants in intervocalic and preconsonantal environment.

As described in Chapter 2, the category boundary between geminates and singletons in production was established using the Discriminant Analysis, which places

	F	p	eta-squared
Environment	$F(1,4) = 11.423$	< 0.05	0.741
Geminacy	$F(1,4) = 166.518$	< 0.001	0.977
Interaction	$F(1,4) = 7.215$	0.055	

Table 3.6: Effect of Environment and Geminacy on consonant duration in Russian.

	Geminates (ms)	Singleton (ms)	G/S ratio
Intervocalic	326	190	1.7
Preconsonantal	277	170	1.6

Table 3.7: Geminate and singleton durations and their ratios in intervocalic and preconsonantal environment in Russian.

the boundary half-way between the group centroids. The category boundary between singletons and geminates was significantly higher in the intervocalic than in the preconsonantal environment ($F(1,4) = 11.052$, $p < 0.05$; eta-squared = 734).

Perception

Figure 3.2 demonstrates the results of the perceptual experiment, averaged across participants and plotted as a percentage of "long" responses on the y-axis against the stimulus duration (19 steps) on the x-axis.

Statistical analysis showed that the parameters of the individual identification functions in the intervocalic and the preconsonantal condition did not differ significantly neither in terms of the steepness of the slopes (β coefficients) nor in terms of the perceptual boundary (Median level). As figure 3.2 shows, the two average curves appear equal in steepness and are not displaced with respect to each other along the duration scale (they overlap).

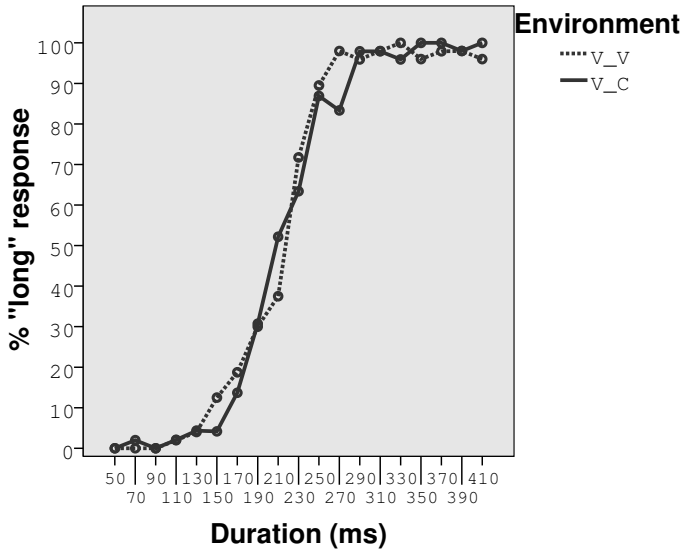

Figure 3.2: Perception of consonants in intervocalic and preconsonantal environment by Russian participants.

Perception and Production

Joint analysis of the category boundaries in perception and production showed that the boundary was on average lower in perception than in production (a significant effect of Modality) but the difference was much less pronounced in the preconsonantal environment (a significant interaction between Modality and Environment). The effect of Environment is due to the fact that the category boundary was on average higher in the intervocalic than in the preconsonantal condition.

Statistical effects are summarized in table 3.8. Figure 3.3 illustrates the interaction between the two factors. Mean values for the category boundaries are shown in Table 3.9.

	F	p	eta-squared
Environment	$F(1,28) = 6.118$	< 0.05	0.179
Modality	$F(1,28) = 166.518$	< 0.01	0.228
Interaction	$F(1,28) = 7.005$	< 0.05	0.200

Table 3.8: Effect of Environment and Modality on category boundary in Russian.

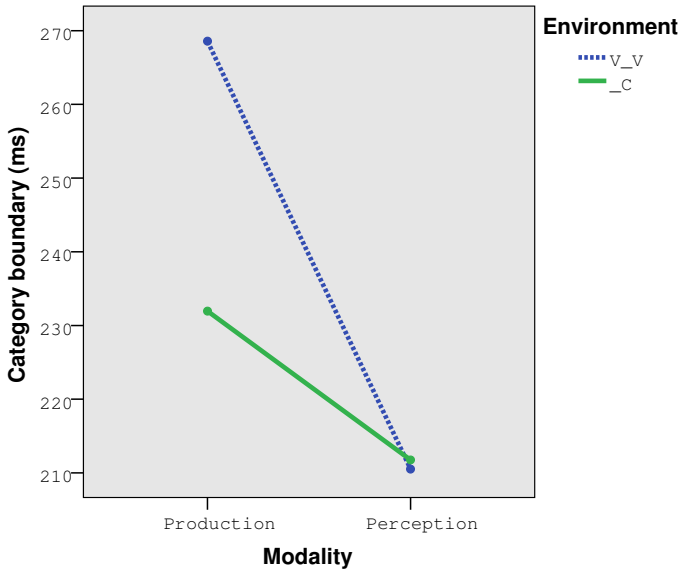

Figure 3.3: Perception and production category boundary in intervocalic and preconsonantal environment in Russian.

	Intervocalic (ms)	Preconsonantal (ms)	Average
Production	269	231	250 (SD 12)
Perception	211	212	211 (SD 6)

Table 3.9: Category boundary in intervocalic and preconsonantal environment in Russian.

	F	p	eta-squared
Geminacy	$F(1,4) = 105.647$	< 0.01	0.964
Position	no effect		
Interaction	no interaction		

Table 3.10: Effect of Position and Geminacy on consonant duration in Russian.

3.4.3 The effect of position: word-initial vs. word-final

Production

Word-initial singletons and particulary geminates were on average longer than word-final ones (a 19 ms difference) although this difference did not reach significance.

Figure 3.4 shows that the difference between singletons and geminates was somewhat greater in the word-initial position although this effect did not reach significance as an interaction. Statistical effects are summarized in table 3.10. Table 3.11 shows the mean duration of geminates and singletons in the word-initial and the word-final positions and the corresponding geminate/singleton ratios.

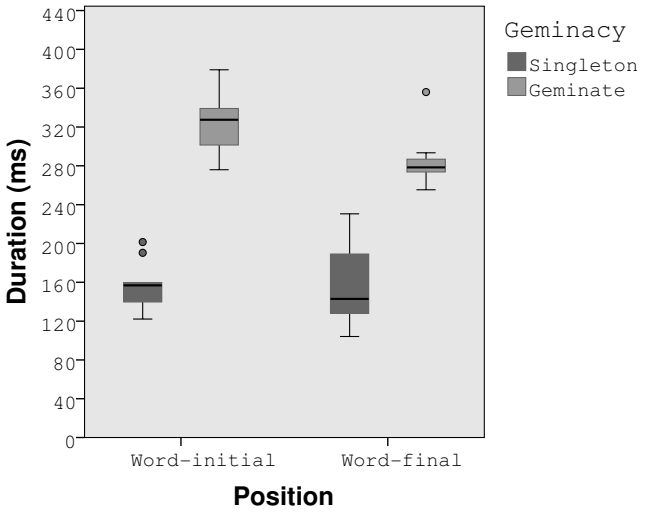

Figure 3.4: Duration of Russian consonants in word-initial and word-final position.

	Geminates (ms)	Singleton (ms)	G/S ratio
Word-initial	323	158	2
Word-final	285	156	1.83

Table 3.11: Geminate and singleton durations and their ratios in word-initial and word-final position in Russian.

The boundary between singletons and geminates was on average greater in the word-initial position than in the word-final one, and this difference came out as a non-significant trend ($p = 0.66$) in the statistical analysis.

Perception

Participants' responses in the perceptual experiment are shown in figure 3.5.

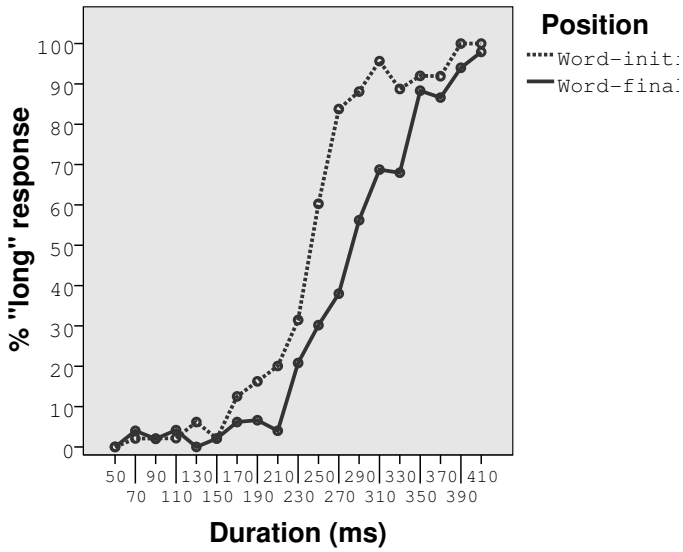

Figure 3.5: Perception of consonants in word-initial and word-final position by Russian participants.

We can see that the average identification curve was somewhat steeper in the word-initial condition. The mean values of the β coefficients were also indicative

of a higher average slope in the word-initial condition but this effect did not reach significance.

The category boundary in perception was significantly *lower* for the word-initial than the word-final consonants ($F(1,4) = 11.812$, $p < 0.01$, eta-squared $= 0.33$), an effect that we can see in figure 3.5 as a displacement of the word-initial identification curve towards the lower end of the durational scale.

Production and perception

Although the word-initial consonants were (non-significantly) longer than the word-final ones, and a category boundary in production was (non-significantly) higher for the word-initial than the word-final consonants, the category boundary in perception was significantly *lower* for the word-initial than the word-final consonants. This asymmetry resulted in a significant interaction between Modality and Position, illustrated in figure 3.6. Statistical effects of this analysis are summarized in table 3.12.

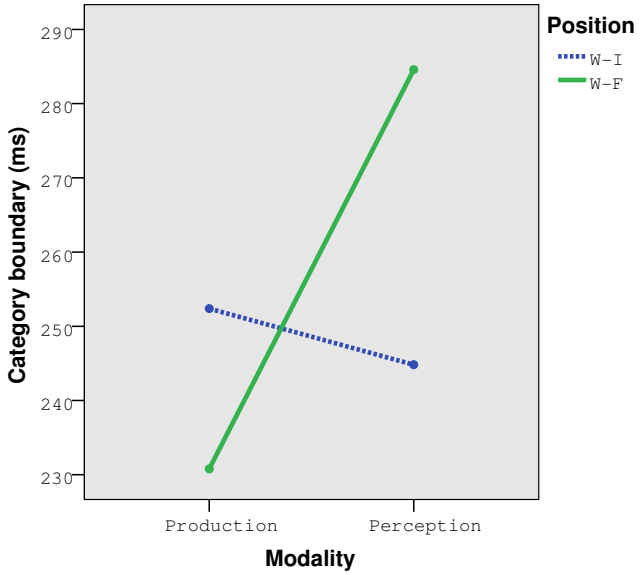

Figure 3.6: Perception and production category boundary in word-initial and word-final positions in Russian.

	F	p	eta-squared
Position	no effect		
Modality	no effect		
Interaction	$F(1, 28) = 5.371$	< 0.05	0.161

Table 3.12: Effects of Position and Modality on category boundary in Russian.

3.4.4 The Effect of stress: following stress, preceding stress, or no stress

Production

Geminate and singleton consonants were longer in the *following stress* condition than in the other two stress related conditions. The difference between geminates and singletons was somewhat less pronounced in the following stress position (a ratio of 2.1) but this effect did not reach significance as a Geminacy-Stress interaction. Figure 3.7 illustrates these results. Statistical effects are summarized in table 3.13. Mean duration values are given in table 3.14.

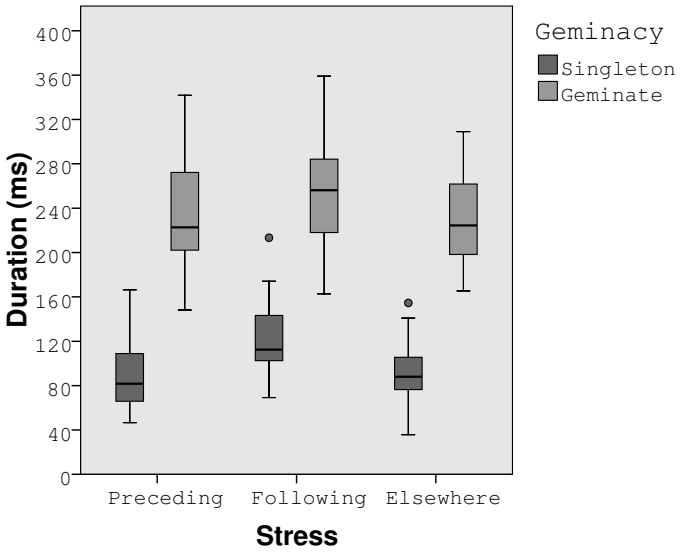

Figure 3.7: Duration of Russian consonants in three stress positions.

	F	p	eta-squared
Stress	$F(2,8) = 10.996$	< 0.01	0.733
Geminacy	$F(1,4) = 164.994$	< 0.001	0.976
Interaction	no interaction		

Table 3.13: Effect of Stress and Geminacy on consonant duration in Russian.

Stress	Geminates (ms)	Singleton (ms)	G/S ratio
Preceding	235	90	2.6
Following	256	121	2.1
No stress	232	91	2.55

Table 3.14: Geminate and singleton durations and their ratios in three stress positions in Russian.

The boundary between geminates and singletons was also significantly higher in the *following stress* condition($F(2,8) = 15.074$, $p < 0.01$, eta-squared $= 0.79$) reflecting the greater consonant duration in this condition.

Perception

Participants' identification of the stimuli in the three stress conditions is shown in figure 3.8. We can see a small displacement of the curves along the duration axis but no pronounced difference in terms of the steepness of the slope.

Analysis of the transformed β coefficients showed that the steepness of the identification curves was not affected by the stress factor.

Analysis of the perceptual boundary location showed that all three conditions differed from each other significantly in terms of the location of the category boundary ($F(2,48) = 11.798$, $p < 0.001$; eta-squared $= 0.33$): consonants in the following stress condition had the highest boundary, followed by the consonants in the no stress condition, which were followed by the consonants in the preceding stress condition (the average identification curves in figure 3.8 are ordered in exactly this way).

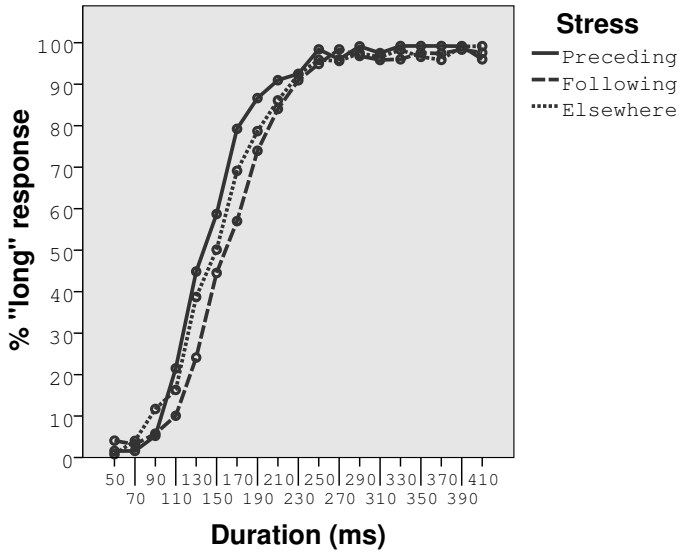

Figure 3.8: Perception of consonants in three stress positions by Russian participants.

Production and perception

Consonants were the longest when followed by stress; consequently, the production boundary between short and long consonants was the highest in this condition as well. The perception boundary reflected this fact as well - the boundary was the highest in the following stress condition.

Consonants preceded by stress and not-stress adjacent consonants did not differ in average duration and in terms of the category boundary in production. There was, however, a difference between these two in terms of the category boundary in perception: the boundary was lower in the preceding stress condition (listeners switched to “geminate” perception at a shorter duration in this condition than in the no stress condition). This difference resulted in a non-significant trend for the Modality-Stress interaction, as shown in table 3.15 and illustrated by the figure 3.9.

The effect of Stress in this analysis is due to the fact that category boundaries in the following stress condition were consistently the highest in both production and perception (pairwise comparisons showed that an average boundary in this condition was significantly higher than in the other two conditions).

	F	p	eta-squared
Stress	F(2,56) = 15.698	< 0.001	0.359
Modality		$p = 0.09$	
Interaction		$p = 0.096$	

Table 3.15: Effect of Stress and Modality on category boundary in Russian.

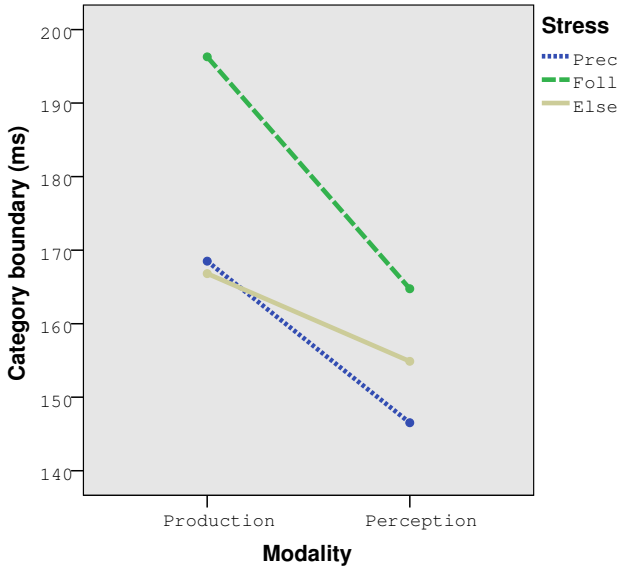

Figure 3.9: Perception and production category boundary in three stress positions in Russian.

3.4.5 The effect of manner of articulation

Production

Analysis of duration showed that fricatives and voiceless stops produced by speakers of Russian were significantly longer than voiced stops, nasals, and liquids. There were no significant differences within each of the two groups. These differences are illustrated in figure 3.10.

Table 3.16 shows the average singleton and geminate consonant durations and their ratios for different consonantal manners. The difference between geminates and singletons quantified in terms of the durational ratio showed the following pattern: $s > l > d > n > t$, although this difference was not significant as a Geminacy-Manner interaction. Statistical effects of this analysis are summarized in table 3.17.

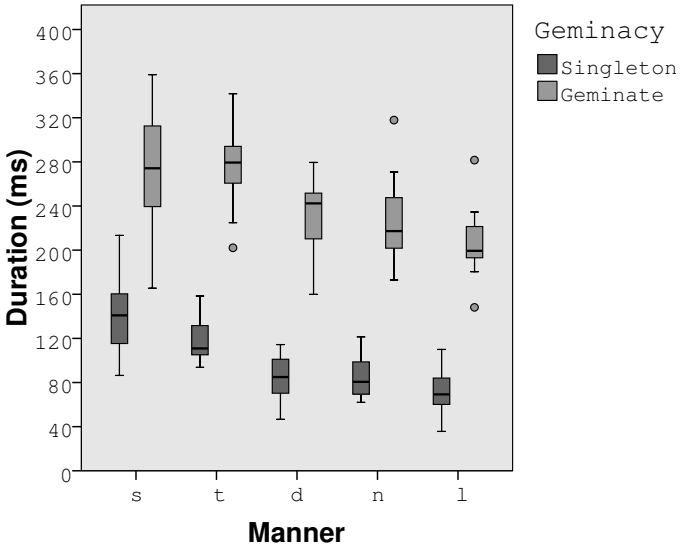

Figure 3.10: Duration of Russian consonants of different manners of articulation.

The boundary between singletons and geminates was significantly higher for voiceless stops and fricatives ([s] and [t]) than for voiced stops, nasals, and liquids ([d], [n], [l]), without any significant differences within each group: $F(4, 16) = 24.583$, $p < 0.001$; eta-squared = 0.86.

Consonant	Geminates (ms)	Singleton (ms)	G/S ratio
s	270	140	1.93
t	275	118.5	2.32
d	230	84	2.73
l	207	74	2.80
n	225	86	2.62

Table 3.16: Geminate and singleton durations and their ratios for consonants of different manners of articulation in Russian.

	F	p	eta-squared
Manner	$F(4, 16) = 26.734$	< 0.001	0.870
Geminacy	$F(1, 4) = 165.626$	< 0.001	0.976
Interaction	no interaction		

Table 3.17: Effect of Manner and Geminacy on consonant duration in Russian.

Perception

Results of the perceptual experiment averaged over participants are shown in figure 3.11.

Analysis of the β coefficients showed that the identification functions were significantly steeper for [n] and [l] than for [t] and [d]; they were also steeper for [s] than for [t] ($F(2, 54) = 5.09$, $p < 0.01$; eta-squared = 0.18, with Greenhous-Geisser correction). Average transformed β coefficients are shown in the table 3.18 (due to the reciprocal transformation, lower values mean greater steepness of the curve).

Location of the perceptual boundary differed significantly between manners ($F(4, 92) = 43.167$, $p < 0.001$; eta-squared = 0.652): the order roughly followed the pattern of the boundaries in production : [s] and [t] having higher boundaries than [d], [n], and [l].

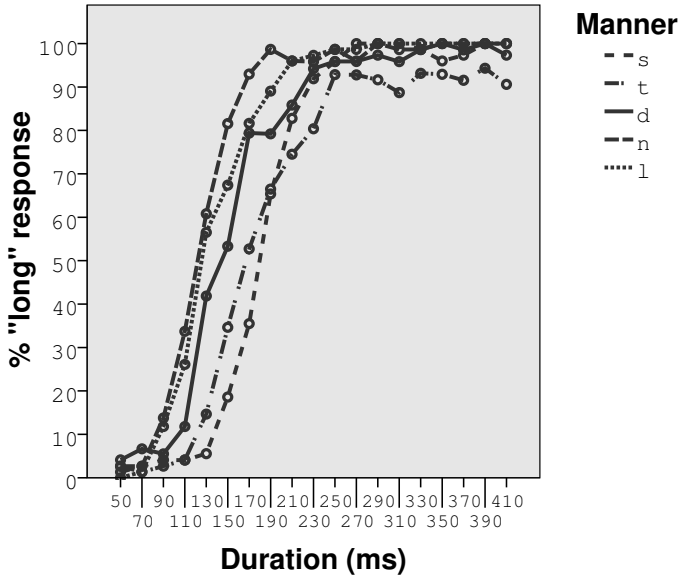

Figure 3.11: Perception of consonants of different manners of articulation by Russian participants.

	Transformed β coefficient	Standard deviation (ms)
s	17	19
t	29	27
d	20.5	12.5
n	14	12
l	14	9

Table 3.18: Mean β coefficients for consonants of different manners of articulation in Russian

	F	p	eta-squared
Manner	$F(4, 108) = 35.011$	< 0.001	0.565
Modality	$F(1, 27) = 4.088$	$= 0.053$	0.131
Interaction	no interaction		

Table 3.19: Effect of Geminacy and Manner on consonant duration in Russian.

Production and Perception

Statistical effects of this analysis are summarized in table 3.19. Effect of Manner is due to the fact that both perception and production boundaries decreased in values from [s, t] to [d, n, l]. The effect of Modality is due to the fact that for all manners boundary was consistently lower in perception than in production.

3.5 Conclusion

The results of the investigation of consonantal duration in production followed the patterns indicated in the previous literature: consonants were on average longer between two vowels than in adjacency to other consonant, demonstrating an effect of shortening in clusters (Davidson and Roon, 2008; Zlatoustova, 1962). Durations of the word-medial and peripheral consonants were not directly compared in this experiment, but a comparison of the word-initial and word-final consonants showed that these two were not significantly different. There was a non-significant increase in duration in the word-initial position, which lends some support to the speculations based on the results of Kochetov (2006) that word-initial lengthening in Russian may be more pronounced than word-final lengthening.

Consonants were also, unsurprisingly, longer in the onsets of the stressed syllables (in the following stress condition) and did not differ in duration between the preceding stress and the no stress condition. This finding goes against the expectation of the Allophonic duration hypothesis. The Allophonic duration hypothesis states that geminacy in the *post-stress* environment is conditioned by the lengthening effect of

stress. However, singleton consonants *preceded by stress* are syllabified as onsets of the following, *unstressed* syllables, and, if the augmenting effect of stress is bounded by the domain of the syllable, their duration is not predicted to be affected by stress, as was shown by this experiment. These consonants are in fact as short as consonants not adjacent to stressed vowels on either side.

Finally, voiceless obstruents, fricatives and stops, were shown to be longer than voiced stops and sonorants, liquids and nasals - a manner-based durational difference that is quite universal across languages.

The Ratio Hypothesis predicts that the amount of the durational difference between geminates and singletons will be *greater* in contexts that demonstrate a higher incidence of geminate-singleton contrasts crosslinguistically. This prediction was partly supported for some of the environments considered. In particular, the geminate-singleton durational difference was significantly greater in the intervocalic than in the preconsonantal contrasts, as predicted. A greater duration distinction was also found in the word-initial contrasts than in the word-final contrasts but it was not significant. Thus, the support for the Ratio hypothesis was quite modest based on the results of the Russian experiments. Another question that remains to be answered is whether the direction of the increase in the durational difference is the same across languages (e.g., geminate/singleton ratio always being higher for the intervocalic than for the preconsonantal contrasts).

Even in the absence of such a powerful perceptual cue to the geminate-singleton contrast as an increased difference in duration, evidence was revealed that the perceptibility of the contrast differed across contextual environments. The direction of the difference was typically in the expected direction: lower for contexts where geminate-singleton contrasts are avoided crosslinguistically. Thus, the Perceptual Hypothesis, which states that a decreased perceptual distinctiveness leads to the lower frequency of the geminate-singleton contrasts in certain contextual environments, received considerable support in this investigation.

The Perceptual Hypothesis predicts that contrast distinctiveness will be lower for the consonant-adjacent than the intervocalic geminate-singleton contrasts and this was supported by this experiment. There was a significant singleton bias in the

perception of consonant length in the preconsonantal environment, which shows that listener preferred to categorize consonants as "short" in this environment. A proposed source of this effect is a higher degree of uncertainty about the category membership triggered by a lower perceptual contrast distinctiveness, which in turn results from the relative difficulties in identifying the boundaries — the beginning and the end-points of the target consonants, the length of which is being evaluated.

It is more difficult for the listeners to pin-point the moment in time when one consonant ends and another begins, while it is relatively easier to do this for the transition between a consonant and a vowel. Thus, consonant-adjacent segments suffer from a "fuzzy boundary" effect. Not being able to tell reliably the boundaries of the segment complicates the estimating of its duration and makes more difficult the decision concerning the category membership (short or long) of this consonant, especially when the duration of the consonant is ambiguous (not extremely short or extremely long).

There were no differences however between the two environments in terms of the steepness of the curve. A possible explanation is that the two conditions chosen, intervocalic vs. C+nasal/C+liquid, do not provide a great enough perceptual difference. If the comparison was between an intervocalic and a C+obstruent conditions, the difference in terms of the contrast distinctiveness might have revealed itself not only as a singleton bias in the preconsonantal environment but also as a difference in the steepness of the curves.

A singleton bias was also detected in the perception of length in the word-final position compared to the word-initial position. The conditioning factor of this effect is less clear. While it is possible that some acoustic factor differentiates between the word-final and the word-initial contrasts, another possibility is that a higher psycholinguistic salience of the word-initial position is what triggers the effect. Simply, listeners pay more attention to the word-initial segments and thus are better able to detect small acoustic differences, including those of duration.

The steepness of the identification curve appeared to be higher for the word-initial contrasts, clearly visible on the graph of the average identification functions and visible as a quantitative difference in terms of the average β coefficients. The

fact that this difference did not reach significance may also be attributed to the nature of the experimental stimuli. Both word-initial and word-final consonants in this experiment were either preceded or followed by a vowel-initial/final word: *po savap - pas avap*. This has made the comparison between the two conditions more acoustically equivalent, as well as approximated the natural setting where words typically appear in contexts. On the other hand, this design may have worked in the direction of minimizing the effect. Even though a short pause was inserted between the two words, participants still could and most likely did use the end-point of the neighboring vowel as a perceptual anchor in evaluating the approximate duration of the following/preceding word-initial or word-final consonant. Thus, the task was somewhat simplified compared to the scenario where participants would be presented with *absolute* word-initial and word-final contrasts. In such a design, I would expect a more dramatic difference between intervocalic and peripheral contrasts in terms of the perceptibility of the distinction, as well as, possibly, a more dramatic difference between the word-initial and the word-final contrasts. A significant difference in terms of the steepness of the curves would potentially be one of the indications of a more pronounced perceptual difference.

Differences in terms of distinctiveness between contrasts across various stress positions were modest at best. Only a near-significant trend was detected that pointed in the direction of a relative singleton bias in the non-stress adjacent condition compared to the preceding stress condition. Thus, the results of the Russian experiment were inconclusive and the evaluation of this factor is postponed until the experimental data and typological data from other language groups are considered.

Comparisons across different manners of articulation did show a significant difference in terms of the contrast distinctiveness, indicated by the effect on the steepness of the slopes. Surprisingly, the effect was not in the expected direction. Podesva (2000, 2002) and Kawahara (2006, 2007) argue, on perceptual grounds, for the inferiority of the durational contrast in sonorants. This experiment, however, showed that listeners were better able to categorize nasal and liquid consonants into short and long than voiced and voiceless stops. Voiceless fricatives also fared better than voiceless stops. Relative frequencies of occurrence of geminate consonants of different

manners may have something to do with this pattern. As mentioned above, nasals are extremely frequent geminates in Russian, followed by [s] and [l], which do better frequency-wise that the rest of the consonantal inventory. These most frequently geminating consonants in Russian demonstrate the highest degree of perceptual contrast distinctiveness.

Another statistical effect that deserves a mention is the general tendency for perceptual boundaries to be lower than boundaries in production (a Modality effect). I am not aware of any other study that uses this kind of comparison, thus it is possible that this difference is simply a methodological artifact - a general property of the comparison between boundaries determined by discriminant analysis in production and those determined by logistic regression in perception. However, if this was the case, the effect would presumably be parallel for all conditions. That is, a tendency for boundaries to be lower in perception would be of the same magnitude across different contextual environments. The magnitude was not the same, however, resulting in Modality-Condition interactions (interpreted as a relative singleton-geminate bias).

An alternative explanation is that this effect is a manifestation of an overall "geminate bias" in the perception of length. It appears, that Russian listeners categorized stimuli as geminates in all conditions more readily than was predicted by the production data. A category boundary in production indicates a point of maximum separation between the two clouds of data. The expectation is that only after this point had been surpassed would listeners start categorizing stimuli as "long". However, this perceptual switch happened earlier in most contexts, although the effect was more pronounced for some of them. A possible cause of this effect is the fact that stimuli for the perceptual experiment were constructed using naturally recorded words where the target consonant was a *geminate*. That is, to induce a perception of a singleton the target consonants were *shortened*, as opposed to lengthening original singletons. It is possible, and in fact very likely, that certain acoustic properties of the stimuli prepared in this fashion biased the listeners towards the perception of geminates. One of such clues is contained in the duration of the vowel that preceded the target consonant, which has been shown to affect the perception of consonant length (Pickett et al., 1999). A similar effect was reported by Lisker (1985) who observed

in an experiment with a similar design that a speaker of Marathi while listening to Marathi words, placed a boundary between the geminate and the singleton consonants between 140 and 160 ms for the stimuli based on original singleton, and between 120 and 140 ms for the stimuli based on the original geminate. Five native speakers of American English in the same experiment placed the boundary in the same location for both sets of stimuli. These results show, as in the experiment reported here, that geminate bias in perception results from attending to stimuli that were created using words with geminates, and that only native speakers of the language are sensitive to this difference.

In a later study, Hankamer et al. (1989) demonstrated the same effect for the speakers of Turkish and Bengali: both groups switched to the perception of geminate consonants at a shorter duration of the stimulus (about 8 ms difference) if the target consonants were originally geminates as opposed to singletons.

Interestingly, this general "geminate bias" of the present experiment was not as strong for the word-edge contrasts (in fact it was reversed word-finally) as for the medial, intervocalic/preconsonantal contrasts. It is possible that the contrast in both word-initial and word-final position was less well-defined perceptually than in the intervocalic and preconsonantal environments, causing higher levels of uncertainty in the listeners reflected in the preference for the "singleton" label in perception. Since word-medial and word-edge consonants were not directly compared in this experiment, a statistical significance of this difference remains to be verified.

To conclude, the results of the acoustic and perceptual investigation of consonant duration contrast in Russian demonstrated that the perceptual distinctiveness of the contrast was *lower* in the preconsonantal than the intervocalic position; in the word-final than the word-initial position; in in voiced and voiceless stops than in nasal, liquid, and fricative consonants. Stress did not have a significant effect on the distinctiveness of the durational contrast in Russian. These findings lend support to the view that geminate-singleton contrasts are avoided in adjacency to other consonants and word-finally due to the lower perceptual distinctiveness of the contrast in these positions. The role of stress and consonantal manner in shaping the typology of the geminate-singleton contrasts does not appear to be distinctiveness-related based on

the results of this investigation.

Chapter 4

Experiment 2: American English

4.1 Overview

This chapter starts with a brief overview of the relevant production and perception studies that address consonant length in English. Experimental results are reported in section 4.4, section 4.5 offers some concluding remarks.

4.2 Consonant length in English

Consonant length in English is not phonemic, although it has a number of important linguistic functions. Phonetic lengthening of consonant corresponding to the positional combination of identical segments on the boundaries of morphemes and words has been reported in English: e.g., *nighttime, unknown, white tie, the race sends* (Bailey, 1983; Delattre, 1968; Kaye, 2005). Hughes and Trudgill (1979) report that in Pontypridd, South Wales, intervocalic consonant are lengthened if the preceding vowel is stressed, as in *city* [ˈsɪtti]. This effect is in all likelihood due to Celtic influence: according to Fynes-Clinton (1913) and Koch (1989), in Welsh consonants [p t k m] can variably occur as geminates in the intervocalic post-stress position.

Perception of consonant length by speakers of English (which would indicate, for example, the difference between *the topic* vs. *the top pick*) has been examined in a number of studies (Pickett and Decker, 1960; Repp, 1978) which report a perceptual

boundary between short and long consonants in the intervocalic environment at about 200 ms. In general, speakers of English were found to be able to detect a durational difference of about 20-25 ms: Just Noticeable Difference or JND (Huggins, 1972; Klatt and Cooper, 1975; Pisoni, 1977). Thus, differences below this limit were hypothesized to play only a minor role in perception (Klatt, 1976).

Huggins (1972) also reported that listeners were most tolerant to duration increases in word-initial consonants. The longest duration was also required in some conditions for the word-initial consonants to be noticeable. Another interesting effect observed in this study is that the perceived sentence stress shifted towards the words where the initial consonant was lengthened.

Klatt and Cooper (1975) report that a JND was smallest in their study for vowels and fricatives in the first syllable of disyllabic words. They also observed that participants had difficulty locating the offset of the frication noise unless it was followed by an abrupt voicing onset.

Some relevant conclusions that can be drawn from the results of these studies are the following. Speakers of English are able to detect changes in the segments' duration despite the fact that this feature is not contrastive in their language. They can complete tasks that involve categorization of the segments as "short" or "long". Some results concerning response to durational changes as a function of the contextual environment suggest that lengthening word-initially and under stress is a phenomenon expected by the listeners (Huggins, 1972). There is also some evidence that listeners may be more sensitive to durational changes in the initial portion of the word than in the subsequent ones (Klatt and Cooper, 1975) and that certain kinds of segments (e.g., vowels and fricatives) may condition a better response to the changes in duration. At the same time, there is an indication that final fricatives may present a particular challenge for perception of duration (Klatt and Cooper, 1975).

4.3 Prosodic effects on consonant duration in English

Factors such as prosodic boundaries and prominence have been reported to affect segmental duration in English in a systematic way. Lengthening at the edges of prosodic constituents, including domain-initial and domain-final lengthening, has been reported in numerous studies, although phrase-initial and phrase-final durational modifications appear to be somewhat better documented than word-edge related phenomena. Word-initial and word-final lengthening has been reported by Klatt (1975); Oller (1973); Umeda (1975) and more recently by Beckman and Edwards (1990); Byrd (1993); Fougeron and Keating (1997); Nakatani et al. (1981); Turk and White (1999) and Turk and Shattuck-Hufnagel (2000). Word-initial lengthening in particular was reported in Oller (1973) (consonants), Nakatani et al. (1981) (syllables), Byrd (1993) (nasals), Turk and White (1999) (consonants), Fougeron and Keating (1997) (articulatory and durational effects on nasals), Turk and Shattuck-Hufnagel (2000) (consonants). Word-final lengthening was reported in Oller (1973) (consonants), Nakatani et al. (1981) (syllables), Beckman and Edwards (1990) (vowels), Byrd (1993) (nasals), Turk and White (1999) (syllables), Fougeron and Keating (1997) (articulatory and durational effects on vowels). These studies suggest that word-initial lengthening affects mainly consonants while word-final lengthening can be realized on vowels and full syllables, as well as consonants.

Another factor affecting segmental duration in English is stress-related augmentation of duration. Results in this area are relatively consistent: they all point towards durational enhancement of consonants in the onsets of stressed syllables as opposed to the post-stress and non-stress adjacent consonants.

Longer consonant duration in the pre-stress position for English was reported in Cho and Keating (2009); Klatt (1974); Oller (1973); Turk (1992); Umeda (1975); van Son and van Santen (2005). An observed increase in duration varied between 10-30 ms.

For example, Turk (1992) showed that stops of all manners of articulation in American English were longer in the pre-stress position than in the post-stress and

unstressed positions, the latter two not differing from each other. The increase in duration was about 20-30 ms on average, except alveolar consonants where the difference was exaggerated due to flapping in non pre-stress environments and reached around 50-70 ms. Turk (1992) also established that voiced stops increased their duration in the onsets of stressed syllables primarily through the increase in the closure duration while voiceless stops relied on the increase in the duration of aspiration.

Phonetic environment has also been shown to have an effect on segmental duration. Haggard (1973) and Klatt (1973) report that consonants decrease in duration when in clusters.

Thus, the results of these studies indicate that in English consonant shortening applies in clusters, while consonant lengthening happens in the onsets of stressed syllables and at the edges of words: word-initially and word-finally. In the latter case, it is not clear, however, whether the degree of lengthening is higher in the word-initial or the word-final position.

4.4 Results

4.4.1 Summary

First, a brief summary of the findings resulting from the statistical analysis of the perception and production data gathered from the speakers of American English is presented. The speakers of English were not asked to produce words with geminate consonants. This limits the possible analyses somewhat. Since there are no data on the geminate consonants, Discriminant Analysis is not possible. Therefore, a category boundary in production cannot be determined and compared to the category boundary in perception. Thus, the possibility of *singleton bias* can be identified only on a speculative basis. However, based on the results of the Russian experiment it seem fairly plausible that (a) durational increase during gemination is fairly proportionate to the average singleton duration. That is, if a singleton is longer due to prosodic reasons, a geminate in this position will be longer as well. And, (b) the category boundary in production consistently corresponds to the distribution of the durational

values: that is, if both geminates and singletons are longer, the category boundary will be greater.

Based on these two observations, it is reasonable to assume that those consonants that are longer in production as singletons would correspond to a category boundary at a greater duration in production, even though this boundary cannot be determined due to the lack of production data on geminates. Thus, it is possible to make an informal evaluation of the collected data and make a reasonable prediction as to where the singleton bias would have been observed if data on geminates were available. The tables in this section present this information as an informal conclusion based on the available data.

The comparison between the intervocalic and preconsonantal contrasts revealed that there was a non-significant trend for the curves to be steeper in the intervocalic environment that in the preconsonantal one. This suggests that contrast distinctiveness is somewhat lower in the preconsonantal condition (table 4.1).

The available data also make it possible to propose that a singleton bias is likely in the preconsonantal environment. Consonants were shorter in the preconsonantal condition than the intervocalic consonants. As figure 4.1 shows, this allows us to project that on average geminates would also be shorter in the preconsonantal condition. Consequently, the category boundary in production would accommodate for this difference and appear at a smaller durational value for the preconsonantal stimuli. However, figure 4.1 also shows that the category boundary *in perception* does not reflect differences in production, appearing in the same location for both intervocalic and preconsonantal conditions. We can see that in the preconsonantal environment the perceptual boundary is shifted in the direction of the geminate with respect to the presumed category boundary in production. This shows that the listeners were reluctant to label the target consonants as "long" despite the fact that durationally the perceived stimuli already crossed over into the that area where the consonants in production would be intended geminates. In other words, in their identification they stuck to the singleton label longer than was justified by the available and projected production data

The comparison between the word-initial and word-final positions showed that the

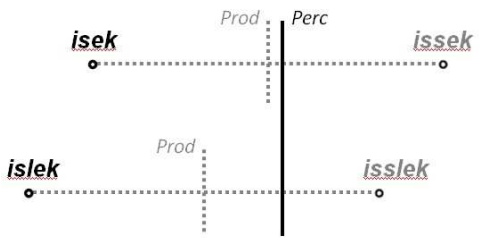

Figure 4.1: Possible singleton bias.

PARAMETER	DIRECTION	SIGNIFICANCE	EXPECTATION
Steepness	V_V > _C	non sign.	As expected
Singleton bias	_C	N/A	As expected

Table 4.1: Effect of Environment: English.

contrast distinctiveness is likely to be lower in the word-final position for the speakers of American English. As table 4.2 shows, there was a non-significant trend for the slopes of the identification functions to be steeper in the word-initial position. The available data also allow us to predict that a singleton bias is likely in the word-final position (word-final consonants were non-significantly *shorter* than the word-initial ones, but perceived as geminates at a significantly *greater* duration).

The comparison of the preceding stress, following stress, and no stress conditions suggested the presence of a singleton bias in the non-stress adjacent position (non-stress adjacent consonants were shorter than than the other two types, but they were perceived as geminates at a significantly greater durational value).

Analysis	DIRECTION	SIGNIFICANCE	EXPECTATION
Steepness	W-I > W-F	non-sign.	Against
Singleton bias	W-F	N/A	Against

Table 4.2: Effect of Position: English.

Analysis	DIRECTION	SIGNIFICANCE	EXPECTATION
Steepness	no difference	—	—
Singleton bias	V_V	N/A	As expected

Table 4.3: Effect of Stress: English.

Analysis	DIRECTION	SIGNIFICANCE	EXPECTATION
Steepness	[n,l] > [t,d] [s] > [t]	*	Against: [t, s] > [d, n, l]
Singleton bias	[d], [t]	N/A	Against

Table 4.4: Effect of Manner: English.

The comparison of the consonants of different manners of articulation revealed that the contrast distinctiveness was highest for [n], [l], and [s] based on the analysis of the steepness of the curves. In addition, a singleton bias can be predicted, on the basis of the available data, for [t] compared to [s] (voiceless stops were shorter than [s] but perceived as geminates at a greater duration) and for [d] compared to [s] (voiced stops were shorter than [s] but perceived as geminates at the same greater duration).

A more detailed overview of the statistical analysis follows.

4.4.2 The effect of the immediate phonetic environment: intervocalic vs. preconsonantal

Production

The analysis of consonant duration in the intervocalic and the preconsonantal environments in English showed that the intervocalic consonants were significantly longer than the preconsonantal ones ($F(1,4) = 845.535$, $p < 0.01$, eta-squared $= 0.857$). This effect is illustrated in figure 4.2. Mean values are summarized in table 4.5.

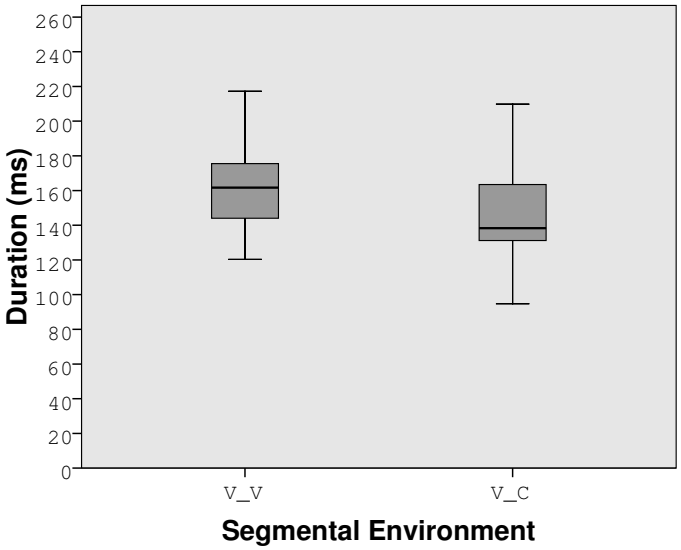

Figure 4.2: Duration of English consonants in intervocalic and preconsonantal environment.

	Duration (ms)	SD
Intervocalic	162	19
Preconsonantal	143	22

Table 4.5: Consonant duration in intervocalic and preconsonantal environment in English.

Perception

Participants' responses in the perceptual experiment are shown in figure 4.3. We can see that the two functions overlap in a manner similar to that observed for the Russian participants. Analysis of the β coefficients showed that there was a non-significant trend for the intervocalic identification curves to be steeper than the preconsonantal identification curves ($p = 0.089$).

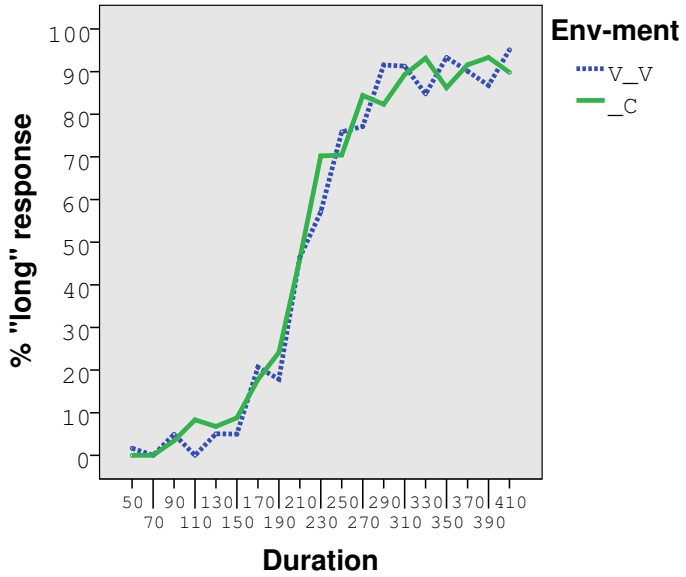

Figure 4.3: Perception of consonants in intervocalic and preconsonantal environment by American participants.

The analysis of perceptual boundary location showed that it was not affected by the segmental environment: the boundary was on average in the same location for both the intervocalic and the preconsonantal identification functions.

4.4.3 The effect of position: word-initial vs. word-final

Production

The effect of position on the duration of the consonants in English was non-significant, although there was an average difference of 15 ms in favor of the word-initial consonants. The mean durations are summarized in table 4.6 and shown in figure 4.4.

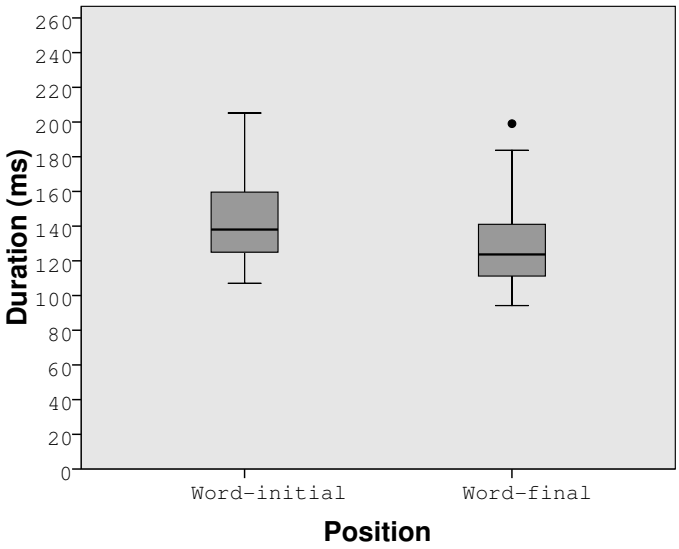

Figure 4.4: Duration of English consonants in word-initial and word-final position.

	Duration (ms)	SD (ms)
Word-initial	145.5	27
Word-final	130	21

Table 4.6: Consonant duration in word-initial and word-final position in English.

	Boundary (ms)	SD (ms)
Word-initial	246	46
Word-final	267	45

Table 4.7: Perceptual boundary in word-initial and word-final position in English.

Perception

Averaged identification curves of the English participants are shown in figure 4.5. We can see a clear separation between the two curves in the middle portion of the graph and a slight increase in steepness for the word-initial consonants.

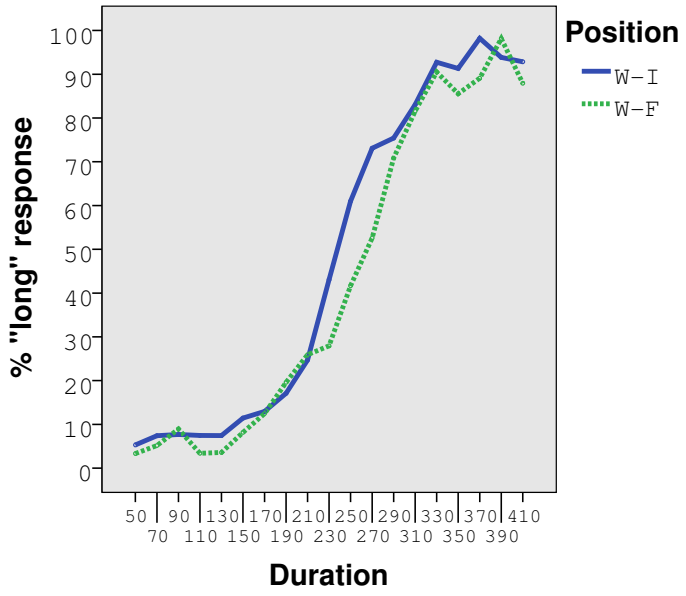

Figure 4.5: Perception of consonants in word-initial and word-final position by American participants.

Analysis of the β coefficients showed that the differences in terms of the steepness of the curves was in favor of the word-initial consonants, as suggested by the averaged curves. However, this difference was not significant.

Analysis of the perceptual boundary location revealed a significant effect of position($F(1, 27) = 6.516$, $p < 0.05$, eta-squared $= 0.194$): the perceptual boundary was

	Mean (ms)	SD (ms)
Preceding stress	76.5	10
Following stress	102	12
No stress	71	8

Table 4.8: Mean consonant duration in three stress conditions in English.

on average at a lower durational value for the word-initial consonants than for the word-final ones. The mean values are summarized in table 4.7.

4.4.4 The effect of stress: preceding stress, following stress, and no stress

Production

English consonants were significantly different in duration under the effect of stress ($F(2, 8) = 32.958, p < .001$, eta-squared $= .892$): consonants followed by stress were the longest, followed by consonants preceded by stress, which were followed by consonants between two unstressed vowels.

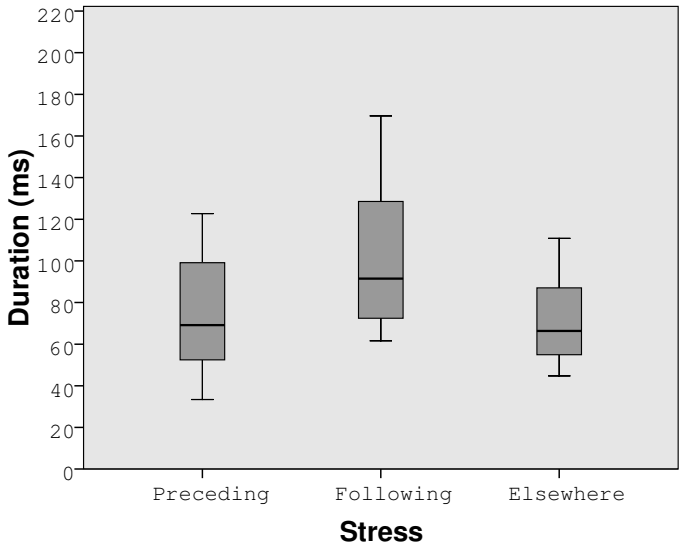

Figure 4.6: Duration of English consonants in three stress positions.

These differences are illustrated in figure 4.6. Mean durations are summarized in table 4.8.

Perception

Figure 4.7 shows the response curves averaged over participants. We can see that the three curves are separated from each other but do not show any obvious differences in terms of the steepness of the curves.

Analysis of the β coefficients as an indication of the steepness of the curves confirmed that there were no significant differences among the response functions in the three stress conditions.

Analysis of the perceptual boundary location showed that the category boundary was significantly greater in the no stress condition than in the other two conditions: $F(2, 58) = 8, 57, p < .01$, eta-squared $= .228$ (the difference between the preceding stress and the following stress condition approached significance at $p = 0.088$). The average boundary location is shown in table 4.9.

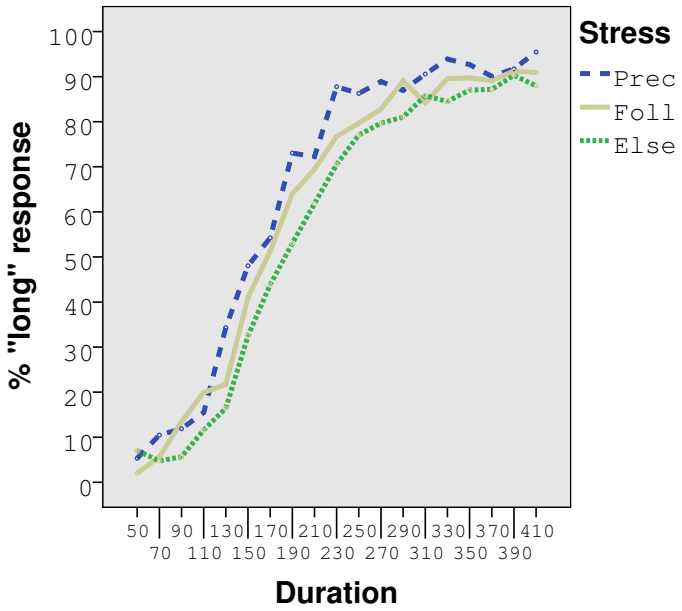

Figure 4.7: Perception of consonants in three stress positions by American participants.

	Boundary (ms)	SD (ms)
Preceding stress	171	51
Following stress	178	48
No stress	195	66

Table 4.9: Perceptual boundary in three stress conditions in English.

	Mean (ms)	SD (ms)
s	115	7.5
p	104	11
b	74	15
l	66.5	8
n	58	6

Table 4.10: Consonant duration for consonants of different manners of articulation in English.

4.4.5 The effect of manner of articulation

Production

Analysis of the consonant duration showed there was a significant effect of manner of articulation ($F(4, 16) = 59.655, p < .001$, eta-squared = .937): [s] was the longest, followed by [p], followed by [b]. Sonorants [l] and [n] demonstrated the shortest duration. Pairwise comparisons showed that all manners of articulation were significantly different from each other. These differences are illustrated in the figure 4.8. Mean durations are summarized in the table 4.10.

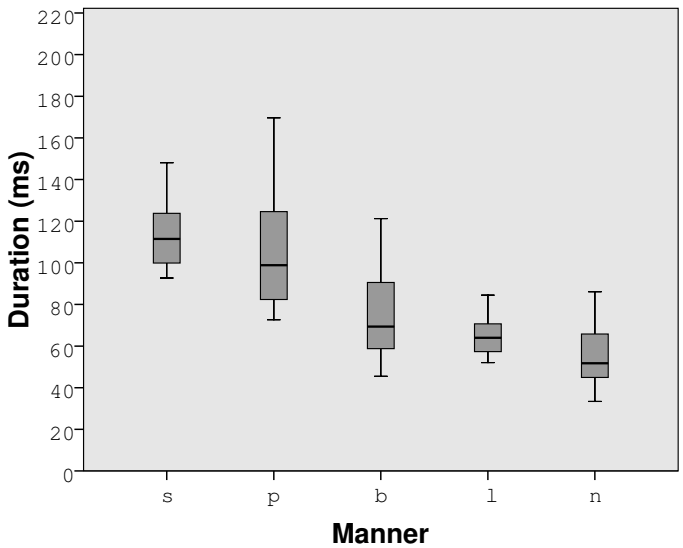

Figure 4.8: Duration of English consonants of different manners of articulation.

Perception

Figure 4.9 demonstrates the average response curves for the consonants of different manners of articulation. In addition to a separation between the curves along the duration axis we can see a pronounced difference in terms of the steepness: sonorants ([n] and [l]) and fricative [s] show the steepest cross-over between singleton and geminate categories, while voiced and voiceless stops [d] and [t]) demonstrate the most gradient, non-categorical curves.

Analysis of the β coefficients showed that the slopes were indeed the steepest for [n], [l], and [s]: the mean values are shown in the table 4.11 (lower values mean steeper slopes). The difference was significant between [s] and [t], as well as between [n], [l] and [t],[d] ($F(4, 120) = 7.255$, $p < .001$, eta-squared = .195).

Analysis of the category boundary in perception showed that the effect of manner was significant ($F(4, 84) = 43.426$, $p < .001$, eta-squared = .678). The order of the durational boundaries was the following: t > s,d, > n > l, where every > corresponds to a significant difference. The mean values are summarized in the table 4.12.

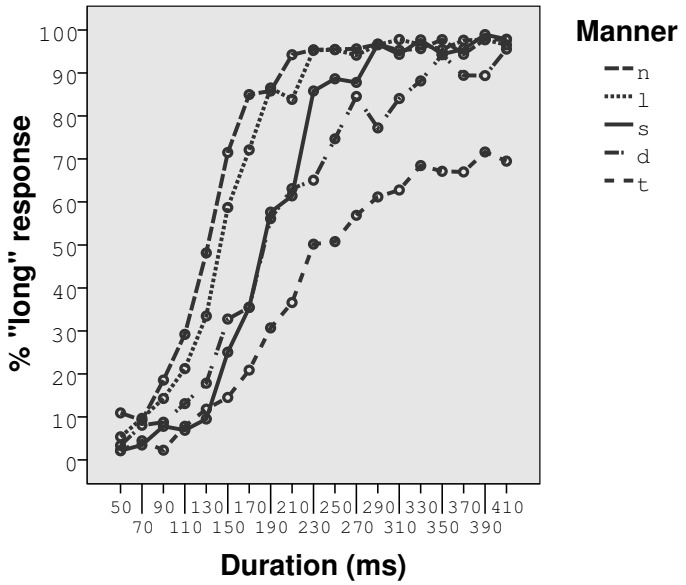

Figure 4.9: Perception of consonants of different manners of articulation by American participants.

	Mean β	SD (ms)
s	21	16
p	35	32
b	26	23
l	18	17
n	18	14

Table 4.11: Mean β coefficients for consonants of different manners of articulation in English.

	Category boundary (ms)	SD (ms)
s	191	27
t	248	70
d	182	30
n	131	22
l	146	24

Table 4.12: Mean category boundary for consonants of different manners of articulation in English.

4.5 Conclusion

Results of the analysis of the durational measurements in most respects confirmed the findings of the previous literature and followed the same pattern as the results of the Russian experiments.

Consonants were shorter when followed by another consonant as opposed to the intervocalic environment, demonstrating an effect of cluster shortening (Haggard, 1973; Klatt, 1973).

Consonants did not differ in duration between the word-initial and word-final positions, although word-initial ones, as in Russian, were non-significantly longer. Consonants were longer when in the onsets of the stressed syllables (following stress condition) than in the preceding stress or no stress condition.

Surprisingly, consonants preceded by stress were also significantly longer than those not adjacent to stress although the difference in duration was quite small - 5.5 ms. This effect suggests that a domain of stress-related duration augmentation may not be limited to stressed syllables and possibly can spread rightwards onto the onsets of the following syllables. However, the small magnitude of the durational increase means that this effect is only minimally or possibly not at all perceptually relevant (according to Huggins (1972); Klatt and Cooper (1975); Pisoni (1977) a Just Noticeable Difference in duration for speakers of English is at least 20 ms).

As in Russian, voiceless fricatives and stops were longer in American English than voiced stops, nasals, and liquids. The durational separation between the categories was better defined than in the Russian results, each manner being significantly different from other ones: $s > p > b > l > n$.

The Ratio hypothesis could not be tested on American English material since no durational data were collected for geminate consonants. The Perceptual Hypothesis could only be tested statistically as a comparison of the β coefficients of the individual identification functions. Comparison of the production data for singletons and the perceptual boundary data was also used in order to informally estimate the possibility of a singleton bias in certain contexts.

The findings relevant for the distinctiveness of the perceptual contrasts were remarkably similar to those established for the Russian participants. The differences between the β coefficients did not reach significance except for the manner of articulation condition but they were in the direction predicted by the Perceptual hypothesis, indicating a lower distinctiveness of the contrast in the consonant-adjacent and the word-final conditions. Contrary to expectations, as for Russian participants, contrast distinctiveness was lower in the perception of duration for the voiced and voiceless stops than for the voiceless fricatives, nasals, and liquids. Steepness of the slopes did not appear to be affected by stress.

A singleton bias was estimated to be likely in the consonant-adjacent, word-final, and non-stress-adjacent positions, as well as for voiced and voiceless stops.

Although, due to the limitations placed by this population of speakers on the experimental design, the statistical analysis of the results was not always possible, the overall direction of the observed differences between the contextual environments was predominantly the same as for Russian speakers. This suggests that the effects registered for speakers of Russian were also influencing the perception of duration by the speakers of English.

To conclude, the results of the experiment with speakers of English were impressively similar to those obtained in the experiment with the speakers of Russian. They suggested that the distinctiveness of the contrast was lower in the preconsonantal than in the intervocalic environment; in the word-final than in the word-initial position, in stops than in voiceless fricatives, nasals, and liquids; and (possibly) in the non-stress adjacent than in the stress-adjacent position. These findings support the view that geminates may be avoided crosslinguistically in adjacency to other consonants and in the word-final position due to the lower perceptual distinctiveness of the duration-based contrasts in these contexts.

The role of stress is still inconclusive. There may be reasons to believe that a non-stress adjacent position is less suitable perceptually for durational contrasts than stress-adjacent environments but they do not explain why the post-tonic environment in particular is favored for the geminate-singleton contrast.

The Allophonic duration hypothesis claims that a durational increase conditioned

by stress explains this preference. However, consonants *followed* by stress would be the most likely candidates for duration phonologized as gemination since these were measured as the greatest in duration for both Russian and English participants. Surprisingly, in English consonants preceded by stress also showed a small increase in duration.

Typological studies observe that sonorants, except perhaps nasals, are not likely geminates, compared to obstruents, voiceless stops in particular. The present investigation suggests that this pattern is not due to manner-based differences in the contrast distinctiveness since fricatives, nasals, and liquids consistently came out as the best in terms of the degree of perceptibility of the durational contrast .

Chapter 5

Experiment 3: Italian

5.1 Overview

In this chapter I will first provide a brief overview of the status of the geminate-singleton contrast in Italian and consider a few relevant studies addressing consonant length in Italian, as well as segmental duration as a function of prosodic factors. Section 5.4 summarizes the results of the statistical analysis. Section 5.5 provides a conclusion and discussion.

5.2 Phonemic consonant length in Italian

Italian is one of the well known languages with phonemic consonant length. In present-day standard Italian, which is based on the Tuscan dialect of Florence, any consonant can be geminated: [t d ʧ ʤ p b k g f v s m n l r]. Some are considered inherently long and do not have singleton counterparts. These include [ʃ: ʤ: ts: ʎ: ɲ:]. Voiceless fricative geminate [s:] does not have a singleton counterpart in the intervocalic position in the Northern varieties of Italian, where a singleton [s] becomes a voiced [z]. The Southern and Central varieties contrast [s] and [s:] intervocalically.

Gemination is meaning differentiating in Italian: *sete* "thirst" - *sette* "seven". Durational contrast in consonants is implemented mostly intervocalically and the majority of geminates occur in disyllabic words after stressed vowels (Borelli, 2002;

Pickett et al., 1999), although geminates can also be found before stressed vowels: *uccello* [u**ʧ:**ˈel:o] "bird" and between two unstressed vowels: *uccellino* [u**ʧ:**el:ˈino] "little bird". Geminate stops and labiodental fricatives [f] are also found before liquid consonants, as in *soffrire* "to suffer" and *applicato* "applied". The most common geminates in Italian according to Bortolini and Zampolli (1979) are [l:] and [t:] each of which accounts for 20% of all Italian geminates.

Italian inherited geminate consonants from Latin and developed additional ones through a number of phonological processes: cluster assimilation, compensatory lengthening, gemination before glides, and stress-related gemination. The latter was attested in Latin as well, where the post-tonic consonants could geminate or be protected from weakening (Loporcaro, 1997). In Italian geminates developed after primary stress as in *fémmina* "female" as well as after a secondary stress as in *àccadémia* "academy".

Besides lexical gemination Italian has assimilation-based gemination as in *tecnico* [tɛ́n:iko] "technical", false geminates at the word boundaries as in *al Lido* [al:ido] "to the Lido (beach resort)", and a famous post-lexical phonosyntactic word-initial gemination - Raddoppiamento Sintattico (RS) (Borelli, 2002). Raddoppiamento Sintattico is generally triggered by preceding words with final stressed vowels as in *cittá bella* [ʧɪttabbella] "beautiful city". A small group of words with penultimate stress, e.g., *cóme "how", dóve "where", quálche* "some" and unstressed monosyllables, such as *a* - *a Torino* "to Turin" can also trigger RS.

Dialects of Italian differ in terms of their treatment of lexical geminates as well as RS. Northern dialects of Italian lost the geminate-singleton contrast. Gemination, however, is present in most regional varieties of Standard Italian. Raddoppiamento Sintattico is absent even in the local varieties of Standard Italian in the North.

A series of acoustic studies, part of the Gemination Project (GEMMA) of the University of Rome, La Sapienza investigated durational contrasts in Italian fricatives (Giovanardi and Di Benedetto, 1998), stops (Esposito and Di Benedetto, 1999), nasals (Mattei and Di Benedetto, 2000), and affricates (Faluschi and Di Benedetto, 2001). The overall conclusion these studies arrived at is that consonant duration and preceding vowel duration are the only reliable acoustic correlates of gemination

in Italian across consonant types. A comparison of geminate/singleton ratios across consonant types revealed that nasals had the highest ratio in Italian: a 134% duration increase, compared to a 101% increase for stop geminates and a 73% increase for fricative geminates. Affricates had the smallest geminate/singleton ratio with a 62% increase in duration.

Pickett et al. (1999) focused on the effects of speaking rate on the durational contrast in Italian. They were particularly interested in identifying an invariant correlate that serves as a basis for category discrimination. They established that a ratio between the closure duration and the preceding vowel duration presented a fairly stable correlate of gemination across speaking rates. However, the same ratio could not be used for categorization in different positions with respect to stress. From the perceptual point of view, they concluded that closure duration was a primary cue to geminacy in Italian, while preceding vowel duration was an important but secondary factor.

5.3 Gemination and prosodic effects on segment duration

A number of studies looked into the quality of the geminate-singleton contrast as a function of the consonant type and contextual position and addressed the general effect of prosody and stress on segmental duration in Italian.

In terms of the degree of the durational contrast between geminates and singletons, stress-adjacent positions appeared to provide an advantage, especially the intonationally prominent post-tonic position (Payne, 2005). It has also been reported that word-medial sonorants, especially [l], had higher geminate/singleton ratios than voiceless stops and fricatives (Mattei and Di Benedetto, 2000; Payne, 2005). Voiced stops in particular may be characterized by a low geminate/singleton ratio (Payne, 2005).

Studies report that consonants in Italian tend to be longer in adjacency to stress, both when preceded and followed by stress (Farnetani and Kori, 1986; Payne, 2005).

In terms of prosodic boundary effects, Payne (2005) mentioned a weak tendency for the word-initial singletons to be longer than the word-medial ones, while Farnetani and Kori (1986) reported that word-initial consonants increased in duration only if the syllable was stressed. Syllable-final consonants were generally longer according to Farnetani and Kori (1986) although nothing can be said of word-final consonants since Italian words do not usually end in consonants.

Word-initially consonant duration appeared to undergo compression in consonant clusters. Word-medially, however, when the first component of the cluster was syllabified as an offset, it increased rather than decreased in duration (Farnetani and Kori, 1986).

Studies also reported a shorter inherent duration for sonorants in comparison to fricatives and stops (Farnetani and Kori, 1986; Payne, 2005) for both singletons and geminates.

Overall, these findings suggest that we may expect a duration increase in consonants adjacent to stressed vowels and a durational decrease in clusters. It is not clear whether word-final or word-initial lengthening will be realized by speakers of Italian and to what degree.

5.4 Results

5.4.1 Summary

In the beginning of this section I will briefly summarize the main findings of this experiment based on the statistical analysis of the production and perception data from the speakers of Italian. Italian participants did not record any geminate consonant in the prevocalic/preconsonantal conditions since these were word-initial in the Italian experiment and word-initial geminate is not found in Italian. Geminates were also not recorded by Italian participants in the word-initial/word-final conditions because no word-final or word-initial geminates are found in Italian. Thus, the Discriminant Analysis and the statistical evaluation of the perception/production asymmetries were not possible in these conditions. The suggested singleton bias in these cases is based

PARAMETER	DIRECTION	SIGNIFICANCE	EXPECTATION
Steepness	V_V > _C	*	As expected
Singleton bias	_C	N/A	As expected

Table 5.1: Effect of Environment: Italian.

Analysis	DIRECTION	SIGNIFICANCE	EXPECTATION
Steepness	W-I > W-F	*	Against
Singleton bias	none	N/A	—

Table 5.2: Effect of Position: Italian.

on the informal evaluation of the available perception and production data.

A comparison of intervocalic and preconsonantal contrasts showed that contrast distinctiveness was *lower* in the *preconsonantal* environment. Identification functions were significantly less steep for the preconsonantal targets and there were indications that a singleton bias was affecting the perception of length in the preconsonantal environment for Italian participants (table 5.1): consonants were pronounced as significantly shorter by Italians if they were followed by another consonant, however, in perception, they had a significantly *higher* category boundary than the intervocalic consonants.

A comparison between the word-initial and the word-final contrasts showed that the perceptibility of the distinction between geminates and singletons was higher in the word-initial position, as evidenced by a significantly steeper identification curves in the word-initial position (table 5.2).

The results of the analysis of the effect of Stress on the geminate-singleton contrast in Italian were somewhat unexpected. Like for Russian and English, there was no difference in terms of the steepness of the identification functions. There was, however, evidence for the singleton bias in both non-stress adjacent and, surprisingly, preceding stress condition (table 5.3). Possible causes for this effect are discussed in section 5.5.

Analysis	DIRECTION	SIGNIFICANCE	EXPECTATION
Steepness	no difference	—	—
Singleton bias	V́_,V_V	*	Against
Ratio	V́_ < _V́, V_V	*	As expected

Table 5.3: Effect of Stress: Italian.

Analysis	DIRECTION	SIGNIFICANCE	EXPECTATION
Steepness	[s,d,n,l] > [t]	*	Against:
	[s] > [d]		[t, s] > [d, n, l]
Singleton bias	[d], [t]	non-sign.	Against
Ratio	[s,n,l] > [d] > [t]	*	Against

Table 5.4: Effect of Manner: Italian.

The durational difference between geminates and singletons was especially pronounced in the preceding stress condition; a significance of this effect was confirmed by an interaction between Geminacy and Stress in the analysis of the durational measurements.

The examination of the contrast distinctiveness as a function of the manner of articulation of the consonant revealed that voiceless stops suffered a decreased perceptual distinctiveness between singletons and geminates, as demonstrated by the lowest steepness of the identification functions for this consonant. Voiced stops were the second worst after the voiceless stops. There was also a non-significant tendency for a singleton bias in the perception of length in stop consonants. The geminate/singleton ratios, on the other hand, were the lowest for [d] and [t], although a general significant interaction between Manner and Geminacy may be driven mainly by the fricative consonant and attributed to the exaggerated difference between singleton fricatives, which were voiced, and geminate fricatives, which were voiceless.

The following sections provide details of the statistical analysis.

	Duration (ms)	SD (ms)
Prevocalic	153	15
Preconsonantal	113	9

Table 5.5: Consonant duration in prevocalic and preconsonantal environment in Italian.

5.4.2 The effect of immediate segmental environment: pre- and intervocalic vs. preconsonantal

Production

Duration of Italian consonants was measured in the initial prevocalic and in the initial preconsonantal position. Only singletons were produced in this condition. Analysis of the data showed that prevocalic word-initial fricatives in Italian were significantly longer than preconsonantal word-initial fricatives: $F(1,7) = 158.605$, $p < 0.001$, eta-squared = 0.958. Figure 5.1 illustrates the difference. Mean durations are summarized in table 5.5.

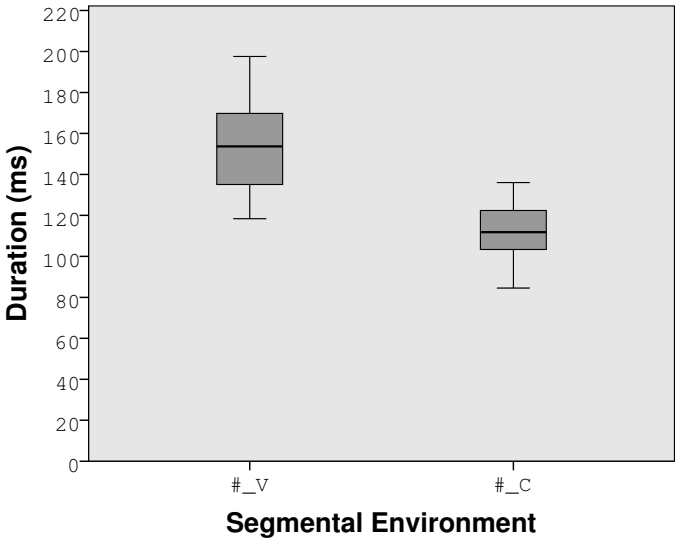

Figure 5.1: Duration of word-initial Italian consonants in prevocalic and preconsonantal environment.

	Transformed β coefficient	SD
Intervocalic	23	15
Preconsonantal	33	25

Table 5.6: Mean β coefficients for intervocalic and preconsonantal consonants in Italian.

Perception

Figure 5.2 shows average identification functions for the perception of duration by Italian participants in the intervocalic and preconsonantal environments. We can see that the curves are somewhat separated and that the intervocalic environment possibly conditions a somewhat steeper identification function.

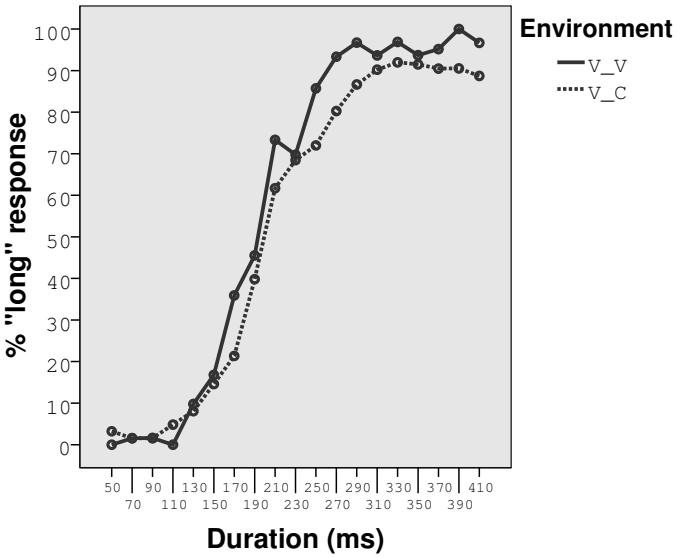

Figure 5.2: Perception of consonants in intervocalic and preconsonantal environment by Italian participants.

Analysis of the β coefficients showed that the identification functions were significantly steeper in the intervocalic environment than in the preconsonantal environment: $F(1, 31) = 6.432$, $p < 0.05$, eta-squared $= 0.172$. Mean values are summarized in table 5.6.

	Category boundary (ms)	SD (ms)
Intervocalic	198	45
Preconsonantal	217	68

Table 5.7: Perceptual category boundary in intervocalic and preconsonantal environment in Italian.

	Duration (ms)	SD (ms)
Word-initial	122	23
Word-final	133.5	37

Table 5.8: Consonant duration in word-initial and word-final position in Italian.

Analysis of the perceptual category boundary showed that it was significantly greater for the preconsonantal than the intervocalic environment: $F(1, 30) = 4.982$, $p < 0.05$, eta-squared $= 0.142$. The mean values are shown in table 5.7.

5.4.3 The effect of position in the word: word-initial vs. word-final

Production

Only singletons were recorded by Italian participants in this condition. Analysis of the durational measurements showed that there was no significant difference between the word-initial and the word-final fricative singletons in Italian, although word-final consonants were on average somewhat longer. Word-final position also conditioned more variability in segmental duration, as shown in the figure 5.3. Mean durations are summarized in table 5.8.

Perception

Average response curves are presented in figure 5.4. As we can see the identification curve for the word-initial consonants is steeper than the one for the word-final

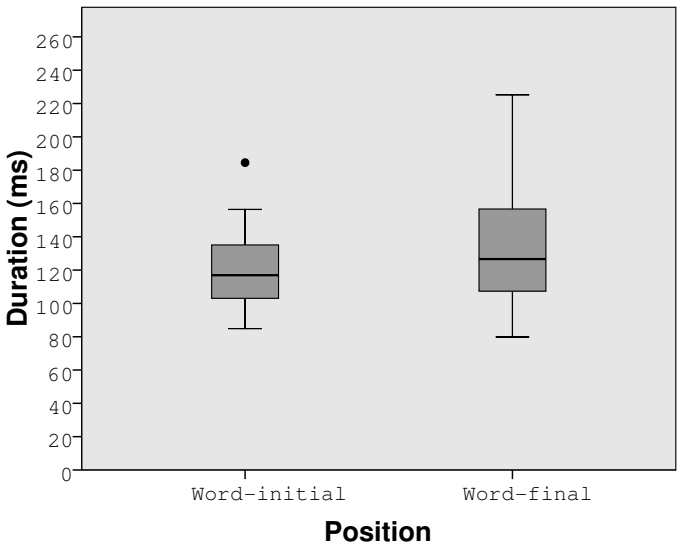

Figure 5.3: Duration of word-initial and word-final consonants in Italian.

	Transformed β coefficient	SD
Word-initial	26	20
Word-final	43	27

Table 5.9: Mean β coefficients for word-initial and word-final consonants in Italian.

consonants. This observation was confirmed statistically in the analysis of the β coefficient of the individual identification functions. The slope was significantly steeper for the word-initial than for the word-final consonants: $F(1, 26) = 13.331$, $p < 0.01$, eta-squared $= 0.339$. Mean values of the β coefficients are summarized in table 5.9.

Analysis of the perceptual category boundaries showed that they did not differ significantly between the word-initial and the word-final position.

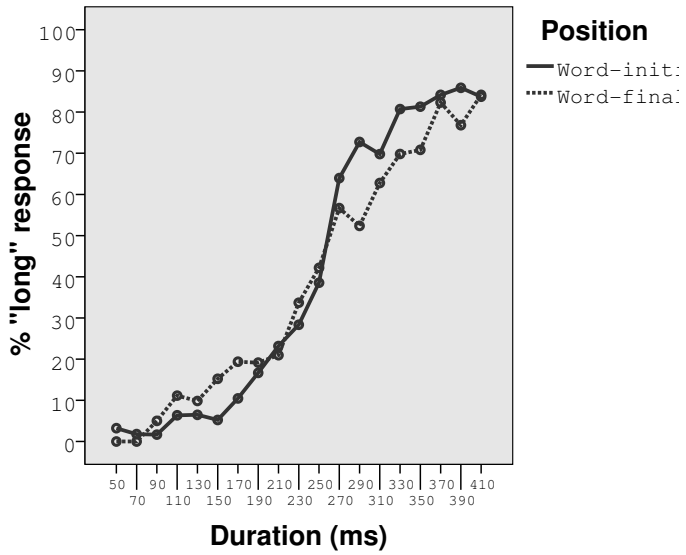

Figure 5.4: Perception of word-initial and word-final consonants by Italian participants.

5.4.4 The effect of stress: preceding stress, following stress, and no stress

Production

Analysis of the durational measurements showed that in Italian consonants in the onsets of stressed syllables (the following stress condition) were significantly longer than consonants in the preceding stress and the no stress conditions. The effect of Geminacy and the Geminacy-Stress interaction were also significant. The differences are illustrated in the figure 5.5. The statistical effects are summarized in table 5.10. Mean durational values and geminate/singleton ratios are shown in table 5.11.

A significant interaction between Geminacy and Stress is due to the fact that in the preceding stress condition the durational difference between singletons and geminates was greater than in other stress positions. A singleton consonant in the preceding stress condition was similar in duration to a singleton consonant in the no stress condition; however, a geminate consonant in the preceding stress condition

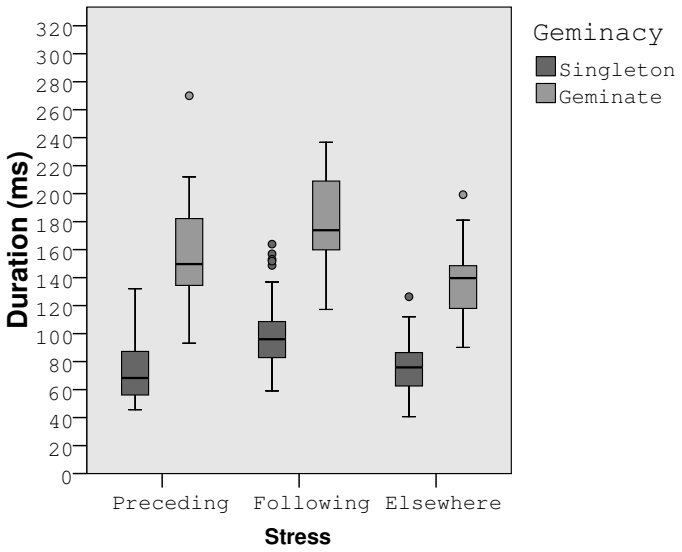

Figure 5.5: Duration of Italian consonants in three stress positions.

	F	p	eta-squared
Stress	$F(2, 14) = 37.221$	< 0.001	0.842
Geminacy	$F(1, 7) = 350.921$	< 0.001	0.980
Interaction	$F(2, 14) = 6.094$	< 0.05	0.465

Table 5.10: Effect of Stress and Geminacy on consonant duration in Italian in Italian.

Stress	Singleton (ms)	Geminates (ms)	G/S ratio
Preceding	73.5	156	2.13
Following	100	178	1.78
No stress	76	137	1.80

Table 5.11: Geminate and singleton durations and their ratios in three stress positions in Italian.

was longer than a geminate consonant in the no stress condition. A follow-up t-test showed that geminates preceded by stress were significantly longer than not adjacent to stress geminates: $t(78) = 6.426,\ p < 0.001$.

Analysis of the category boundary between geminates and singletons showed that the boundary was affected by Stress ($F(2, 14) = 39.544,\ p < 0.001$; eta-squared $= 0.850$): it was significantly higher for the consonants followed by stress than for the consonants preceded or not adjacent to stress (no difference was detected between the latter two groups). This effect reflects the fact that consonants, both geminates and singletons, were generally longer in the following stress condition.

Perception

Average response curves of the Italian participants are shown in figure 5.6. We can see that the curves overlap and there is no visible difference between them in terms of steepness. Analysis of the β coefficients confirmed that steepness of the identification functions was not affected by Stress.

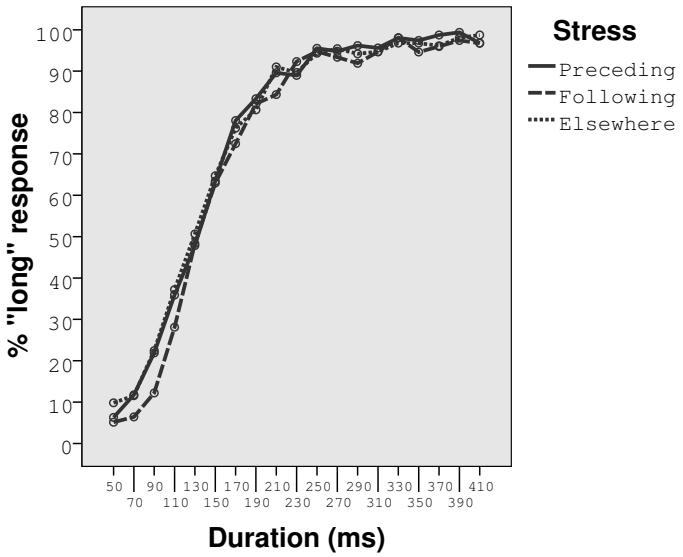

Figure 5.6: Perception of consonants in three stress positions by Italian participants.

Analysis of the perceptual boundaries showed that they were affected by Stress:

	F	p	eta-squared
Stress	$F(2, 72) = 17.917$	< 0.001	0.332
Modality	a trend	$p = 0.07$	
Interaction	$F(2, 72) = 4.120$	$p < 0.05$	0.103

Table 5.12: Effect of Stress and Modality on category boundary in Italian.

in response to the higher average duration (and higher category boundary in production) consonants in the following stress condition were identified as geminates at a significantly higher durational value than consonants in other stress conditions ($F(2, 50) = 5.291$, $p < 0.05$; eta-squared = 0.154, with Huynh-Feldt correction).

Production and Perception

When production and perception categories were analyzed together a significant interaction was detected between the Modality factor and the Stress factor. This interaction is illustrated in figure 5.7.

Figure 5.7: Perception and production category boundary in three stress positions in Italian.

Statistical effects are summarized in table 5.12.

A significant effect of Stress is due to the fact that consonants followed by stress had a higher category boundary both in perception and production. A near-significant trend for Modality is due to the fact that category boundaries were consistently higher in perception than in production across stress conditions for Italian participants. There was an interaction between Modality and Stress because the category boundary for the preceding and the no stress conditions was much higher in perception than in production (consonants needed to be longer to be perceived as geminates) while this effect was not as pronounced for the following stress condition.

5.4.5 The effect of manner of articulation

Production

There were significant differences in duration among consonants of different manners of articulation recorded by Speakers of Italian, as well as a significant interaction between Geminacy and Stress. These differences are illustrated in figure 5.8. Statistical

	F	p	eta-squared
Manner	$F(4, 28) = 96.704$	< 0.001	0.933
Geminacy	$F(1, 7) = 350.921$	< 0.001	0.980
Interaction	$F(4, 28) = 11.630$	$p < .001$	0.624

Table 5.13: Effect of Manner and Geminacy on consonant duration in Italian.

effects are summarized in table 5.13. Mean durations and geminate/singleton ratios are shown in table 5.14.

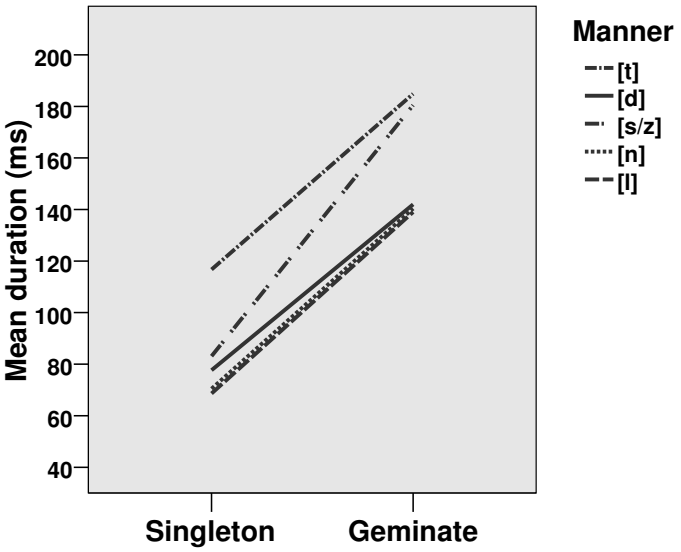

Figure 5.8: Duration of Italian consonants of different manners of articulation.

LSD (*least significant difference*) pairwise comparisons showed that all manners of articulation significantly differed from each other except [d] - [n], and [n] - [l]. The overall order of durations was the following: $t > s > d > n,l$.

The interaction between Geminacy and Manner was due to the fact that the increase in duration for geminates was not the same for every consonant type. In particular, fricatives show the highest geminate/singleton ratio, which is explained by the fact that singleton [s] became [z] in the pronunciation of Italian participants. The order of the geminate/singleton ratios was the following: $s/z > n,l > d > t$.

	Singleton (ms)	Geminates (ms)	G/S ratio
t	117	185	1.58
d	78	142	1.83
ss-z	83	180.5	2.17
n	70.5	140	1.99
l	69	139	2.02

Table 5.14: Geminate and singleton durations and their ratios for consonant of different manners of articulation in Italian.

Analysis of the category boundary showed that it was affected by the Manner factor ($F(4, 28) = 99.032$, $p < 0.001$; eta-squared = 0.934). The boundary values followed closely the differences in the overall consonant duration: the order of the boundaries was the following: $t > s > d > n,l$. There were no significant differences in the [d]-[n] and the [n]-[l] pairs.

Perception

Participants' responses in the perceptual experiment are presented in the figure 5.9. We can see that there is some separation among the curves along the duration axis which roughly follows the order of the durational differences in production: $t > s > d > n,l$. In terms of the steepness of the slope, [t] stands out with the shallowest slope.

The analysis of the β coefficients showed that the steepness of the identification functions was affected by the Manner factor ($F(4, 124) = 13.666$, $p < 0.001$; eta-squared = 0.306): [t] had a significantly less steep slope than the rest of the consonants. There was also a non-significant trend for the difference between [d] and [s], [d] having a less steep slope. Average values of the transformed β coefficients are shown in table 5.15.

The analysis of the perceptual category boundaries showed a significant effect of Manner: $F(4, 116) = 39.877$, $p < 0.001$; eta-squared = 0.579. Perceptual boundaries followed the order of the production boundaries: $t > s > d > n > l$. Every pairwise difference was significant.

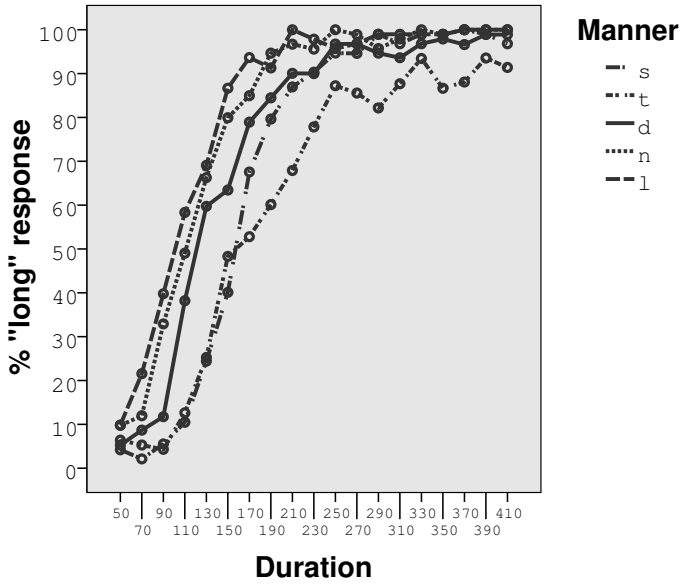

Figure 5.9: Perception of consonant of different manners of articulation by Italian participants.

	Transformed β coefficient	Standard deviation (ms)
s	16	13
t	38	27
d	21	19
n	19	14
l	17	11

Table 5.15: Mean β coefficients for consonants of different manners of articulation in Italian.

	F	p	eta-squared
Manner	$F(4, 144) = 26.576$	< 0.001	0.425
Modality	a trend	$= 0.05$	
Interaction	no interaction		

Table 5.16: Effect of Manner and Modality on category boundary in Italian.

Production and Perception

A joint analysis of the production and perception category boundaries showed that there was no significant interaction between Modality and Manner. The overall effect of Manner was significant, due to the fact that the same consonants had higher category boundaries in both production and perception. The effect of Modality approached significance at a p value of 0.05: category boundaries were consistently higher in perception than in production. This effect was not as pronounced for nasals and liquids as for stops and fricatives (see figure 5.10) although this difference did not reach significance as a Modality-Manner interaction. Statistical effects are summarized in table 5.16

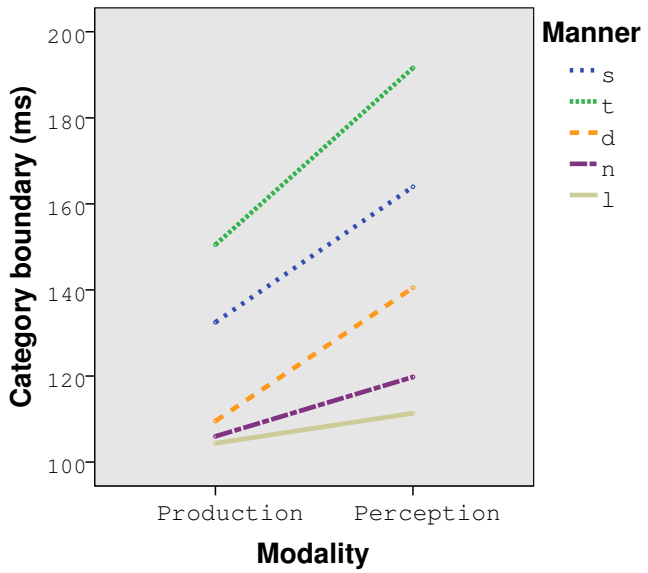

Figure 5.10: Perception and production category boundary for consonants of different manners of articulation in Italian.

5.5 Conclusion

The results of the durational measurements showed that, in words spoken by Italian participants, consonants were lengthened in the onsets of stressed syllables. Consonant shortening occurred in clusters as opposed to the intervocalic environment. When asked to pronounce word-final consonants, which are not commonly found in Italian, participants did not realize any significant durational difference between the word-final and the word-initial fricatives. However, word-final fricatives were pronounced with a greater degree of variability (a higher standard deviation), which is likely to be a consequence of the fact that Italian speakers are not particularly familiar with production of the word-final consonants.

As in Russian and American English, Italian voiceless stops and fricatives were longer in duration than voiced stops, nasals, and liquids.

In terms of the amount of the durational difference between geminates and singletons, which could be evaluated only for relative positions with respect to stress,

and different manners of articulation, it was established that consonants preceded by stress were realized with a greater durational gap between singletons and geminates. Interestingly, while singletons after stressed vowels are syllabified as onsets of the following syllables, geminates after stressed vowels are ambisyllabic, providing a coda to the stressed syllable and an onset to the following, unstressed syllable. Thus, it is not surprising that geminates are longer after stress - the part of the geminate consonant that belongs to the stressed syllable is affected by the lengthening property of stress. This, however, was detected in present experiment only for Italian participants and not for Russian ones. A possible explanation is that Italian, unlike Russian, is a weight-sensitive language. For Italian, therefore, it may not only matter that the stressed syllable *has* a coda; but lengthening the coda consonant further may contribute additional weight to the stressed syllables. Similarly, Farnetani and Kori (1986) found that consonants were lengthened in codas of stressed syllables even when followed by another, heterosyllabic consonant.

Voiced stops and sonorants also had a higher geminate/singleton ratio than voiceless stops. Fricatives were a special case in this experiment, since in the Northern varieties of Standard Italian intervocalic [s] is realized as [z], thus a difference in voicing boosted the durational difference between short and long fricatives in the production of Italian speakers.

The perceptual distinctiveness of the durational contrast, measured as a relative steepness of the identification curves as well as a presence of a relative singleton bias in the perception of the length distinction in a particular contextual environment, was lower for the preconsonantal than for the intervocalic contrasts, as well as for the word-final than for the word-initial contrasts.

Surprisingly, there was some evidence for lower perceptibility of the contrast in both non-stress-adjacent targets and those preceded by the stress, compared to the following stress condition. It manifested itself as a more pronounced raising of the category boundary in perception compared to the following stress condition. In the following stress condition, on the other hand, the boundaries were very comparable in both perception and production. This effect is connected to the fact that Italian participants showed a general tendency to have higher category boundaries in

perception than in production - a general "singleton bias". They were reluctant to categorize consonants as geminates even beyond the point which separated short and long consonants in production. This is the exact opposite of what has been established for Russian participants, who showed a general "geminate bias" in their perceptual responses. While the geminate bias in the responses of Russian participants was explained by their sensitivity to the secondary acoustic cues in the stimuli (which tell them that the target consonants were geminates originally), the singleton bias for the Italian participants can be explained by the fact that the experimental stimuli for the perceptual experiment were recorded by a speaker of Russian. Thus, the secondary acoustic cues to geminacy that Italians are accustomed to may be absent, ambiguous, or contradictory, in Russian implementation. This confusion manifested itself as a general singleton bias.

What happened in the case of the three stress conditions is that the singleton bias was less pronounced in the following stress condition. A possible explanation for this difference is that there is an upper limit for the perception of geminacy. That is, 150 ms is possibly a point after which all intervocalic consonants are heard as geminates independently of the environment. Consonants followed by stress, being longer to begin with, reach this limit in perception quite quickly, while consonants in other positions lag behind. Therefore, what we observe here may be a *ceiling effect* rather than a genuine singleton bias in the preceding stress and no stress conditions.

In terms of the differences in contrast perceptibility among different manners of articulation, sonorants ([n] and [l]) together with voiceless fricatives demonstrated the highest contrast distinctiveness. On the other hand, stops, voiceless stop [t] in particular, were affected by a decreased contrast distinctiveness.

To summarize, similarly to the Russian and American English results, data from the Italian participants demonstrated that the distinctiveness of the contrast was lower in the preconsonantal than in the intervocalic environment; in the word-final than in the word-initial position, and in stops than in voiceless fricatives, nasals, and liquids. Stress results were again the most inconclusive, both non-stress-adjacent and consonants preceded by stress showing signs of a lower contrast distinctiveness.

A conclusion that can be drawn from these observations is that the crosslinguistic

preferences for the geminate-singleton contrasts in the intervocalic environment over the preconsonantal one can be explained in terms of the relative perceptibility of the durational contrasts in these contexts. The fact that there are more languages with final than initial geminates cannot be explained by the perceptibility factors, since the results of the present experiments point towards higher contrast perceptibility in the word-initial position than in the word-final one. Stress-related crosslinguistic gemination patterns do not appear to have contrast distinctiveness as their underlying cause either.

The differences among manners of articulation once again went against the typological facts, distinctiveness being highest for the sonorant consonants which are presumably less common geminates than obstruent consonants. Whatever explains this typological pattern, it does not appear to be related to the differences in the distinctiveness of the geminate-singleton contrast as a function of the consonant type.

Chapter 6

Contrast distinctiveness across languages: universal and language-specific effects

6.1 Introduction

Since the design of the perceptual experiment was identical across the three groups of participants, the results of this experiment, quantified in terms of the β coefficients of the individual identification functions, can be considered all together in a single statistical analysis with Language (Russian, English, or Italian) as an additional between-subject independent factor.

This joint analysis is also justified by the fact that considering the data for each language separately revealed, in the majority of cases, evidence of the predicted effects, where the difference was in the expected direction but either non-significant or near-significant. This suggests that we are tapping into a real effect, but the experiment may not have enough power to demonstrate it conclusively. In the perceptual experiments of this type every stimulus is typically presented multiple times to each participant. In the present experiment each participant responded only once to each stimulus, which increased the probability of errors and lowered the probability of detecting significant effects. Testing a greater number of participants can help increase

	F	p	eta-squared
Environment	$F(1, 84) = 4.426$	< 0.05	0.05
Language	$F(2, 84) = 4.342$	< 0.05	0.094
Interaction	a trend	0.083	

Table 6.1: Effect of Environment and Language on β coefficients.

the power of the experiment. Thus, combining the responses from all three groups of participants in a single statistical analysis can serve exactly this purpose.

In addition, this type of analysis allows us to compare the perceptual results across different language groups and see the universal tendencies in comparison to the language-specific ones.

6.2 The effect of environment: intervocalic vs. preconsonantal

6.2.1 Summary

In this analysis, the effect of Environment on the transformed β coefficients was significant, as was the effect of Language; there was also a non-significant trend for a Language-Environment interaction. The statistical effects are summarized in table 6.1. The differences are illustrated in the figure 6.1.

The effect of Environment is due to the fact that the steepness of the slope was lower in the preconsonantal condition than in the intervocalic condition. Figure 6.1 shows that this effect was not observed for Russian (instead we see a non-significant reversal). A possible explanation is that Russians were at ceiling in both conditions because the stimuli were fairly Russian-like and pronounced by a native speaker of Russian.

In terms of the Language effect, the transformed β coefficients of Russian functions were significantly lower than those of the other two groups of participants,

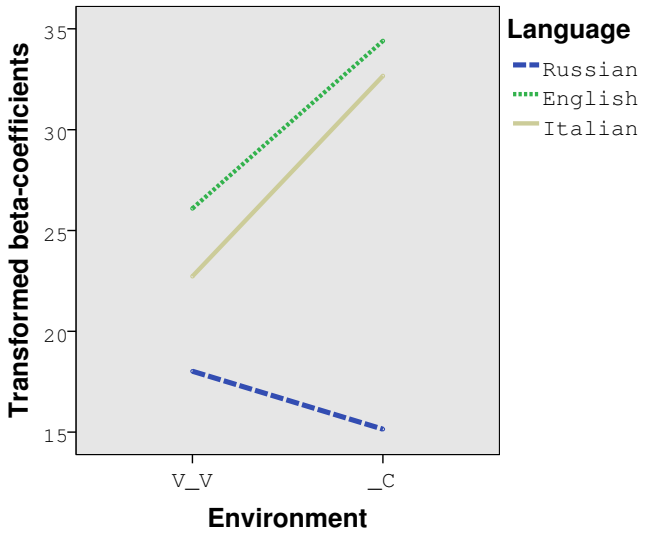

Figure 6.1: Effect of Environment and Language on β coefficients of the identification functions.

	F	p	eta-squared
Position	$F(1, 77) = 9.646$	< 0.01	0.111
Language	no effect		
Interaction	no interaction		

Table 6.2: Effect of Position and Language on β coefficients.

pointing to steeper identification functions, and suggesting that Russian listeners had an advantage when it came to perception of the stimuli used in the experiment.

6.2.2 The effect of position: word-initial vs. word-final

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Table 6.2 summarizes the statistical effects. Figure 6.2 illustrates the differences.

The effect of Position is due to the higher steepness of the slope in the word-initial position. This effect is most pronounced for the Italian participants possibly due to the fact that they had the most trouble perceiving length in the word-final position

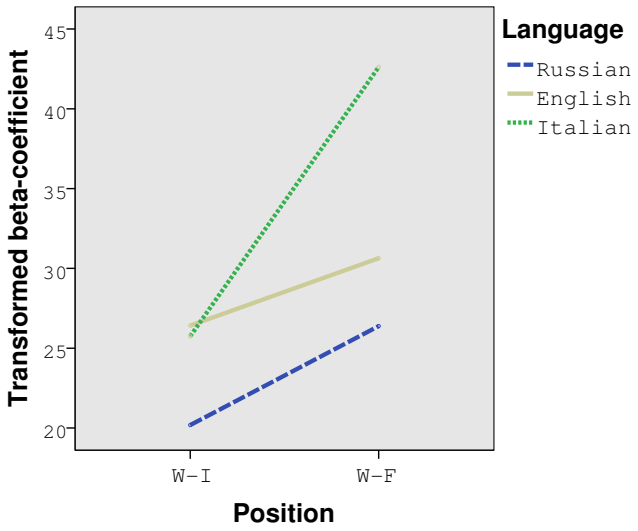

Figure 6.2: Effect of Position and Language on β coefficients of the identification functions.

	F	p	eta-squared
Stress	no effect		
Language	$F(2, 82) = 8.437$	< 0.001	0.171
Interaction	no interaction		

Table 6.3: Effect of Stress and Language on β coefficients.

because neither geminates nor singletons are found word-finally in Italian.

Russians again show the steepest slopes overall and although the effect of Language was not significant, pairwise comparisons showed that the difference between Russian and Italian was significant ($p = 0.04$).

6.2.3 The effect of stress

In the analysis of the effect of stress on contrast perceptibility across languages the only significant effect was that of the Language. The statistical effects are summarized in table 6.3. The difference is illustrated in figure 6.3.

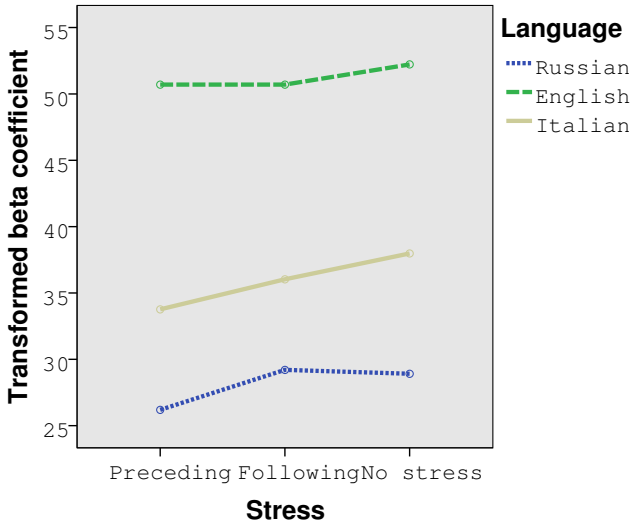

Figure 6.3: Effect of Stress and Language on β coefficients of the identification functions.

Pairwise comparisons showed that English group was significantly different from both Russian and Italian groups. It appears that American participants had the most difficulty with contrast distinctiveness in this condition.

There was no overall Stress effect although pairwise comparison showed that there was a non-significant trend for the identification functions of the consonants preceded by stress to have steeper slopes than those of the consonants not adjacent to stress ($p = 0.075$).

6.2.4 The effect of manner

In the analysis of effect of manner of articulation on perception of the consonant length contrast across participant groups only the effect of Manner reached significance. The statistical effects are summarized in table 6.4. Neither Language nor Manner-Language interaction were detected although quantitatively Russian still showed an advantage in the perceptibility of the contrast with the lowest transformed β coefficients of the three groups, as shown in the figure 6.4. Otherwise, it appears that the

	F	p	eta-squared
Manner	$F(4, 336) = 23.384$	< 0.001	0.218
Language	no effect		
Interaction	no interaction		

Table 6.4: Effect of Manner and Language on β coefficients.

participants treated durational contrasts in a consistent manner across various consonant types (no interaction): pairwise comparisons confirmed that across languages, voiced and voiceless stops [d] and [t] had a significantly lower steepness of the slopes than [s], [n], and [l].

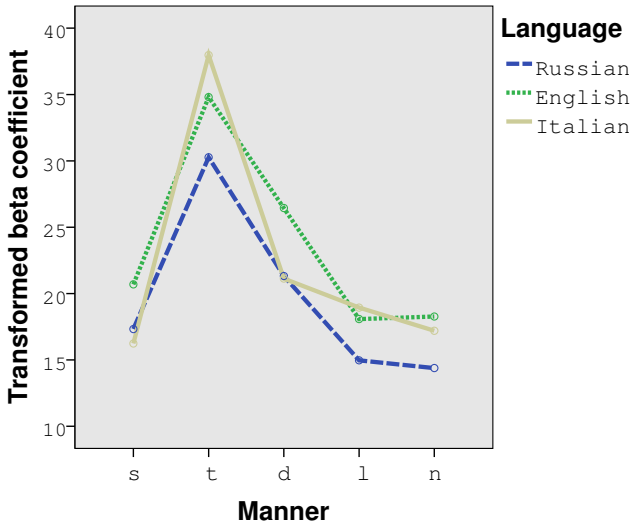

Figure 6.4: Effect of Manner and Language on β coefficients of the identification functions.

6.3 General summary and conclusions

The following tables summarize the findings concerning the relative contrast distinctiveness across the considered contextual environments. The evidence for the lower

Finding	Experiment
Lower steepness of the curve	English, Italian*, overall*
Singleton bias	Russian*, English, Italian

Table 6.5: Evidence for lower distinctiveness in preconsonantal environment.

Finding	Experiment
Lower steepness of the curve	Russian, English, Italian*, overall*
Singleton bias	Russian*, English, Italian

Table 6.6: Evidence for lower distinctiveness in word-final position.

contrast distinctiveness in the consonant adjacent environment as opposed to the intervocalic environment is shown in table 6.5. Stars indicate a significant effect.

The evidence for the lower contrast distinctiveness in the word-final position as opposed to the word-initial position is summarized in table 6.6.

The evidence for the contrast distinctiveness differences among various positions with respect to stress is the most scarce. If anything, there is some indication, based on the singleton bias only, that contrast is of a lower distinctiveness in consonants between two unstressed vowels (table 6.7).

Results for the manner of articulation were the most robust, although in the effect was in the direction opposite to the predicted one. The assumption that sonorant consonants are sub-optimal segments for implementation of the durational contrast due to their higher acoustic similarity to adjacent vowels is challenged by the present experimental results. Voiced and voiceless stops came out as consistently worse in

Finding	Experiment
Singleton bias	Russian, English, Italian

Table 6.7: Evidence for lower distinctiveness in the no-stress condition.

Finding	Detected for
Lower steepness of the curve	Russian*, English*, Italian*, overall*
Singleton bias	English, Italian

Table 6.8: Evidence for lower distinctiveness in the stop consonants.

terms of the contrast perceptibility (6.8).

Although the magnitude and statistical salience of the effects differed across languages, partly due to the language-specific factors (e.g Russians were the best, possibly at ceiling in some cases, when it came to the perception of the contrast in the stimuli read by a speaker of Russian; Italians had more difficulty than other language groups with length identification in the word-final position) and partly due to the insufficient power of the experiment, the effect was virtually always in the predicted direction for the first two comparisons. Thus, the conclusion that can be drawn from this observation is that (a) the observed effect in the perceptibility of the contrast is a language-independent effect, a general characteristic of the perception of durational contrasts in the relevant contextual environments. And, (b) the direction of the effect aligned well with the predictions of the Perceptual hypothesis, in particular, that the perceptual distinctiveness of the contrast would be lower in the environments where geminate-singleton contrasts are less frequently observed crosslinguistically. Thus, the relative contrast distinctiveness emerges as a good candidate for the underlying cause of the typological tendencies observed across languages, in particular the tendency to restrict the geminate-singleton contrasts to the word-medial, intervocalic position as opposed to the consonant-adjacent and the word-final contexts. Word-initial contrasts were relatively well-defined perceptually and perceived with a higher success than the word-final contrasts. This, while not in agreement with the typological observations, is not a surprising effect. The word-initial environment is likely to be psycholinguistically prominent, possibly due to greater attention paid to onsets of words. The present results provide a good fit to the previous findings. For example, Redford and Diehl (1999) showed that initial consonants were significantly more

identifiable than final consonants in CVC monosyllables.

The findings concerning the effect of stress on contrast perceptibility are not particularly convincing. There is limited evidence of decreased contrast perceptibility between two unstressed vowels, but no reasons to believe that preceding stress is conditioning a better response than following stress. Thus, a presumed crosslinguistic tendency for geminates to occur often in the post-tonic position cannot be attributed to a better perceptibility of the contrast between geminate and singleton consonants in this position. An alternative explanation is offered in Chapter 7.

Manner differences were quite robust although not in the direction outlined by the previous research. Against expectation, sonorant consonants, together with fricatives, demonstrated a higher rather than lower distinctiveness of the short-long opposition. If this perceptual difference served as a basis of the crosslinguistic typology we would expect to see more sonorant geminates as opposed to obstruent geminates, which appears to be the opposite of the actual observed pattern (apart, perhaps, from nasals, which do emerge as a frequent choice for gemination).

This finding may not be as surprising as it seems if we consider the fact that sonorants and fricatives are segments which have acoustically salient realization *throughout* their duration (periodic signal for sonorants, frication noise for fricatives). Stops on the other hand are cued by transient signals, such as release burst at the offset, but the bulk of their duration is virtually silence (a low frequency and low intensity voicing signal in case of voiced stops).

Thus, perception of duration in sonorants and fricatives may be compared to the perception of duration of *filled gaps*, while perception of duration in stops may be compared to the perception of duration in *unfilled gaps*. Wearden et al. (2007) showed that unfilled intervals (silent breaks in tones) were perceived as significantly shorter than filled intervals (tones) of identical duration. Unfilled gaps were judged as 55% to 65% of the duration of the filled intervals. This can certainly account for the singleton bias observed in the perception of duration in stop consonants. However, in this study the *contrast* between short and long segments was also less well defined in stop consonants (lower steepness of the slope), suggesting that listeners did not only hear them as shorter, but they also were more unsure about categorizing them into

short and long.

A striking difference between these results and the previous findings (e.g., Kawahara (2006) who established that durational distinctions in obstruents were perceived with greater success than in sonorants by Arabic listeners) and a possible connection with the perception of filled vs. unfilled gaps, warrants further research in this area.

In terms of the ratio between geminate and singleton consonants, no pattern consistent enough to justify crosslinguistic tendencies has emerged, apart from the consistently higher ratios for sonorants and voiced stops compared to voiceless obstruents. In addition, the contrast was relatively better defined in terms of the geminate/singleton ratio in the intervocalic environment in Russian and in the preceding stress environment in Italian.

The Allophonic duration hypothesis, which connects gemination after stress with a general durational increase in the post-stress consonants, was not confirmed. In most cases, durational increases involved pre-stress consonants only, and only in English were post-stress consonants somewhat lengthened as well, although the magnitude of this lengthening is perhaps too small to trigger the perceptually driven phonologization of length.

Chapter 7

Constraints on Geminates and Geminate Typology

7.1 Explanation in linguistics

One of the major goals of linguistics is to answer the question of *why* linguistic systems are they way they are, what the driving forces behind the rules and principles that govern languages are, and where these principles come from. The rise of generative linguistics (Chomsky, 1957, 1965) has been largely motivated by such explanatory goals.

One of the approaches to explanation in linguistics appeals to functional forces that underpin the formal rules and structures which generate the language. Although the idea that functionally motivated facts of speech articulation, perception, and cognitive processing play a role in the way languages are structured is not new in linguistics and phonology in particular (Lindblom, 1990; Martinet, 1952; Ohala, 1983), it has been undergoing a renaissance in recent decades. This renewed interest can be attributed in part to a greater sophistication of the available research equipment and associated advances in experimental work. The introduction of optimality theory (Prince and Smolensky, 1993), a new framework for modeling phonological systems, may be another reason why functional motivations in linguistics are being explored with greater vigor. The architecture of optimality theoretic models, based on the

interaction and competition of ranked and violable constraints, allows the implementation of phonetic factors in phonology without running into the eternal question of why languages remain diverse while subject to the same functional pressures. The way optimality theory resolves this issue is by allowing each language to achieve its own balance between universal constraints through a language-specific constraint ranking — by assigning higher priority to some constraints and demoting others. The advantage of the optimality theory based approach is that it allows one to reconcile the two main objectives of modern phonology: to provide an explicitly formulated theoretical machinery generating linguistic structures — grammar (the generative approach)— and to invoke deeper functional reasons as precursors of grammatical choices (the functional approach). In this chapter I will develop an optimality theoretic model which generates asymmetries in the distributional typology of geminate consonants and relies on functionally motivated constraints based on the results of the perceptual experiments.

Two major types of functional explanations in phonology are discussed in section 7.2 and approaches to implementing phonetics in phonological grammar are addressed in section 7.3. Section 7.4 introduces a particular theoretic framework implemented within optimality theory on which the analysis of geminate typology in this work is based — contrast dispersion theory (Flemming, 1995, 2004; Liljencrants and Lindblom, 1972), and the ways in which it is adopted for current purposes. The rest of the chapter is dedicated to the details of the formal model which accounts for the distributional properties of geminate inventories across languages. Section 7.4.3 briefly reviews the main experimental results and their significance for the functionally-based grammar proposed here. The basic architecture of the proposed model, including OT constraints, is also outlined in this section. Section 7.5 provides an overview of the positional typology of consonantal length contrasts. Sections 7.6, 7.7, 7.8, and 7.9 consider in some detail four languages as representatives of the possible language types generated by the model. The factorial typology of the model is developed in sections 7.10 through 7.12. Section 7.13 addresses the issue of consonant sonority as a factor in geminate typology. Approaches to between-language frequency are discussed in section 7.14.

7.2 Ease of articulation, ease of perception, and markedness

Typically the two main functional forces addressed by phonologists working in a phonetically-based framework are "ease of articulation" and "ease of perception". Articulatory differences between speech sounds are more easily observable and have a longer history of research. For example, most of the generally accepted distinctive features in contemporary phonology are based on articulatory properties of sounds, as introduced in the Sound Pattern of English (Chomsky and Halle, 1968).[1] In modern generative phonology the markedness of a sound is often viewed as stemming from the relative difficulty of its articulation. Speech sounds with more complex articulation are presumed to require more articulatory effort and are therefore more rare typologically. For example, implosive stops involve an additional articulatory movement — lowering of the larynx — and are more rare than plain voiced stops (Flemming, 2004). Similarly, palatalized or velarized stops are marked relative to plain stops (Padgett, 2001).

However, the understanding of markedness as a property of the sound itself, without making any reference to external conditions, such as the context in which the sound occurs, has a serious drawback. This is especially relevant for the second part of the phonetic motivation: perceptual factors. It has been demonstrated that contextual factors play an important role in defining the perceptual properties of the sound. For example, it is well known that acoustic properties of many consonantal sounds are most easily perceived in intervocalic environment, where external cues, such as formant transitions, provide help in consonant identification. A consonantal environment, especially in the following position, complicates the identification significantly. As a result, preconsonantal obstruents are prone to neutralization and other repair actions, such as metathesis. Thus, consonants in general may be considered as "marked" in a preconsonantal environment.

[1] Although in the work of Jakobson, which predates the Sound Pattern of English, distinctive features were defined primarily in terms of acoustics (Jakobson and Halle, 1952).

Paradigmatic relationships play an important role as well. More articulatorily effortful implosives are also more acoustically distinct from unaspirated voiceless stops and may be preferred for that reason when contrasting with voiceless stops (Flemming, 2004). This also shows that it is in fact the interaction of articulatory and perceptual factors that shape phonological inventories. Although perceptual considerations are the focus of this work, the need for counterbalancing articulatory constraints is also apparent.

An important characteristic of perceptually-based markedness is that the perceptibility of a sound is essentially the perceptibility of the contrast between this sound and other sounds in the language it is in opposition with. To perceive a sound, linguistically speaking, means to identify or categorize it, to distinguish a sound from other contrasting ones used in the language. This suggests that perceptibility depends on how well the sound is distinguished auditorily from its competitors. Thus, perceptibility of the sound is really *perceptibility of the contrast*.

The perceptibility of contrasts may be absolute, that is, not dependent on context, in some cases, e.g., the perceptual difference between the labiodental fricative [f] and the interdental fricative [θ] is poorly cued irrespective of the context and is rarely used by languages. However, in many cases perceptual distinctiveness turns out to be largely a matter of context. Certain contrasts are better perceived in certain environments. For example, a contrast between palatalized and plain stops does not benefit from a pre-front high vowel environment where plain consonants will become palatalized to a certain degree due to coarticulation (Padgett, 2001). In addition, the main cues to some phonological features are not concentrated in the segment itself but hosted by the adjacent segments. For example, place features of the stop consonants mainly reside in the formant transitions of the adjacent vowels (Jun, 2004; Wright, 2004).

Thus, the perceptual markedness of a sound must be evaluated with regard to the sounds it is in contrast with and the phonetic environments it occupies.

The perceptual properties of phonological contrasts and their consequences for phonological typology are addressed in the work of a line of researchers (Boersma, 1998; Flemming, 2004; Hume and Johnson, 2001; Jun, 2004; Steriade, 2001; Wright,

2004, and references therein). The main prediction of perceptually-driven phonology is that languages adopt a number of strategies to eradicate the less perceptible phonological contrasts: sounds with poor acoustic/perceptual cues to their phonological identity, often due to contextual effects, are expected to be either neutralized or enhanced. As I will show here, the relative scarcity of durational contrasts in certain environments may be attributed to selective neutralization triggered by the lower perceptibility of the contrast in these environments, and modeled with functionally motivated constraints on contrast distinctiveness.

7.3 Phonetics in phonological grammar

Although it is generally acknowledged that functional forces such as the ease of production and the ease of perception provide a valid explanation for a number of phonological phenomena, opinions are divided on whether and how these phonetic factors should be incorporated into formal grammar. One view claims that functional considerations must lie outside of linguistics proper. Formal grammar therefore must contain only those features of languages that cannot be attributed to language-external forces (Anderson, 1981).

At the opposite end, there is a variety of proposals which explore the ways of incorporating phonetics into phonology. One approach relies on phonetically-motivated ranking of the OT constraints, while the constraints themselves are not explicitly phonetics-based. In Gordon (1999, 2004) the ranking of the constraints related to syllable weight is motivated by the average coda sonority in each specific language.

There are a few possible objections to this approach. First, since only the end result of the phonetic effect, but not the effect itself, is incorporated into the grammar, the relevant constraints often have to be extremely detailed and numerous (Steriade, 2001). Second, since the phonetically-based motivation is not explicit, it remains a mystery, when we consider the grammar on its own, where the constraints or their rankings come from (Hayes et al., 2004; Padgett, 2001). Third, the phenomena explained by the same underlying phonetic reason lose any evidence of this connection in the grammar. Such an approach often cannot provide an *explicitly* unified account

of the related linguistic facts.

Another possibility, explored here, is to introduce the phonetic factor itself into the grammar as a "scheme for generating constraints" on linguistic structures (Hayes et al., 2004). An example of this approach is the family of Minimal Distance constraints (MinDist) introduced by Flemming (1995, 2004). Instead of using constraints that prohibit a certain number of vowels of a certain phonetic quality (due to the fact that such vowels would be mutually indistinguishable) MinDist constraints refer to the minimal auditory distance among the members of an inventory. This approach drastically reduces the complexity and the number of constraints necessary to model the phenomena, making the grammar more concise and transparent with respect to the cause of the restriction. It also makes possible a unified account of the related processes which would otherwise appear unconnected.

7.4 Contrast dispersion theory

7.4.1 Overview

A theory that constitutes the basis of the analysis proposed here is conceptually and formally a synthesis and a continuation of the ideas expressed in the work of Steriade (2001, 2008), Flemming (1995, 2004), Padgett (2001, 2003) and others. The main hypothesis is that maintenance of contrast distinctiveness is a major driving force in linguistic systems. A main function of language is communication, which requires expressiveness. Expressiveness relies on phonological features as the building blocks of linguistic meaning. The ability to realize contrastive sounds with maximum acoustic distinctiveness to ensure their successful discrimination is critical for communication. A major prediction of this theory, therefore, is that languages will have strategies in place to ensure that the contrasts are effectively differentiated acoustically and perceptually. We know that acoustic cues and their respective perceptibility are not independent of phonetic context, a more concrete prediction is that in contexts where sounds are poorly differentiated perceptually from their phonological competitors, some kind of repair will be attempted. There is general agreement that there are

two main pathways of remedying such situations: neutralization or enhancement (Flemming, 2004; Steriade, 2008).

It is unclear whether these two strategies are equally available to languages as repairs of poorly cued contrasts. An impression one might form from reading the literature on perceptually based phonology is that neutralization is a more frequent choice than enhancement. However, since enhancement can potentially involve subtle phonetic changes not otherwise used for phonemic contrast, instances of enhancement may be overlooked especially if no detailed phonetic analysis of the contrasting sounds is undertaken. Neutralization involves a change between two phonological categories and is easier to notice.

In terms of grammar architecture, these assumptions presuppose the existence of constraints on contrast, or more precisely, constraints on the acoustic distinctiveness of the contrasting phonemes. Such constraints can be viewed as "perceptual markedness" constraints, and their function is to regulate the minimum level of acoustic-perceptual distinctness along a phonological dimension between the members of the inventory that a language accepts. A highly ranked constraint of this type prohibits poorly cued contrasts and leads to a repair — neutralization or enhancement.

To allow for typological varieties, every language is expected to exercise this ban on the perceptually confusable contrasts with a varying degree of stringency. This variability is achieved by counterbalancing the effects of perceptual distinctiveness constraints with "expressiveness" constraints. Such a constraint requires that a contrast is to be maintained despite its perceptual shortcomings so that the expressive function of the language is supported by a maximum number of building blocks — phonological contrasts.

A third force also needs to be entered into the equation: a requirement that a minimal amount of articulatory effect is expended during the production of speech. Flemming (2004) formulates these three competing functional forces as shown in 7.1:

(7.1)
1. Maximize the distinctiveness of the contrast
2. Maximize the number of contrasts
3. Minimize articulatory effort

According to Flemming (2004) there is an inherent conflict between the requirement to maximize distinctiveness and the requirement to maximize the number of contrasts, as well as between the requirement to maximize distinctiveness and the requirement to minimize articulatory effort.

Flemming (2004) assumes that there is no direct conflict between "Maximize the number of contrasts" and "Minimize articulatory effort", as contrasts may be maintained with minimal articulatory effort in languages that allow low perceptual distinctiveness. However, we may also consider that maintaining *any contrast* presupposes additional articulatory effort. Having to pronounce voiced consonants in addition to voiceless consonants is more effortful that sticking to voiceless ones only. In this sense, contrast means new sounds to produce, which means more effort. This will certainly be true for the current model, where a contrast between short and long consonants is considered. Geminate consonants are generally believed to require more articulatory effort (Kirchner, 2004) and maintaining the contrast along the duration dimension includes the necessity to articulate geminate consonants. Therefore, in the current approach, "Minimize articulatory effort" does conflict directly with "Maximize the number of contrasts".

In the remainder of the section I will discuss the exact formulation of the constraints expressing these functional forces, as introduced by Flemming (2004), and point out the modifications I make to Flemming (2004)'s model.

7.4.2 Constraints on contrast distinctiveness

There are two main features of the constraints on distinctiveness that are of importance. First, they make reference to a functional force that is outside of the grammar proper. In order to be able to use these constraints, one must possess some amount of information about the contrasts under discussion that is not based on their distributional properties alone. This information must come from acoustic or perceptual experiments. In other words, we must know about the acoustic and perceptual properties of these contrasts before modeling their behavior in the grammar.

Second, in order to allow for linguistic variability with respect to the limit of

perceptual distinctiveness permitted, the requirement of contrast distinctiveness is to be expressed as a *family* of constraints with an internal universal ranking structure, where the "stricter" constraints are ranked progressively lower than "less strict" constraints.

Every constraint in the family penalizes a deficiency in perceptual distinctiveness of a certain degree: less strict constraints prohibit the most severe cases of perceptual confusability and let pass all others; the "strictest" constraints prohibit all contrasts except the most perceptually distinct ones.

Flemming (1995, 2004) focuses the discussion of the relative contrast distinctiveness on the differences between phonological inventories of varying sizes. The assumption is that maintaining a greater number of phonological contrasts along the same phonetic dimension reduces the distinctiveness among the phonemes. Since the phonetic dimension has a limited range, more contrasts means less acoustic distance between them. Thus, (1) languages are predicted to always select their contrasts from the extreme ends of the available phonetic space (a dispersion effect, closely related to the notion of contrast enhancement), and (2) fewer contrasts provide greater distinctiveness.[2] This seems to be the case for vowel inventories. Languages with only three vowels typically include [i], [u], and [a] — the most peripheral points of the vowel space.

Thus, in Flemming (2004)'s model less perceptually distinct candidates are the ones with a greater number of members in the inventory. Here, I demonstrate that contrast distinctiveness is also subject to evaluation with respect to the contexts where the contrast occurs. In the present model, the competing candidates are members of the same phonological inventory — consonant length contrasts, with the same number of items: two (singleton and geminate), but realized in a variety of contextual

[2]Voicing contrast along the VOT dimension may be an interesting case: the most acoustically distinct categories selected from the opposite ends of the scale are prevoiced consonants (large negative VOT) and aspirated consonants (large positive VOT). To my knowledge, very few, if any, languages build their consonant voicing contrast in this fashion. Typically, the contrast is between prevoiced and short-lag (voiceless unaspirated) consonants, as in Russian and Spanish; or between short lag and long lag (aspirated) consonants, as in English. Moreover, all three categories in the same language are also quite uncommon, although this would increase the number of contrast presumably without compromising acoustic distinctiveness any further (examples include Thai, Hindi, Nepali, Sindhi).

positions. The assumption explored here is that certain contextual environments exercise the same kind of detrimental effect on the distinctiveness of the contrast as cramming more members into the same phonetic space does. Therefore, unlike in Flemming (1995, 2004), distinctiveness varies as function of contextual environment rather than as a function of the number of members of the inventory.

In addition, in the current model, no a priori universal ranking among the constraints on distinctiveness is implemented. The structure of the markedness constraints used here is such that each constraint bans a successively larger subset of contexts on the scale of perceptibility. As shown in the upcoming sections, candidates that violate less strict constraints will also violate more strict constraints. Thus, a stringency approach to modeling the perceptibility effect is adopted here (de Lacy, 2002, 2004a,b; Kiparsky, 1994; Prince, 1997).

Another major deviation from Flemming (2004)'s approach relates to the external, experimental basis of the distinctiveness constraints. Flemming (2004) relies on acoustic data in formulating the distinctiveness constraints, trusting that a relevant difference in the acoustic dimension corresponds reasonably well to distance in the perceptual domain. This approach is well suited for cases where acoustic correlates of the perceptual distinction are well known, such as perception of vowel quality as a function of the two lower formant frequencies (Fry et al., 1962). However, there are several general objections to this method.

(1) Non-linearity of auditory perception. It is now well known that the relationship between the acoustic signal and its perception by the human auditory system is not linear — acoustic space is warped and distorted as it is processed by the organs of audition and transformed into neural signals (Johnson, 1997). Thus, our knowledge of the acoustic parameters does not automatically presuppose knowledge of their perceptual consequences. In particular, the distance between two points on the acoustic dimension does not always translate to a proportional distance along the perceptual dimension. For example, spectral differences in the lower frequency domain are exaggerated while spectral differences in the higher frequency domain are smeared in the auditory representation of the signal.

(2) Secondary cues. As Flemming (2004) himself points out, relative distinctiveness along a single acoustic dimension can be determined with much greater confidence than relative distinctiveness in multidimensional space. Thus, Flemming (2004)'s distinctiveness constraints are relativized to the amount of distance between categories along a single acoustic dimension. While it is a common practice in phonology to reduce phonological contrast to a single acoustic feature, which usually corresponds to the so called primary cue and often has the most pronounced perceptual effect on the categorization of the relevant sounds, it is also well known that phonological distinctions are typically based on multiple acoustic cues — in addition to the primary cue, supplementary or secondary cues are distinguished. Whether deliberately introduced to increase the perceptual distinctiveness of the contrast, or a natural acoustic consequence of the articulatory setting (e.g., differences in the F0 contour as function of consonant voicing [3]) they can be and are used by listeners in categorization tasks. In addition, it has been shown that listeners' reliance on secondary cues in categorization increases when the contribution of the primary cue is ambiguous, e.g., set at a value not found in natural speech, in the in-between section of the acoustic range of the cue (see, for example, Haggard et al. (1970) on voicing contrasts). Secondary cues are also more pronounced in perception when additional cognitive load is imposed on the listeners (Gordon et al., 1993). Thus, it is unwise to rely on the distinctions in the primary cue alone, especially in situations where its contribution may be diminished by contextual or processing factors.

(3) Selective attention. Perceptual effects may not necessarily follow from any acoustic property at all but arise as an artifact of the processing mode — possibly a particular method of allocating cognitive resources such as the effect of selective attention (Gordon et al., 1993). For example, perceptual benefits of CV transitions compared to VC transitions may arise due to differences in selective attention rather than actual acoustic differences (Fujimura et al., 1978).

(4) Indeterminacy of the phonetic analysis. In their search for the acoustic cues that affect the categorization of the sounds, phoneticians must cast their net wide

[3] Although these may be actively suppressed when potentially interfering with another phonological contrast. For example, F0 contour variation corresponding to consonant voicing is suppressed in tonal languages (Francis et al., 2006).

and still there is never a certainty that one will be found among the candidates considered. The fact that acoustic correlates of a certain perceptual effect have not been found does not presuppose their non-existence. In the situation of the richness of the acoustic signal and the impossibility of considering every feature, acoustics alone may not be an adequate guide to perception.

Ideally, we would like to have both answers at our disposal, that is, to know exactly which *acoustic* cues cause a particular *perceptual* reaction. However, if a choice must be made, it appears more reasonable to rely on the results of perceptual investigations. Ultimately, what determines the distinctiveness value of the contrast is how well the phonemes are distinguished *perceptually*, independently of their acoustic separation along a particular acoustic dimension. Thus, in the present model, the distinctiveness constraints are relativized to the amount of perceptual rather than acoustic distance between the phonological categories in a particular contextual environment. Of course, the disadvantage of this approach, which needs to be mentioned, is that it does not address the question of the acoustic correlate of the consonant length distinction which may be at work in changing the perception of the contrast in different contexts. The decision to use recorded, rather than synthesized, stimuli for the experiment was dictated by the desire to preserve all the naturally occurring acoustic correlates of the durational contrast.

7.4.3 Experimental results

Results of the experiments on the perception of singletons and geminates by speakers of Russian, American English, and Italian, presented in Chapters 3, 4, and 5, demonstrate that the perceptibility of contrast, or the perceptual distinctiveness between the contrasting sounds, is not the same across different contextual environments. The distinction between short and long consonants is more perceptible in some contexts than in others. Keeping in mind that the experiment only captures the perception of the distinction by speakers of these three languages and that only a limited number of segmental contrasts was tested, we can calculate the degree of distinctiveness for each environment and build a hierarchy of contrast distinctiveness constraints based

Condition	β coefficient
Intervocalic (V_V)	22.53
Word-initial (WI)	24.24
Preconsonantal (_C)	28.23
Word-final (WF)	33.35

Table 7.1: Transformed β coefficients as function of position in the word.

on these data. The two measurements of perceptibility of the contrast used in the experiments were the location of the perceptual boundary between singletons and geminates (median of the logistic function) and the steepness of the identification curve (a reciprocal transformation of the β coefficient of the logistic function). Since the location of the perceptual boundary is only revealing when compared with the production data, which was not collected for all three languages, I will base the calculation of the perceptual distinctiveness on the β coefficient of the logistic function.

A transformedβ coefficient averaged across individual subjects in all three languages was calculated for each environment: intervocalic, preconsonantal, word-initial, and word-final. The values are reported in table 7.1. Since the reciprocal transformation was applied, lower values correspond to steeper slopes in the original function, and therefore, higher distinctiveness of the contrast.

Based on these experimental results, the contrast distinctiveness between short and long [s] is highest in the intervocalic condition, followed by the word-initial and the preconsonantal conditions. It is lowest in the word-final condition, as shown in 7.2:

(7.2) V_V > WI > V_C > WF

Values for contrast distinctiveness in pre-stress, post-stress, and unstressed environments were collected in the same way and are reported in table 7.2. With respect to stress, post-stress environment conditioned the sharpest perceptual difference between the two categories, followed by pre-stress environment. In the unstressed environment the distinctiveness was the lowest (7.3):

Condition	β coefficient
Post-stress	37.51
Pre-stress	39.20
Unstressed	40.34

Table 7.2: Transformed β coefficients as a function of stress.

Condition	β coefficient
l	16.61
n	17.34
s	17.92
d	22.81
t	34.32

Table 7.3: Transformed β coefficients as function of manner of articulation.

(7.3) Post > Pre > Unstressed

Distinctiveness was also compared as a function of the manner of a consonant's articulation. The values are presented in table 7.3. Distinctiveness of the contrast decreases in the order shown in 7.4:

(7.4) [l] > [n] > [s] > [d] > [t]

Thus, contrast distinctiveness constraints used here make reference to the perceptual distinctiveness level established experimentally for each condition.

In terms of the exact formalization of the distinctiveness constraints, in Flemming (2004) constraints refer to the minimal distance between the contrasting sounds along some acoustic dimension and are formulated as shown in 7.5:

(7.5) MinDist = (acoustic)Dimension:distance

For example, MinDist = F1:2 requires that members of the vowel inventory are separated from each other at least by 2 steps on the first formant dimension.

The steps are established by dividing the F1 range into equidistant portions roughly corresponding to differences between vowels if a maximum naturally occurring number of vowel distinctions is fitted into the space. MinDist = dimension:n is ranked above MinDist = dimension:n+1.

In my formulation, MinDist refers directly to minimal distinctiveness in a particular context, rather than indirectly through minimal acoustic distance. Thus, MinDist_{V_V} requires that phonological categories are perceptually distinct at least to the same degree that they are distinct in an intervocalic environment. Constraints on minimal distinctiveness that will be used here are defined in 7.6-7.8. For an example of this approach, see tableau 7.9.

(7.6) MinDist_{V_V} = "Perceptual distinctiveness at least on intervocalic level".

(7.7) MinDist_{WI} = "Perceptual distinctiveness at least on word-initial level".

(7.8) $\text{MinDist}_{\_C}$ = "Perceptual distinctiveness at least on preconsonantal level".

(7.9)

	$\text{MinDist}_{\_C}$	MinDist_{WI}	MinDist_{V_V}
a. ata-atta			
b. ta-tta			*
c. atCa-attCa		*	*
d. at-att	*	*	*

Note another difference between the two models: in tableau 7.9 candidates do not incur multiple violations of the stricter distinctiveness constraints. Multiple violations occur because the acoustic distance between *every two* members of the inventory is evaluated by the MinDist constraints in Flemming (2004)'s model, and each pair's violation is counted. In the present model the inventory always contains a maximum

of two members, so that there is always a maximum of one violation per MinDist constraint.[4]

7.4.4 Constraints on contrast maximization

In Flemming (2004)'s system Maximize Contrast is a positive constraint which selects an inventory with the highest number of contrasts. In the present model, since the durational contrast always contains at most two categories (short and long), instead of competing with other durational inventories, contrast along the durational dimension competes with two cases of neutralization: where only single or only double consonants are found (7.10). A contrast maximization constraint used here is defined in 7.11.

(7.10)

	MaxContrast
a. ☞ ata-atta	
b. ata	*!
c. atta	*!

(7.11) MaxContrast = "Maintain a contrast along a given phonological dimension".

It is the variable ranking of the MaxContrast constraint within the hierarchy of MinDist constraints that results in crosslinguistic variation with respect to the contrast distinctiveness. Depending on the exact ranking of MaxContrast relative to the MinDist constraints, a particular limit is set on the minimal contrast distinctiveness required in the languages. As a result, only a certain number of categories per acoustic dimension is allowed, leading to languages with different inventories.

[4]For simplicity I assume that durational contrast for consonants is always binary, which is typically the case. For an example of a three-way length distinction see Estonian (Lehiste, 1966; Prince, 1980).

Similarly, the contrast may be allowed only in certain contexts, resulting in languages where contrast is realized in certain positions only.

7.4.5 Constraints on effort minimization

In Flemming (2004)'s model, effort minimization constraints perform a function of eliminating low distinctiveness contrasts, which cannot be realized with higher distinctiveness without incurring additional articulatory effort. Flemming (2004) also mentions the close connection between the availability of the acoustic cues for phonological contrasts and context where the contrast is realized. In a certain context a contrast may be less distinct and therefore neutralized due to a relevant MinDist constraint.

In the current model, effort minimization constraint performs the additional task of excluding the possibility of "neutralization to the marked". If a contrast is not possible due to insufficient distinctiveness, neutralization is the answer. However, an inventory with two members could potentially neutralize to either one of the two. That is, we could expect languages with only singletons and languages with only geminates. Effort minimization constraint removes the second option by making long consonants always a suboptimal choice.

Effort minimization is also a way to enforce a language without any contrast, even the most perceptually distinct, along the considered dimension. Since geminates are effortful articulations, a system with a contrast is penalized by an effort minimization constraint to the same degree as languages with geminates only.

The formulation of the effort minimization constraint, adopted from Kirchner (2004), is shown in 7.12. The specific constraint that will be used in the model, Lazy_L, prohibits long consonants and aspirated consonants, assuming that both length and aspiration require an additional amount of biomechanical energy (shown in 7.13 and 7.14). This constraint will be shortened to Lazy in most tableaux for simplicity.

(7.12) LAZY_n = "Do not expend effort $\geq n$".

(7.13) LAZY_L = "Do not lengthen consonants".

(7.14)

	MinDist	LAZY$_L$
a. ata-atta	*!	*
b. ☞ ata		
c. atta		*!

7.4.6 Input and output

The notion of input is eliminated from the version of optimality theory developed in Flemming (2004). Thus, there is no place for input-output correspondence and faithfulness constraints. The candidates are evaluated only from the point of view of their surface markedness — perceptual (contrast distinctiveness constraints), articulatory (effort minimization constraints), and expressiveness (contrast maximization constraints). At the same time, contrast maximization constraints play a role similar to those performed by faithfulness constraints in traditional OT — they work towards ensuring the most diverse output.

7.5 Positional typology of geminates

In order to supplement the experimental results with additional typological evidence, more than 50 languages were examined with respect to the type and distribution of geminate consonants as well as phonological processes affecting geminates. An effort was made to focus on languages where geminate consonants were truly contrastive rather than instantiations of allophonic lengthening. Languages in the sample were selected based on the availability of the sources and prior knowledge that contrastive consonant length was to be found in the language. Many were drawn from the compilations put together in Podesva (2002) and Muller (2001).

In this section I will discuss the positional typology of geminate consonants. More data on the typology of the interaction between stress and geminacy is available in

section 7.11. Manner and geminacy are addressed in section 7.13.

Overall, the generalizations about the crosslinguistic distribution of consonant duration contrast across contextual positions that were reviewed in section 1.3.3 of Chapter 1 were confirmed in this survey. Almost without exception, the considered languages contained geminates in the intervocalic position. Consonant adjacent, word-initial, and word-final geminates were considerably more rare. There appears to be a strong implication that if a language allows geminates in non-intervocalic position, the intervocalic ones are also to be found. The only exception concerns a handful of languages that permit word-initial geminates only: Pattani Malay, Saban, Yapese, Ngada, and Nhaheun (Muller, 2001).

In terms of linguistic phenomena that target the non-intervocalic geminates, we can observe a general tendency to eliminate or prevent the creation of such forms. This tendency manifests itself in a variety of ways, including limitations on *phonological inventories* (passive neutralization in the terminology of Hayes, 2009); *neutralization* (which often creates morphophonemic alternations where a geminate is realized in intervocalic position but not otherwise), *contrast enhancement*; *blocking* of the phonological processes that would have resulted in the non-intervocalic geminate, *variation*, and historical *sound change*. In the remainder of this section I will present some examples and briefly address their implications for the phonological modeling of the crosslinguistic distribution of geminate consonants.

Limitations on *phonological inventories* are the most obvious way in which the distribution of geminates is restricted. Many languages simply do not allow non-intervocalic geminates and in the absence of historical or synchronic phonological processes that could create such geminates, no evidence of active neutralization is available. Such languages include Bengali (Ferguson and Chowdhury, 1960; Lahiri and Hankamer, 1988), Maranungku (Tryon, 1970), Oromo (Lloret, 1997), Somali (Puglielli, 1997). Pajak (2012) also points out Ancient Greek (Steriade, 1986), Japanese (Kawahara, 2005), and Hopi (Crothers et al., 1979; Thurgood, 1993).

In addition to a categorical prohibition against non-intervocalic geminates, many languages allow them but in a limited set of environments or in a very small number. It also appears that postconsonantal geminates are somewhat more common than

preconsonantal ones. Thus, in Finnish, postconsonantal geminates are found after nasals or liquids: *kartta* [kartta] "map" (Karlsson, 1999, p. 13), *vintti* [vintti] "attic". In a very limited number of loanwords, nasal+geminate combinations are attested in Cypriot Greek: /ʃɐmˈppu/ [ʃɐmˈpp^{h}u] "shampoo" (Armosti, 2009, p. 6). Ge'ez allows geminates preceded by liquids only: *nägärkkäni* "you spoke to me" (Gragg, 1997b, p. 180). In Nez Perce geminates can be preceded by a glottal stop: [tiʔnnux] "quick death" (Aoki, 1970, p. 37).

Preconsonantal geminates may be subject to similar limitations. In Italian geminates are typically found intervocalically but occasionally geminated [f] and stop consonants can be placed before liquids. However, minimal pairs in this environment are rare.

(7.15) *soffrire* [soffrire] "to suffer"
applicare [applikare] "to apply"
attribuire [attribuire] "to appropriate"

Word-initial geminates are sometimes a subset of the consonantal phonemes of the languages, but a particular tendency in this case is difficult to determine. While consonant-adjacent geminates are clearly preferred next to sonorants across languages, limitations on word-initial geminates appear to be of a more language-specific character. It is not difficult to justify that continuants should be preferred on perceptual grounds in absolute word-initial (and word-final) position due to the constant presence of an acoustic signal throughout their duration. However, only Hatoma in the sample of languages studied by Muller (2001) limits word-initial geminates to continuants (more on the limitations on the type of geminates allowed word-initially can be found in Muller, 2001). Other languages, on the contrary, may exclude certain continuant geminates from word-initial position. For example, in Selayarese laminopalatal nasal [ɲ], velar nasal [ŋ], and alveolar approximant [r] can appear as geminates word-medially but only as singletons word-initially (Mithun and Basri, 1986, pp. 222, 225).

The peculiar limitations on word-initial geminates can sometimes be explained by

morphological factors. Since oftentimes gemination word-initially arises from complete assimilation in clusters created by morpheme concatenation, certain geminates are absent from this set pseudo-accidentally: there are no prefixes that contain them. In dialects of Arabic, word-initial geminates often result from the combination of certain one-consonant prefixes, for example, a marker of definiteness, or proclitics, with stem-initial consonant, and consequent assimilation: /l-trab/ [t-trab] "the ground" (Moroccan Arabic). Thus, in Syrian Arabic, [f], [g], [k], [h], voiceless uvular stop [q], velar fricatives [x, ɣ], pharyngeal fricatives [ħ, ʕ], and the glottal stop [ʔ] are not found as geminates word-initially (Cowell, 1964, p. 23).

Just as consonant-adjacent geminates are sometimes marginally present in the phonology, in the sense that only a small number of lexical items contains them, word-initial and word-final geminates may also be rare in languages that allow them. In Ponapean (Harrison, 1995c), word-initial and word-final geminates are permissible but infrequent. In Amharic word-final geminates can be found only occasionally (Leslau, 1997, p. 459).

Neutralization processes also target primarily the non-intervocalic geminates, especially consonant-adjacent and word-final ones. *Enhancement* strategies, typically vowel epenthesis, are also sometimes applied to word-initial, word-final, and consonant-adjacent geminates.

Underlying preconsonantal geminates are realized as singletons in some dialects of Arabic, for example Iraqi Arabic (Erwin, 1963, p. 30) and some varieties of Syrian Arabic (Cowell, 1964, p. 24):

(7.16) Iraqi Arabic: /dabbrat/ [dabrat] "she arranged"
Syrian Arabic: [waʔʔef] "stop" (masc.) - [waʔfi] "stop" (fem.)

Neutralization is also frequently applied to geminates in word-final position. Many dialects of Arabic participate in this process, realizing their final geminates as singletons (see for example, Cowell, 1964, pp. 23–24 and Erwin, 1963, p. 30). In Modern Mandaic a regular process degeminates all word-final long consonants (Malone, 1997, p. 146). Similarly, Maltese final geminates are reported to become short word-finally (Borg, 1997b, p. 251).

(7.17) Iraqi Arabic: [maħallaat] "places" - [maħal] "place"
Syrian Arabic: /m̥ayy/ [m̥ay] "water"
Modern Mandaic: /rabb/ [rab] "large" (predicative form)
Maltese: [fomm-i] "my mouth" [fom] "mouth"

Quite often, word-final degemination is limited to cases when a consonant-initial word follows the final geminate. Final geminates preserve their contrastive length when a vowel follows, that is, essentially in the intervocalic position. This is reported, for example, for Persian (Mahootian, 1997). The pre-pausal condition is somewhat special and can cause neutralization or preservation of length depending on the language. For example, in Hungarian (Pycha, 2010), Thurgovian Swiss German (Kraehenmann, 2001), and the Uri dialect of German (Seiler, 2009) geminates are safe in pre-pausal position but are subject to neutralization before consonants.

(7.18) Hungarian: [hɔll] "he hears" - [hɔlvɔ] "hearing"

Historically, word-final geminates have also been targeted by neutralizing sound change processes. Thus, Jastrow (1997, p. 336) reports that in the Ǧubb'adīn dialect of neo-Aramaic word-final geminates were lost in the course of historical sound change. Similarly, multiple dialects of German over time disposed of their word-final geminates (Seiler, 2009).

It would not be surprising if word-initial geminates were equally discriminated against in phonologies. However, I have not come across many clear cases of consonant length neutralization in word-initial position. Blevins (2004a) provides several examples of neutralization of word-initial and word-final geminates. The former included the degemination of initial geminates in the Lac Simon dialect of Ojibwa and the reinterpretation of initial geminates as aspirated stops in Tuvaluan (Polynesian): *kkémo* > k^h*émo*, which possibly is related to a general tendency to hyperarticulate initial geminates to increase their perceptibility (Blevins, 2004a, p. 182). In Thurgovian Swiss German, Kraehenmann (2001) reports, absolute-initial stop geminates are not audible — not surprisingly, taking into account a complete lack of acoustic cues to the beginning of a silent stop closure. However, Kraehenmann and Lahiri (2008) showed

that an articulatory gesture is preserved for initial geminate consonants in Thurgovian Swiss German, suggesting that the inevitable acoustic neutralization is not a consequence of a deliberate action. For Hindi, Ohala (2007) notes that "geminates usually are not pronounced in word-initial or word-final position" (p. 363).

On the other hand, there are some well-known cases of other types of repairs involving word-initial geminates. In Maltese, word-initial geminates are supplied with a prosthetic vowel when not preceded by a vowel-final word or in the post-pausal environment (Borg, 1997b; Hume and Johnson, 2001):

(7.19) /t-dierek/ [iddierek] "to rise early" (3rd, past imperf.)
/kkopya/ [ikkopya] "he copied"

In Marshallese, word-initial geminates are resolved using a similar strategy. Interestingly, epenthesis *into* a geminate is an available option as well as prosthesis (Harrison, 1995b):

(7.20) /ppiŋ/ [ippiŋ]/[pipiŋ] "skilled in jumping"

Epenthesis may be viewed as an instance of enhancement: word-initial geminates are more clearly audible when preceded by an epenthetic vowel. They can also be considered an example of contrast neutralization: the singletons and geminates are no longer contrastive word-initially, since all word-initial geminates are now intervocalic.

In Cypriot Greek, which permits word-initial and intervocalic geminates, geminate stops are *enhanced* by aspiration, both initially and medially. Thus, the enhancement applies to geminates across the board, independently of their contextual environment, although it is the word-initial ones that are particularly in need of this feature. However, there is also evidence of additional enhancement maneuvers in word-initial position: when a preceding word ends in a consonant (nasal), the nasal deletes when followed by a word-initial geminate (or cluster) (Muller, 2001, p. 148).

(7.21) /ton + ppara/ [to ppara] "the money"

Cases of similar repairs of word-final geminates are also attested. In Wolof, word-final geminates are pronounced with an epenthetic schwa (Bell, 2003).

(7.22) /napp/ [nappə] "ear"

In Hungarian, epenthesis breaks down combinations of stem-final geminates and following consonant-initial suffix (Ringen and Vago, 2011):

(7.23) *hallani* /hɒll-ni/ [hɒllɒni] "to hear" (infin.)

The same processes that express themselves categorically as restrictions on phonological inventories and as neutralization emerge in a more stochastic manner in examples of *variation*. In Russian, non-intervocalic geminates are more likely to degeminate than intervocalic ones and word-final degemination is virtually exceptionless.

(7.24) /rassol/ [rʌssol] "brine" - /rasskaz/ [rʌskaz] "story"
/stressa/ [stressə] "stress" (Gen.) - /stress/ [stres] "stress" (Nom.)
/passoritʲ/ [pʌssoritʲ] "to cause to quarrel" - /ssora/ [sorə] "quarrel"

In Hungarian, concatenated or "fake" geminates variably degeminate when flanked on the left or on the right by another consonant. The probability of degemination depends on the sonority of the flanking consonant: degemination is obligatory next to obstruents, optional next to nasals, and not attested next to liquids (Pycha, 2010), (Siptár and Törkenczy, 2000, pp. 291–292).

(7.25) *koszt-tól* /kosttoːl/ [kostoːl] "from food"
tank-ként /tɔŋkkeːnt/ [tɔŋkkeːnt]/[tɔŋkeːnt] "like a tank"
talp-pont /talppont/ [tɔlppont] "foot-end"

Finally, there are cases of *blocking* of the phonological processes that would result in the creation of geminate consonants in non-intervocalic environments. In Yagua short vowel deletion, which normally takes place between alveolar consonants and /n/ or /r/, is blocked if resulting in a three-consonant cluster or a preconsonantal geminate (Payne and Payne, 1990).

(7.26) riyarǫ́ǫ́vạạ<u>nunt</u>iy *riyarǫ́ǫ́vạạ<u>nnt</u>iy "they made noise again"

In Hungarian, gemination itself is blocked if a resulting geminate would otherwise be non-intervocalic. Certain suffixes in Hungarian cause gemination of the root-final consonant:

(7.27) /vɔʃ-ɔl/ [vɔʃʃɔl] "iron" (instr.)
/ʧɔt-ɔl/ [ʧɔttɔl] "buckle" (instr.)

Gemination is blocked when the root ends in a consonant cluster so that the resulting geminate would be postconsonantal.

(7.28) /ɔkt-ɔl/ [ɔktɔl] *[ɔkttɔl] "with a nude"
/vɛrʃ-ɛl/ [vɛrʃɛl] *[vɛrʃʃɛl]"with a poem"

To summarize, clear instances of action against non-intervocalic geminates have been registered in the phonologies of various languages. Such geminates are affected by passive and active neutralization, blocking, and repairs. Interestingly, word-initial and word-final geminates are often avoided only if preceded/followed by a consonant, suggesting that there is a connection between the prohibition against medial and peripheral consonant-adjacent geminates. Taking into account the fact that medially postconsonantal geminates appear to be more common than preconsonantal ones, possibly due to the fact that CV transitions are more helpful in identifying various consonantal features, including duration,[5] word-initial geminates may be expected to be more common than word-final ones. This expectation may also be reinforced by the fact that across languages onsets are favored over codas; therefore, consonant-*initial* words are much more likely than consonant-*final* ones. Thus, on the level of the utterance, word-final geminates have a greater chance of being followed by a consonant than word-initial ones of being preceded by a consonant.

These generalizations do not seem to be supported by crosslinguistic inventories: generally, more languages allow final than initial phonemic geminates (Taylor, 1985), although in the current survey which focuses on surface geminates, initial ones

[5]Psychological literature points to the fact that identifying the offset of the signal is more difficult than identifying its onset (Efron, 1970; Kemp and Irwin, 1979). Thus, having a vowel on the troublesome final end of the geminate is very helpful, while having it at the beginning, where the identification is already at ceiling, may not be changing much.

prevail because underlying final geminates are neutralized in several languages. In terms of patterns of neutralization and other repairs, both word-final and word-initial geminates are frequent targets, although among the languages considered, word-final geminates are more often subject to neutralization, especially in the preconsonantal environment, while word-initial geminates are repaired through enhancement such as epenthesis. Sometimes, these approaches coexist in the same language: both Maltese and Dubai Arabic are reported to epenthesize before word-initial geminates but degeminate word-final ones (Borg, 1997b; Hoffiz, 1995, pp. 61, 64). Independent factors, such as stress-related preferences for the epenthesis site (avoidance of epenthetic vowels in stressed positions), may be responsible for this asymmetry (Alderete, 1995).

An overall rarity of initial geminates may of course be the reason why more examples of neutralization are not uncovered. In addition, the resistance of word-initial geminates to neutralization may be explained by their morphological significance: many result from assimilation on the boundary of morphemes (more on morphological factors in section 7.10.3). The relative abundance of word-final geminates, despite their potential perceptibility shortcomings, may also be related to the role underlying geminates play in the moraic structure of the languages (more on this in section 7.11).

Word-initial geminates are also the only ones, it appears, that defy the implication non-intervocalic $\rightarrow$ intervocalic geminates, since some languages allow word-initial but not intervocalic geminates. Thus, the only clear implicational patterns in the data concern the fact that medial consonant-adjacent (pre- or postconsonantal) and final contrastive geminates always imply intervocalic geminates in the language. The implications *within* the set of non-intervocalic geminates are more difficult to determine. A certain direction is suggested by the experimental results offered here. Although it has to be taken cautiously due to experimental limitations, these results reflect the real psychoacoustic properties of the perception of duration and can affect the linguistic use of this feature.

In terms of experimental limitations, it is important to keep in mind that only a limited set of environments and consonants was tested here. Languages clearly contain geminates of various types, and contrast perceptibility is defined by the interaction between the contextual environment and a type of the consonant: e.g., duration

of voiceless stops is more perceptible word-finally than word-initially. Thus, the perceptibility index for a particular environment in each individual language may differ as function of the types of geminates likely to be found there. For example, Gordon (2004) proposed that weight-by-position was more likely to be assigned to singleton codas in languages with a greater proportion of high-sonority codas.

In addition, the proposed constraints refer to the actual phonetic features of the phonological contrast. Thus, knowing the details of phonetic implementation of the contrast in each language is important for the discussion of whether the proposed model can account for the distribution of geminates in the language. For example, word-final geminates in Wolof are supplied with an epenthetic vowel (Bell, 2003), which in all likelihood largely increases the perceptibility of the contrast such that it will no longer be subject to the appropriate MinDist constraint. Similarly, in languages like Norwegian and Swedish, consonant and vowel length are in complementary distribution: geminate consonants are always preceded by phonemically short vowels and never by phonemically long vowels. Assuming vowel length is more perceptible that consonant length, this relationship greatly remedies the perceptual shortcomings of the singleton-geminate contrast.

A final observation on the typological patterns in geminate distribution that deserves a mention concerns the fact that geminates oftentimes behave in parallel with consonant clusters in various languages. For example, Hungarian epenthesis exemplified above in 7.23 applies equally to consonant clusters and geminates. This has lead some to argue for a "length" rather than "weight" representational analysis of geminate consonants (Ringen and Vago, 2011) or propose solutions that incorporate moraic and cluster-like properties of geminates (Curtis, 2003; Muller, 2001). It was also a source of inspiration for accounts of geminate distribution via general syllable-structure related constraints (Kiparsky, 2002; Kraehenmann, 2001; Muller, 2001).

To counterattack this evidence, Davis (2011) offers examples where geminates pattern differently from consonant clusters. For example, Trukese allows word-initial geminates but does not have word-initial consonant clusters. Pajak (2009b) also reports that in Polish, where complex consonant clusters are abundant, geminates are

restricted to intervocalic and, with certain restrictions, word-initial position. Nevertheless, it remains a fact that syllabic structure limitations often explain geminate distribution in a straightforward manner. Since it is often the case that both perceptibility factors and syllable structure factors are predicted to affect geminates in the same direction, it is impossible to determine conclusively whether one or the other is responsible. However, a possibility I would like to raise is that both — the restrictions on the shape of the syllable and the ones on geminate distribution — may originate from the global contrast-perceptibility optimization system. It is not difficult to imaging that both complex consonant clusters and non-intervocalic geminates are flawed in terms of the perceptibility of the consonantal contrasts.

Alternatively, geminate distribution may be explained by syllable structure, not directly, but via the perceptibility conditions it creates. For example, Kiparsky (2002) observed that dialects of Arabic can be classified as onset- or coda-maximizing, and initial geminates tend to be allowed in the onset-maximizing dialects, while final geminates are found in the coda-maximizing dialects. At the same time, initial geminates in the onset-maximizing language are not likely to be preceded by a complex cluster, which improves their overall perceptual profile. Similarly, final geminates in the coda-maximizing environment are not going to be followed by an elaborate onset, thus being generally more perceptible.

Table 7.4 puts together in a very concise manner information about geminate distribution across various contextual positions in a number of languages. It is important to point out that it should not be taken as a guide to the *phonological* distribution of geminates since I am aiming at capturing their *surface* distribution. That is, in this table I attempt to show, only for languages with contrastive consonant duration, the contexts where the contrasts are actually realized *phonetically*. Thus, although Arabic undoubtedly has underlying final geminates, they are routinely degeminated on the surface in many dialects; that is why Syrian Arabic and Iraqi Arabic are listed without final geminates. Where information on phonetic realization of the phonological contrast was not available, the distribution is listed in its phonemic form.

Word-final geminates were admitted if they were realized at least in the prepausal position. In cases where word-final geminates were confined to prevocalic

environments they were excluded. Thus, Persian is listed without final geminates, but final geminates are indicated for Hungarian.

This compilation is intended only as a rough guide to geminate distribution in a variety of languages based on the sources listed below. Where precise information was not available, inferences were made based on what was known about syllable structure and phonotactics in general. I encourage the readers to consult the original sources to confirm these observations since mistakes and misinterpretations are possible.

Reference guide:

Amharic: Hudson (1997), Leslau (1997)
Bengali: Hankamer et al. (1989), Ferguson and Chowdhury (1960)
Berber: Kossmann and Stroomer (1997), Ridouane (2007), Ridouane (2010)
Blackfoot: Thomson (1978), Proulx (1989), Uhlenbeck (1938)
Bugis: Abas and Grimes (1995), Podesva (2000)
Cypriot Arabic: Borg (1997a)
Cypriot Greek: Muller (2001), Armosti (2009), Newton (1972)
Estonian: Lehiste (1966), Prince (1980)
Finnish: Karlsson (1999)
Ge'ez: Gragg (1997b), Gragg (1997a)
Ilokano: Hayes and Abad (1989)
Hausa: Newman (1997)
Hindi: Ohala (2007), Kaye (1997)
Hungarian: Pycha (2010), Siptár and Törkenczy (2000), Ringen and Vago (2011)
Icelandic: Glendering (1976), Pind (1986), Árnason (2011)
Iraqi Arabic: Erwin (1963)
Isnag: Barlaan (1995)
Italian: Anderson (1984), Loporcaro (1996)
Jordanian Arabic: Abu-Abbas et al. (2011)
Kagayanen: MacGregor (1995)
Kiribati: Harrison (1995a)
Madurese: Clynes (1995)

Language	V_V	#_	post-C	pre-C	_#
Berber	+	+	+	+	+
Moroccan Arabic	+	+	+	+	+
Thurgovian S. German	+	+	+	+	+
Jordanian Arabic	+	+	?	+	+
Cypriot Arabic	+	+	?	?	+
Syrian Arabic	+	+	?	−/+	−
Estonian	+	−	+	+	+
Hungarian	+	−	−	−	+
Icelandic	+	−	−	−	+
Norwegian	+	−	−	−	+
Swedish	+	−	−	+	+
Wichita	+	−	?	+	+
Cypriot Greek	+	+	few loans	−	−
Iraqi Arabic	+	+	−	−	−
Kiribati	+	+	−	−	−
Mele-Fila	+	+	−	−	−
Piro	+	+	−	−	−
Ponapean	+	+	−	−	?
Selayarese	+	+	−	−	−
Woleaian	+	+	?	?	−
Polish	+	some	−	−	−
Blackfoot	+	−	+	+	−
Finnish	+	−	+	−	−
Italian	+	−	−	some	−
Maltese	+	−	?	+	−
Ge'ez	+	−	few	−	−
Nez Perce	+	−	few	−	−
Amharic	+	−	−	−	some
Bengali	+	−	−	−	−
Bugis	+	−	−	−	−
Ilokano	+	−	?	?	−
Hausa	+	−	?	?	−
Hindi	+	−	?	?	−
Isnag	+	−	−	−	−
Kagayanen	+	−	−	−	−
Madurese	+	−	−	−	−
Maranungku	+	−	−	−	−
Modern Mandaic	+	−	−	−	−
Muskogee	+	−	−	−	−
Oromo	+	−	−	−	−
Persian	+	−	−	−	−
Somali	+	−	−	−	−
Yagua	+	−	−	−	−
Wolof	+	−	−	−	−
Pattani Malay	−	+	−	−	−

Table 7.4: Geminate distribution across languages.

Maltese: Borg (1997b)
Maranungku: Tryon (1970)
Moroccan Arabic: Harrell (1962), Heath (1997)
Mele-Fila: Clark (1995)
Modern Mandaic: Malone (1997)
Muskogee: Haas (1938)
Nez Perce: Aoki (1970)
Norwegian: Kristoffersen (2011)
Oromo: Lloret (1997)
Pattani Malay: Hajek and Boedemans (2003)
Persian: Mahootian (1997)
Piro: Matteson (1965)
Polish: Pajak (2009b)
Ponapean: Harrison (1995c)
Selayarese: Mithun and Basri (1986), Podesva (2000)
Somali: Puglielli (1997)
Syrian Arabic: Cowell (1964)
Swedish: Kiparsky (2008a)
Thurgovian Swiss German: Kraehenmann (2001)
Wichita: Rood (1975), Rood (1996), Garvin (1950)
Yagua: Payne and Payne (1990)
Woleaian: Harrison (1995d)
Wolof: Bell (2003)

In the following sections I will consider in more detail a number of languages with contrastive consonant length and show how they can be derived using the contrast dispersion system and the perceptibility constraints proposed here. I will develop the analysis step by step, starting from a "basic model", which includes only a basic set of constraints discussed above: a number of perceptually motivated constraints on contrast distinctiveness, a contrast maximization constraint, and an effort minimization constraint. I will show where the predictions of such a minimal model fail and propose independently motivated additions to the model which will help it better

Lab	Dent	Retr	Pal	Vel	Glot
b p	d t	ɖ ʈ	ɟ c	g k	
			ç		h
m	n			ŋ	
	l				
	r	ɽ			

Table 7.5: Consonantal phonemes of Bengali.

approximate the empirical patterns.

7.6 Bengali

Bengali will be used here as an example of languages where only intervocalic geminates are allowed. Among other languages of this type are Maranungku (Tryon, 1970), Oromo (Lloret, 1997) and Somali (Puglielli, 1997). Bengali is an Indo-European language spoken in Bangladesh and parts of India. It has underlying or tautomorphemic geminates, concatenated or heteromorphemic geminates, and geminates from consonant assimilation in its inventory. See examples in 7.29–7.31 from Lahiri and Hankamer (1988):

(7.29) Underlying: /pa̪t̪ta/ [pa̪t̪t̪a] “whereabouts”

(7.30) Concatenated: /pa̪t̪ + t̪e/ [pa̪t̪t̪e] “spread out” (infinitive)

(7.31) Assimilated: /kor + t̪e/ [ko̪t̪t̪e] “do” (infinitive)

The phonemic system of Bengali includes bilabial, dental, retroflex, palatal and velar stops, all of which can also be contrastively aspirated; three nasals; a trill/flap and a retroflex rhotic; a lateral; and two fricatives. Palatal stops are usually realized as affricates. The phonemes of Bengali are listed in table 7.5 (based on Ferguson and Chowdhury, 1960).

All of the consonantal phonemes can occur as geminates except rhotics, velar nasals, and glottal fricatives. Some examples are shown in 7.32–7.38.

(7.32) [dibi] “thou wilt give” - [dibbi] “oath”

(7.33) [pata] “leaf” - [patta] “trace”

(7.34) [aʈa] “flour”- [aʈʈa] “eight pieces”

(7.35) [c͡ʃokor] “bird” - [c͡ʃokkor] “whirl, sea-sickness”

(7.36) [mala] “wreath” - [malla] “crew of a boat or a ship”

(7.37) [kana] “one-eyed, blind” - [kanna] “crying”

(7.38) [kac͡ʃa] “raw” - [kac͡ʃc͡ʃa] “a weight”

Both /ŋ/ and /h/ have other distributional restrictions in Bengali: the velar nasal is not permitted word-initially and the glottal fricative is not found word-finally after vowels. Similarly, retroflex /ɻ/ does not occur word-initially in Bengali. With respect to geminate /rr/, Ferguson and Chowdhury (1960) remark that although it is expected to arise in particular in the concatenation of nouns ending in /r/ with the animate plural suffix -*ra*, subjects were reluctant to produce it. There appears to be a tendency to avoid long /r/ or a phonetic neutralization of length for this consonant.

Geminates in Bengali are found only in word-medial, intervocalic position. Other non-homorganic consonantal clusters are permitted word-initially: a stop followed by a liquid [dr kl], a fricative followed by a stop, a nasal, or a liquid [st sr], or rarely, a nasal followed by a liquid [ml nr]. Final consonant clusters are unattested, except in foreign words used by multilinguals.

As mentioned in the previous section, the question of the relationship between geminates and consonant clusters is an unsettled one. It appears that in some cases geminates behave like consonant clusters, while in others they are more similar to single segments (Davis, 2011; Muller, 2001; Ringen and Vago, 2011). In moraic theory geminates are viewed as single segments associated with a mora. If we adopt this representation, the restriction placed on the distribution of consonant clusters should

be of no consequence for the distribution of geminates, since geminates are moraic singletons, not clusters. For examples of asymmetric distribution of consonant clusters and geminates see Davis (2011) and Muller (2001).

The geminate distribution facts in Bengali can be captured with the constraint ranking MinDist$_{V_V}$ ≫ MaxContrast ≫ Lazy$_L$ (see tableau 7.39; constraint names are abbreviated to save space).

(7.39)

	MD$_{_C}$	MD$_{WI}$	MD$_{V_V}$	MaxC	Lazy
☞1a. ata-atta					*
1b. ata				*!	
1c. atta				*!	*
2a. ta-tta			*!		*
☞2b. ta				*	
2c. tta				*	*!
3a. atCa-attCa		*!	*		*
☞3b. atCa				*	
3c. attCa				*	*!
4a. at-att	*!	*	*		*
☞4b. at				*	
4c. att				*	*!

In this grammar less stringent MinDist constraints do not play a critical role. MinDist$_{V_V}$ ensures that all singleton-geminate contrasts that are not distinctive at the level of intervocalic environment are filtered out. MaxContrast secures the

phonemic distinction in the intervocalic environment and LAZY prevents neutralization to geminates instead of singletons.

7.7 Cypriot Greek

Grammars that allow only word-initial and word-medial gemination are represented by Cypriot Greek (Armosti, 2009; Arvaniti and Tserdanelis, 2000; Muller, 2001); a number of Austronesian languages, such as Kiribati (Harrison, 1995a), Mele-Fila (Clark, 1995), and Selayarese (Mithun and Basri, 1986); and some varieties of Arabic (Cowell, 1964; Erwin, 1963). In dialects of Arabic word-final geminates are typically present underlyingly (can attract stress), but often are required to degeminate and surface as singletons. As a result, for example, in Iraqi Arabic only word-initial and medial geminates are realized (Erwin, 1963).

A variety of the modern Greek language, Cypriot Greek, is spoken on the island of Cyprus. Cypriot Greek, like a few other varieties of Greek language, has lexical geminates which are found only word-initially before vowels or word-medially between vowels, in native words. Although nasal+geminate sequences are attested in a limited number of loanwords, native phonology does not permit consonant-adjacent gemination. Examples of word-initial and intervocalic geminates are shown in 7.40 and 7.41. Gemination can also result from consonant assimilation at the morpheme boundaries and at the word boundaries, as shown in 7.42 and 7.43. Examples are from Armosti (2009).

(7.40) [pefti] “Thursday” - [ppefti] “he falls”

(7.41) [xaparin] “piece of news” - [apparin] “horse”

(7.42) /tin fɔnin/ - [tiffɔnin] “the voice” (acc.)

(7.43) /na tɔn ðɔ/ - [na tɔððɔ] “to see him”

A peculiar feature of Cypriot Greek geminate stops is that they are heavily aspirated compared to their singleton counterparts. Based on the aspiration feature,

Lab	Lab-Dent	Dent	Alv	Pal-Alv	Vel
p			t		k
				ʧ	
	f v	θð	s	ʃ	x ɣ
m	n				
	l				
	ɾ				

Table 7.6: Consonantal phonemes of Cypriot Greek.

Armosti (2009) groups tautomorphemic and assimilated Cypriot Greek geminates into the category of true geminates because both types exhibit aspiration. He classifies postlexical concatenation of identical consonants across word boundaries (7.44) as false geminates because they are characterized by extended duration alone but lack the aspiration.

(7.44) /ɛn nʧip palja/ - [ɛnʤippaʎʎa] "they are old jeeps"

The consonant inventory of Cypriot Greek includes bilabial, alveolar, and velar voiceless stops; palato-alveolar (in some accounts palatal) affricates; labiodental, interdental, alveolar, post-alveolar, and velar fricatives; bilabial and alveolar nasals; and the liquids [r] and [l]. Some sources include alveolar affricates (Armosti, 2009) and palatal glides (Newton, 1972). There is no phonemic voicing contrast for stops and affricates. Voicing occurs allophonically after nasal consonants and voiced fricatives, depending on the dialect; otherwise, stops and affricates are voiceless. Consonantal phonemes of Cypriot Greek are summarized in table 7.6 (based on Newton, 1972 and Armosti, 2009).

All of these consonantal phonemes can contrast as geminates and singletons, apart from the alveolar and palato-alveolar fricatives [z] and [ʒ] which are always long intervocalically.[6] Armosti (2009), who posits voiceless alveolar affricates in Cypriot

[6] According to Armosti (2009) [ʒ] is a palatalized allophone of [zz], while single [z] occurs only as an allophone of [s].

Greek, also describes them as inherently long in intervocalic position. Examples are shown in 7.45–7.47.

(7.45) [pezzɔ] "I play"

(7.46) /maxazzja/ - [maxaʒʒa] "shops"

(7.47) [papu͡ʦʦ] "shoe"

Geminates do not surface in conjunction with other consonants (no pre- or post-consonantal geminates are allowed). This is supported by the evidence from two processes: first, assimilation is blocked if a postconsonantal geminate would result. Normally an alveolar nasal [n] or a lateral [l] followed by a palatal glides become a palatalized geminate as shown in 7.48–7.49 (from Armosti, 2009):

(7.48) /xalja/ [xaʎʎa] "carpets"

(7.49) /ti(ɣ)anja/ [tiaɲɲa] "frying pans"

But when another consonant precedes a [nj] or [lj] combination gemination is blocked, as shown in 7.50–7.51

(7.50) /ɣljazzo/ [ɣʎazzɔ] "I slip"

(7.51) /aɾnja/ [aɾɲa] "lambs"

Second, word-final alveolar nasals, for example in the definite articles *ton* (masc.) and *tin* (fem.), delete before geminate-initial words (examples in 7.52–7.55 from Muller (2001):

(7.52) [ton tixon] "the wall"

(7.53) [tin petteran] "the mother-in-law"

(7.54) [to pparan] "the money"

(7.55) [to ttavan] "the stew"

Nasals delete in a similar fashion before certain consonant clusters:

(7.56) [to flokkon] "the mop" (*nfl* is an illegal cluster)

(7.57) [tin kremman] "the cream"(*nkr* is an allowed cluster)

Muller (2001) interprets this as evidence for the analogous behavior between geminate consonants and consonant clusters and proposes an analysis where n-deletion is triggered by a necessity to block illegal consonantal clusters. However, underlying heteromorphemic geminates are typically viewed as single segments with long articulation rather than clusters of identical consonants. Therefore, a sequence such as /ntt/, where [t] is a geminate, should be allowable since [n] followed by [t] is attested as an onset cluster: [ntinnume] "I get dressed" (Newton, 1972). An alternative explanation is that the nasal deletes before geminate-initial words because of the distinctiveness-based prohibition against consonant-adjacent geminates.

Distribution of durational contrasts in Cypriot Greek is accounted for by ranking MinDist$_{WI}$ above MaxContrast, as shown in tableau 7.58.

(7.58)

	$\text{MD}_{\_C}$	MD_{WI}	MaxC	MD_{V_V}	Lazy
☞1a. ata-atta					*
1b. ata			*!		
1c. atta			*!		*
☞2a. ta-tta				*	*
2b. ta			*!		
2c. tta			*!		*
3a. atCa-attCa		*!		*	*
☞3b. atCa			*		
3c. attCa			*		*!
4a. at-att	*!	*		*	*
☞4b. at			*		
4c. att			*		*!

In this grammar MinDist_{WI} allows all contrasts with distinctiveness at the level of word-initial context and higher to pass. MaxContrast prevents neutralization in intervocalic and word-initial environments, and Lazy selects the least effortful option (singleton) among the remaining non-contrastive candidates in the preconsonantal and word-final environment.

The distribution of geminate consonants in Cypriot Greek can also be accounted for with the more general constraints on the types of consonant clusters allowed. Muller (2001) takes this approach, deriving n-deletion from the restriction on the consonantal clusters not adhering to a certain sonority profile. This analysis provides

a unified account for the behavior of geminates and consonant clusters without introducing additional constraints. It can also explain the absence of word-final geminates in Cypriot Greek, which does not allow word-final consonant clusters. There are, however, some advantages to the approach proposed here. First of all, it does not require a re-analysis of geminate representation as clusters to accommodate the fact that they behave as consonantal clusters in Cypriot Greek. The present approach can capture the distribution of durational contrast without referring to the distribution of consonantal clusters.

In addition, treating geminates as clusters in this particular case does not allow us to make connections to other languages, where similar restrictions apply to geminations but not consonantal clusters. For example, in Iraqi and some varieties of Syrian Arabic, surface gemination occurs word-initially and intervocalically, and not word-finally (Cowell, 1964; Erwin, 1963). Word-final consonant clusters are nevertheless permitted in these dialects. Thus, there is no reason to prohibit word-final geminates on the basis of a general restriction against consonantal clusters in this position. Geminates may also be found in places where clusters are scarce. In Selayarese initial clusters are very limited — only prenasalized consonants and preglottalized voiced consonants are allowed — but geminates of all types, including voiceless stops, occur freely (Mithun and Basri, 1986).

Thus, the approach proposed here may require an augmentation of the grammar at the level of a single language, but from the point of view of linguistic typology it provides a unified analysis of geminate distribution.

7.8 Maltese

Arabic and its dialects exhibit a range of tolerances towards geminate consonants in various positions. Underlyingly, geminates are found in Arabic word-initially, word-finally, intervocalically, and in consonant-adjacent positions. However, many Arabic grammars point to a tendency for phonetic degemination in the word-final position, where an underlying presence of long consonants is often detectable only by their ability to attract stress. In Iraqi Arabic final long consonants are degeminated in

speech (Erwin, 1963); in Syrian Arabic phrase-final position is a locus for degemination (Cowell, 1964). Maltese is another language reported to neutralize consonant length in word-final position (Borg, 1997b).

Similarly, consonant-adjacent position is often targeted by the neutralization process. In Iraqi Arabic long consonants degeminate before another consonant: /dabbrat/ [dabrat] "she arranged", /salltak/ [saltak] "your basket" (Erwin, 1963). Syrian Arabic is reported to degeminate preconsonantally as well: /waʔʔfi/ [waʔfi] "stop" (fem.) (Cowell, 1964).

Thus, there are at least three types of grammars with respect to distribution of geminates among dialects of Arabic: those that allow only word-initial and intervocalic geminates (some varieties of Syrian Arabic, Iraqi Arabic, possibly Cypriot Arabic), those that allow word-initial, word-medial, and consonant-adjacent geminates (some varieties of Syrian Arabic), and those that allow word-initial, word-medial, consonant-adjacent, and word-final geminates (Moroccan Arabic). There are also reports of dialects of Arabic that exclude word-initial gemination, e.g., Gulf Arabic. These, however, may also require degemination of consonant-adjacent and final geminates, thus limiting the inventory to intervocalic geminates only (Hoffiz, 1995).

Maltese stands out among the dialects of Arabic due to its historical and cultural isolation from the Arabic spoken in the Arabic countries. In addition to the geographic distance from other Arabic-speaking communities Maltese came into a prolonged contact with English and varieties of Italian in the course of its history, giving Maltese its significant linguistic distinctness from other Arabic-based languages. Although its grammatical core is undoubtedly Arabic, most of the recent lexical expansion is due to English and Italian influences.

The consonantal inventory of Maltese differs from Arabic in the loss of emphatic consonants, velar, and pharyngeal fricatives and acquisition of some additional consonants through contact with Italian. Current consonantal inventory for Standard Maltese spoken in urbanized areas, following Borg (1997b), is shown in table 7.7.

Both vowel and consonant duration is contrastive in Maltese. Geminates are found in abundance intervocalically (7.59–7.60), but are also allowed word-initially (7.61–7.62), and preconsonantally (7.63–7.64).

p b		t d				k g	ʔ
	f v		s z	ʃ ʒ			h
			ts dz	tʃ dʒ			
m			n				
			l				
			r				
w					j		

Table 7.7: Consonantal phonemes of Maltese.

(7.59) [ferah] “he rejoiced” - [ferrah] “he made happy”

(7.60) [safar] “travel” - [saffar] “he whistled”

Word-initial gemination in most dialects of Arabic arises from assimilation between various consonantal prefixes and stem consonants. Definite article /l/ fully assimilates to the stem-initial coronal consonant in Moroccan Arabic: [t-trab] “the ground”. In Maltese, alveolar nasal assimilates to stem-initial sonorants in the imperfect paradigm of verbs.

(7.61) [mmu:r] “I go” from /nmu:r/

(7.62) [rri:d] “I want” from /nri:d/

However, after a pause or a consonant-final word, initial geminates require an epenthetic vowel: /hi ssir/ “she becomes” but /int issir/ “you become”. Thus, essentially, word-initial geminates in Maltese are only allowed between two vowels, the first one supplied by the previous word or epenthesis.

Unlike many dialects of Arabic, Maltese is reported to preserve its consonantal length distinction in consonant-adjacent positions at least in some of its spoken varieties (Borg, 1997b):

(7.63) [nizlu] “they descended” - [nizzlu] “they brought down”

(7.64) [ʧahdet] "she denied" - [ʧahhdet] "she deprived"

Word-finally, consonant length tends to be neutralized in Maltese: [fomm-i] "my mouth", but [fom] "mouth" (Borg, 1997b; Cowan, 1970; Erickson, 1973).[7]

The proposed theory predicts the possibility of a language that allows intervocalic, word-initial, and preconsonantal geminates but not word-final geminates. However, Maltese cannot be used as an example since word-initial geminates in this language are repaired by epenthesis unless preceded by a vowel. In fact, it turned out to be rather difficult to identify a language which prohibits a word-final contrast but allows a contrast word-medially before consonants. This is possibly another piece of evidence that word-final degemination is driven by a general need to exclude *preconsonantal* geminates. A single alternative candidate to exemplify this type of distribution among the languages I have examined is Syrian Arabic. Cowell (1964) reports that in the Damascus dialect of Syrian Arabic any consonant can geminate intervocalically, and those resulting from assimilation between consonantal prefixes and proclitics and the first consonant of the stem also appear as initial geminates. Word-finally, "long consonants do not actually contrast with short ones; writing them double simply serves to show the position of the accent and their potential significant length before vowels" (Cowell, 1964, pp. 23–24). Thus, it appears from this description that only prevocalic final geminates get realized phonetically as long.

With respect to preconsonant geminates, Cowell (1964) notes that in many parts of Greater Syria such geminates are rare and, if found, are pronounced as short. Cowell (1964) also adds that in some regions the length is preserved, at least optionally. If these dialects, as Cowell (1964)'s account seems to imply, share the prejudice against word-final geminates, they are captured by the tableau in 7.65, with MaxContrast ranked below MinDist_C.

[7] Hume et al. (2010) reports a significant difference in duration between word-final geminates and singletons in Maltese. It is possible that word-final degemination is mostly found in casual conversational speech, while in the lab setting participants tend to revert to a more formal speech style characterized by hypercorrection in pronunciation.

(7.65)

	$\text{MD}_{\_C}$	MaxC	MD_{WI}	MD_{V_V}	Lazy
☞1a. ata-atta					*
1b. ata		*!			
1c. atta		*!			*
☞2a. ta-tta				*	*
2b. ta		*!			
2c. tta		*!			*
☞3a. atCa-attCa			*	*	*
3b. atCa		*!			
3c. attCa		*!			*
4a. at-att	*!		*	*	*
☞4b. at		*			
4c. att		*			*!

In this grammar $\text{MinDist}_{\_C}$, as the least strict constraint on contrast distinctiveness, eliminates only word-final contrasts. MaxContrast immediately follows and ensures contrastive distribution in all other positions. Lazy selects a winning singleton word-finally.

7.9 Tashlhiyt Berber

Finally, there are languages that choose the number of contrasts over the perceptibility of the difference between the contrasting phonemes. Berber allows geminate

consonants in all four positions: word-initial, intervocalic, consonant-adjacent, and word-final. Languages of this type are not very common — I have located only a few examples: in addition to Berber they include geographically close to Berber Moroccan Arabic (Harrell, 1962; Heath, 1997), Jordanian Arabic (Abu-Abbas et al., 2011) and, with some restrictions, Thurgovian Swiss German (Kraehenmann, 2001).

Berber languages belong to an Afro-Asiatic phylum and are spoken in several regions of Northern Africa, including Morocco and Algeria. All Berber languages have a geminate-singleton distinction, but the primary cue of duration is often supplemented by additional cues, which is why this difference is often considered to be between tense and lax consonants rather than between long and short consonants.

The degree to which these secondary cues are used differs among Berber languages. In some, only [n, m, l, r, h] and voiced pharyngeal fricatives express the distinction exclusively through duration. Common changes accompanying duration differences include a voicing distinction (short voiced vs. long voiceless) or fortition: short fricative vs. long affricate, short approximant vs. long plosive; short spirantized consonant vs. long plosive consonant (geminates avoid spirantization); or short voiced velar fricative vs. long voiceless uvular stop (Kossmann and Stroomer, 1997)

Tashlhiyt Berber expresses the geminate-singleton distinctions for most consonants through durational difference (Kossmann and Stroomer, 1997; Ridouane, 2007), with the exception of emphatic [d], which has a voiceless long counterpart: [ḍ] - [tṭ], the voiced velar fricative, which has a long voiceless uvular stop counterpart: [ɣ] - [qq], and the labiovelar approximant with a long labialized voiced velar stop counterpart: [w] - [gg^{w}].

A consonant inventory of Tashlhiyt Berber is given in 7.8 (sources: Kossmann and Stroomer (1997); Ridouane (2007))[8].

All dental consonants have contrastive pharyngealization, velar and uvular consonants have contrastive labialization. Ridouane (2007) reports that aryepiglottal and glottal geminates are not as common as dental or velar ones and are found mainly in Arabic loanwords. Similarly, pharyngealized (emphatic) nasal and lateral geminates

[8]Ridouane (2007) lists uvular instead of velar fricatives and aryepiglottal rather than pharyngeal fricatives.

Lab	Dent	Pal	Vel	Uvul	Phar	Glot
b	t d		k g	q		
f	s z	ʃ ʒ	x ɣ		ħ ʕ	h
m	n					
	r					
	l					
w		j				

Table 7.8: Consonantal phonemes of Tashlhiyt Berber.

are also less frequent than non-pharyngealized ones and are restricted to Arabic vocabulary. Pharyngealized palato-alveolar fricatives [ʃˤ] and [ʒˤ] occur only as singletons. Plain uvular stops occur only as geminates.

Apart form these restrictions, gemination is abundant in Tashlhiyt Berber vocabulary. There are also virtually no limits on the distribution of the geminate consonants across positions in the word and neighboring segments. Geminates can be found intervocalically, as well as word-initially and word-finally, and in consonantal clusters, including word-initial and word-final clusters. Examples in 7.66–7.68 show geminate stops and fricatives in word-initial, medial, and final positions.

(7.66) [tid] "those" - [ttid] "soap"

(7.67) [itid] "for those" (fem.) - ittid "approach"

(7.68) [ifit] "he gave it" (masc.) - ifitt "he gave it" (fem.)

Examples in 7.69–7.71 show pre- and postconsonantal geminates. Consonant-adjacent environment can be combined with a word-edge position as in 7.71. Clearly, this language sacrifices the distinctiveness of the contrast in favor of the contrast maintenance across all positions. To capture this distribution MaxContrast needs to be ranked above all the MinDist constraints, as shown in 7.72.

(7.69) [askka] "tomorrow"

(7.70) [assfan] “the day before yesterday”

(7.71) [iftt] “he gave it”

(7.72)

	MaxC	MD$_{_C}$	MD$_{WI}$	MD$_{V_V}$	Lazy
☞1a. ata-atta					*
1b. ata	*!				
1c. atta	*!				*
☞2a. ta-tta				*	*
2b. ta	*!				
2c. tta	*!				*
☞3a. atCa-attCa			*	*	*
3b. atCa	*!				
3c. attCa	*!				*
☞4a. at-att		*	*	*	*
4b. at	*!				
4c. att	*!				*

When ranked above all the relevant MinDist constraints, MaxContrast establishes consonant length contrast in all the contexts, independently of the corresponding contrast distinctiveness. The effects of the MinDist constraints and Lazy are irrelevant in this grammar.

7.10 The factorial typology

7.10.1 The basic model

Before embarking on the task of modeling the crosslinguistic typology of contrastive geminates using the set of constraints proposed above, one needs to underline once again the fact that in the business of building typology on the phonetic evidence the predictions may hardly be precise without precise phonetic evidence. The latter is often unavailable due to the extremely labor-intensive and time-consuming character of the data collection process. Thus, most phonetically-based analyses rely on basic phonetic evidence, which, however, seems to suffice to outline at least a broad picture of the predicted typology.

The constraints on contrasts proposed here, I believe, have general validity, and do participate in the formation of the crosslinguistic patterns of geminate distribution. They are relativized to the *degree of perceptibility* singleton-geminate contrasts have in distinct contextual environments. The degree of perceptibility was established in a series of experiments, where perceptibility of duration of the alveolar fricative [s] was tested in intervocalic, initial, final and pre-sonorant position. Strictly speaking, these constraints only predict *with precision* the behavior of geminate consonants in a hypothetical language where only alveolar fricatives have contrastive length and only liquids and nasals are allowed to follow. However, I will assume, pending more detailed experimental evidence, that to a certain degree these data can be generalized to a greater variety of consonants and environments. This is, of course, a simplification, but a necessary one at the moment.

Permutations of the five constraints introduced above result in $5! = 120$ possible rankings but only five distinct output patterns. These patterns are summarized in table 7.9 (contrastive outputs are shaded). This is a core model of contrast dispersion for geminate consonants and will be referred to in the remainder of the chapter as the *basic model*.

These five output patterns represent five possible language types the basic model predicts. Bengali, Cypriot Greek, some varieties of Syrian Arabic, and Tashlhiyt

Output 1	Output 2	Output 3	Output 4	Output 5
ata	ata-atta	ata-atta	ata-atta	ata-atta
ta	ta	ta-tta	ta-tta	ta-tta
atCa	atCa	atCa	atCa-attCa	atCa-attCa
at	at	at	at	at-att

Table 7.9: The factorial typology: Basic model.

Berber reviewed above are representative of the output patterns 2, 3, 4, and 5 respectively. Pattern 1 represents languages that do not allow contrastive relationship between short and long consonants at all, and is derived in this model by ranking the effort minimization constraint, Lazy, above MaxContrast, as shown in 7.73.

(7.73)

	$\text{MD}_{\_C}$	MD_{WI}	MD_{V_V}	LAZY	MAXC
1a. ata-atta				*!	
☞1b. ata					*
1c. atta				*!	*
2a. ta-tta			*!	*	
☞2b. ta					*
2c. tta				*!	*
3a. atCa-attCa		*!	*	*	
☞3b. atCa					*
3c. attCa				*!	*
4a. at-att	*!	*	*	*	
☞4b. at					*
4c. att				*!	*

Relevant for the distributional typology of geminate consonants are the asymmetries that are shown by the factorial typology in 7.9. For example, contrast in word-final position is found in one output pattern. The same pattern allows contrast in all other positions. This relationship between outputs is an *implicational universal* — it holds true for all the languages produced by the model, independently of ranking. Extracting implicational universals from the grammar allows us to see the outputs of the grammar not as random combinations of winning candidates but as a systematic structure where the presence of one particular output form has implications for the rest of the language.

The implicational universals contained in the model presented here make intuitive sense because it is reasonable to expect a language which allows low-distinctiveness final contrasts to also capitalize on having the contrast in positions with higher distinctiveness, such as word-initially, or intervocalically. Formally, this effect is achieved by subjecting the candidates to a family of MinDist constraints of varied degrees of strictness, where each candidate that violates more permissive constraints also violates all the stricter ones. For example, word-final durational contrasts do not have the distinctiveness of preconsonantal contrasts, and it follows that they also do not reach the standards for distinctiveness of word-initial, and intervocalic contrasts.

Implicational universals can be extracted by hand by analyzing the factorial typology a model generates. There exists software (Anttila and Andrus, 2006) that takes a factorial typology as an input and extracts each implicational universal as a pair of input-output mappings (T-order Generator, where "T" stands for "typological"). The following implicational universals are found in the basic model:

(7.74) ata → ta → atCa → at

Neutralization intervocalically implies neutralization word-initially, which implies neutralization preconsonantally, which implies neutralization word-finally.

(7.75) at-att → atCa-attCa → ta-tta → ata-atta

Contrast word-finally implies contrast preconsonantally, which implies contrast word-initially, which implies contrast intervocalically.[9]

7.74 and 7.75 also contain transitive relationships, that is, since contrast word-finally implies contrast preconsonantally and contrast preconsonantally implies contrast word-initially, contrast word-finally also implies contrast word-initially, and so on. So, there are actually six implications contained in each 7.74 and 7.75. These can be fairly incomprehensible if simply listed, pair by pair. T-order Generator presents the implicational universals of the model as a directed graph, as shown in figure 7.1.

[9]Bradley (2001) established a very similar implicational hierarchy for rhotic duration contrasts: word-final, pre- and postconsonantal → word-initial → intervocalic, where a contrast in a given position entails contrast in positions to the right.

Each box contains an input-output pair and each arrow corresponds to an implicational relationship (allowing for transitivity). We can see how the left part of the figure 7.1 corresponds to 7.74 and the right part corresponds to 7.75.

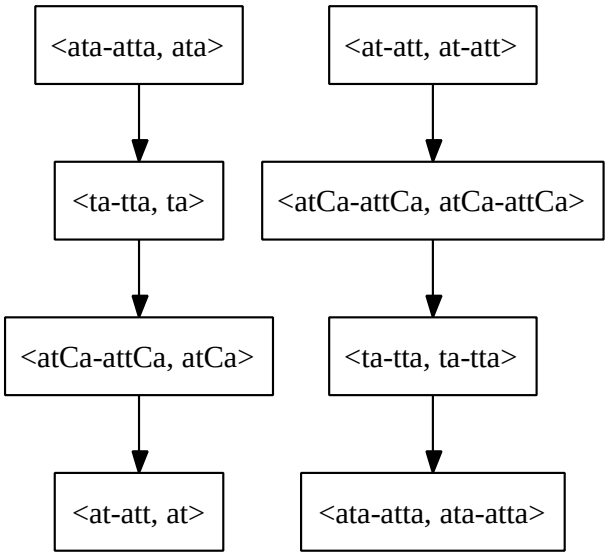

Figure 7.1: Implicational universals in the factorial typology.

Since the factorial typology is built step by step, the implications shown here are not final and will be revised in the following sections.

Table 7.10 presents examples of the language types predicted by the basic model. There are representatives of each of the types, although type 4 turned out quite difficult to locate. Apart from the data on Syrian Arabic (Cowell, 1964), it appears that languages prohibiting word-final geminates in non-prevocalic position tend to exclude preconsonantal geminates as well. This contradicts the prediction of the basic model; however, I will offer here some speculations possibly explaining this contradiction. The preconsonantal condition tested in the present experiment involved a following sonorant — liquid or nasal — some of the most vowel-like consonants. Typological data suggest that languages may prohibit consonant-adjacent geminates with the exclusions of the sonorant-adjacent ones (e.g., Italian, Finnish, fake geminates in Hungarian). It is currently not known how the *overall* perceptibility index for a

	Grammar	Language
Type 1	No geminates	English Mandarin Spanish
Type 2	Intervocalic geminates	Amharic Bengali Madurese Maranungku Oromo Somali Yagua
Type 3	Intervocalic and W-I geminates	Cypriot Greek Iraqi Arabic Kiribati Piro Selayarese
Type 4	Intervocalic, W-I, and pre-C geminates	Syrian Arabic
Type 5	Intervocalic, W-I, pre-C and W-F geminates	Moroccan Arabic Berber

Table 7.10: Examples of the five language types predicted by the basic model.

contrast in a particular contextual environment is calculated in languages. A few possibilities may be considered. On the one hand, a language may prohibit all preconsonantal geminates based on the strongest offender: for example, a pre-obstruent geminate is likely to have a very low perceptibility index. Thus, all preconsonantal geminates are excluded in such languages. Other languages seem to choose a more phonetically detailed approach, allowing only cases with a higher perceptibility index (sonorant-adjacent). For example, Italian only allows pre-sonorant geminates: *applicare*, *soffrire*.

On the other hand, some kind of aggregate value may be computed, where all the likely cases are taken into account and the decision is made based on the *average* perceptibility of all the possible combinations. If the aggregate approach is taken, an overall perceptibility index of preconsonantal contrasts would certainly be lower than that of just pre-sonorant ones. It is also possible that it is *not higher* than the aggregate perceptibility index of word-final contrasts. Thus, excluding both simultaneously is consistent with the perceptibility-based approach if more consonant types are included in the calculation of the perceptibility index. This is a possible way to revise the model to improve its typological predictions.

In the same line of reasoning, an aggregate perceptibility index for *word-initial geminates* may also be expected to be lower than that of the pre-sonorant contrasts. Since the word-initial geminates tested in this environment were fricatives, their duration perceptibility was quite high. Thus, languages may exclude *all* word-initial geminates because of the possibility of a very bad contrast (initial voiceless stops) or because of a low aggregate value of the initial contrasts. At the same time, pre-sonorant or post-sonorant geminates may be allowed. This would explain languages like Italian and Finnish, which allow intervocalic and sonorant-adjacent geminates (pre-sonorant in Italian, post-sonorant in Finnish).

Languages of type 2 are quite easy to locate. This grammar may represent the most common treatment of consonant duration contrast. Type 3 is also not unusual, although many of the languages included in this category belong to the same family: Austronesian. Many of these languages also tend to have a rather restrictive syllable structure where codas are prohibited or limited to a very small set of phonemes. The

number of languages in this category may also be somewhat inflated since Muller (2001)'s survey, which focuses entirely on languages with word-initial gemination, was used here as a partial source of data. Type 5 is substantially more rare than types 2, 3, or, especially, type 1, which is the most frequent pattern.

Clearly, this typology does not cover the whole range of variation among languages with contrastive consonant duration. There are several likely reasons why this is the case. As discussed above, for some of the languages that currently do not fit into the typology, perceptibility is still a probable explanation when more detailed phonetic data are available.

However, it would be naive to expect that the distribution of geminate consonants is governed by perceptibility-related constraints alone. Undoubtedly, there are other relevant factors that come into play, including, for example, constraints on syllable structure. In section 7.11 I will demonstrate how the incorporation of syllable-weight related constraints into the basic model generates a number of languages not predicted by the basic model. In particular, this approach concerns languages which allow word-final geminates but not word-initial, or, in some cases, preconsonantal ones, such as dialects of Norwegian, Icelandic, Swedish, and German. I will also touch upon languages like Wolof, Persian, and Amharic, for which phonemic word-final geminates are reported but are viewed as neutralized in the current approach because their realization appears to be limited to the prevocalic position.

To begin, I will consider another exceptional type of geminate distribution: languages that allow word-initial but not intervocalic geminates. Muller (2001) surveys 29 languages with word-initial geminates and reports five that do not allow word-medial geminates: Ngada, Nhaheun, Pattani Malay, Yapese, and Sa'ban.

Some of these may be only apparent counterexamples. For instance, Muller (2001) notes that most words in Nhaheun are monosyllabic, and as a result there is little possibility for a word-internal contrast. In Ngada, word-initial gemination is a result of the compensatory lengthening following the root-initial schwa deletion, as shown in 7.76 (Jawanai and Grimes, 1995; Moore, 1980). A similar process also takes place word-medially, where in certain environments vowels reduce to schwa and trigger lengthening of the following consonant, as shown in 7.77. This appears to be an

instance of phonetic lengthening, not an underlying contrastive length distinction.

(7.76) /əma/ [mma] "father"

(7.77) /gazi/ [gəzzi] third person oblique pronoun

However, there are also genuine exceptions to the implicational relationship between intervocalic and word-initial contrasts, such as Pattani Malay. These languages can be taken as evidence for the effect of the constraint protecting phonological contrasts in the word-initial position, defined in 7.78 as a sub-type of the MaxContrast constraint.

(7.78) MaxContrast$_{WI}$ = In word-initial position, maintain a contrast along a given phonological dimension.

The motivation for contrast maximization in initial position and its effects on the typology of geminates are discussed in the following section. Here I begin to extend the model beyond the basic cases.

7.10.2 The initiality factor

The exceptional status of word-initial position has been noticed by linguists. Smith (2005) classifies it as a psycholinguistically prominent position and discusses a number of augmentation processes warranted by the word-initial position. Kirchner (2004) allows for special constraints blocking consonant lenition in certain environments, in particular word-initial position. He proposes that "allocation of more robust cues to word-initial position may be viewed as reflecting the greater importance of word-initial consonants in lexical access". Casali (1996) points out that word-initial segments are likely to remained unchanged even when poorly cued. Steriade (2001) uses this argument in her discussion of positional effects in consonant cluster assimilation where she also allows for the "initial deviation" — the fact that initial position is contrast-preserving, even in the absence of robust acoustic cues. Steriade (2001) notes that initial deviation is a general effect, not specific to any particular phonemic

contrast. For a review of the psycholinguistic evidence for the salience of word onsets see Hawkins and Cutler (1988) and references therein.

Thus, the introduction of a constraint preserving phonological contrast in word-initial position appears well-motivated. The effect of this constraint on the grammar described above is that an additional language type is produced, where only a word-initial geminate-singleton contrast is permitted (see tableau in 7.79).

(7.79)

	MaxContrastWI	Lazy
1a. ata-atta		*!
☞1b. ata		
1c. atta		*!
☞2a. ta-tta		*
2b. ta	*!	
2c. tta	*!	*
3a. atCa-attCa		*!
☞3b. atCa		
3c. attCa		*!
4a. at-att		*!
☞4b. at		
4c. att		*!

The factorial typology of the model with this additional constraint is summarized in table 7.11. Output 6 is a new language type, not found in the factorial typology in 7.9. It is a consequence of the additional MaxContrast$_{WI}$ constraint.

Output 1	Output 2	Output 3	Output 4	Output 5	Output 6
ata	ata-atta	ata-atta	ata-atta	ata-atta	ata
ta	ta	ta-tta	ta-tta	ta-tta	ta-tta
atCa	atCa	atCa	atCa-attCa	atCa-attCa	atCa
at	at	at	at	at-att	ta

Table 7.11: The factorial typology with the initiality constraint.

The implicational universals contained in this typology also differ somewhat from those shown in 7.74–7.75 and figure 7.1. The main difference is that under the effect of MaxContrast$_{WI}$ the implicational relationship between intervocalic and word-initial contrast is destroyed. Now, a contrast word-initially does not imply a contrast intervocalically, and neutralization intervocalically does not imply neutralization word-initially, as shown in figure 7.2.

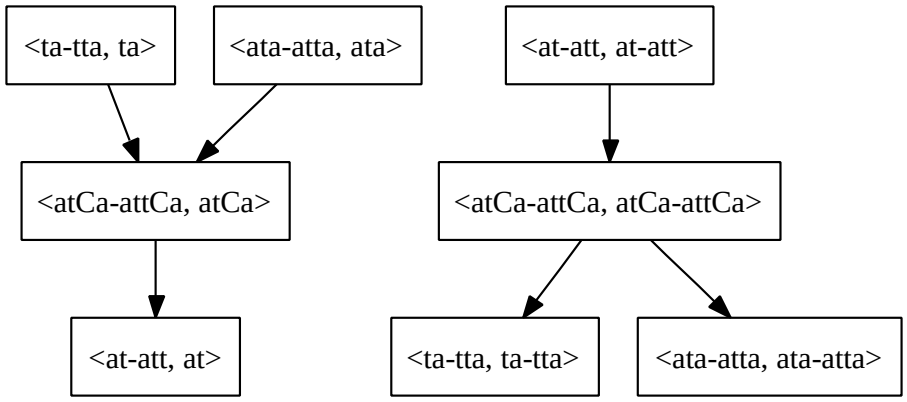

Figure 7.2: Implicational universals with the initiality constraint.

Again, it should be kept in mind that the experiments that the current analysis relies on tested only the relative perceptibility of the durational contrast in alveolar fricatives and only in intervocalic, word-initial, word-final, and consonant-adjacent positions. Alveolar fricatives are well known as sounds most resistant to positional neutralization due to their rich internal acoustic cues, as opposed to stops, which

largely rely on external cues contained in vowel transitions. This is exemplified by frequent instances of metathesis where a stop is relocated to a more perceptually forgiving vowel-adjacent position while a fricative is moved to a more disadvantaged position, as shown in 7.80–7.82.

(7.80) Hebrew: /it-saper/ → [istaper] "get a haircut" (2sg. masc.) (Kenstowicz, 1994)

(7.81) Singapore English: /lisp/ → [lips] (Anttila et al., 2008; Mohanan, 1992)

(7.82) Faroese: /baisk-t/ → [baikst] (Hume and Johnson, 2001)

This sibilant fricative is characterized by a constant, relatively high intensity frication noise throughout its production, which is likely to facilitate the task of estimating its duration in comparison to stops, where the cues to the beginning and end-point of the segment are transient and relatively weak or completely absent (onset of closure/closure voicing, release burst). Thus, it is not surprising that alveolar fricatives in consonant-adjacent and word-edge positions fared quite well in the perceptual test of relative duration. If stops were tested instead a more dramatic difference between contextual positions would be expected. An implication that these experimental limitations have for the present theoretical account is that, since consonantal inventories clearly do not consist of sibilant fricatives only, not all word-initial, word-final, and consonant-adjacent geminates would enjoy the same degree of perceptual distinctiveness, and the overall perceptual index of the contextual position may need to be an aggregate over all the possible consonant types.

The family of MinDist constraints may need to be further broken down to discriminate between the relative perceptibility of the contrast between short and long consonants with respect to the contextual environment *and* the type of consonant involved. A prediction that would follow from this modification is that we would expect to find languages where only certain types of consonants are allowed in perceptually weak positions, in particular those that provide more robust acoustic cues to the duration of the articulation, that is, continuants, including sonorants and fricatives. This prediction is borne out to a certain degree: Muller (2001) reports that several

of the languages in her sample of languages with word-initial geminates place some restrictions on the type of consonants allowed in word-initial position. In Hatoma voiceless obstruent and nasal geminates are found word-medially, but only continuant geminates are allowed word-initially. However, in other cases the restrictions do not appear to follow the predicted direction: e.g., Thurgovian Swiss German limits word-initial geminates to stops (Kraehenmann, 2001).

Morphological factors play an important role in determining the restriction on the types of word-initial geminates allowed in languages — not surprisingly since a lot of morphology takes place at word edges. In dialects of Arabic word-initial geminates often result from the assimilation in the combinations of certain one-consonant prefixes, for example, markers of definiteness or proclitics, with stem-initial consonants. Therefore, it is not unlikely that some of the restrictions on word-initial geminates not apparently governed by considerations of perceptibility can be attributed to morphological factors.

While geminates that result from assimilation on the boundaries of morphemes are typically considered "true" geminates since they usually behave like underlying geminates with respect to relevant phonological phenomena, such as integrity and inalterability, concatenated geminates where no assimilation is involved are referred to as "fake" geminates, and they indeed behave differently in several respects. However, phonetically, there is little differences between true and fake geminates (Lahiri and Hankamer, 1988; Pycha, 2010; Ridouane, 2010) and therefore both are expected to be subject to contrast perceptibility restrictions defined over *phonetic* representations that are used contrastively. The following section considers underlying and concatenated geminates from the perspective of the contrast dispersion approach.

7.10.3 Morphological factor

There is evidence that concatenated geminates are affected by the contrast perceptibility constraints in the same way true geminates are. In a number of languages underlying geminates are found only in adjacency to high sonority consonants such

as nasals and liquids. In Hungarian, fake geminates are degeminated next to obstruents but preserve their length next to liquids and are optionally degeminated next to nasals (Pycha, 2010). Interestingly, underlying geminates in Hungarian are always degeminated in adjacency to other consonants, sonorant or not. Thus, fake geminates are more likely to be realized in a perceptually challenging position than underlying geminates. This can be attributed to the tendency to preserve segmental material on the edges of morphological constituents. Since concatenated geminates are essentially *clusters* of identical consonants, each singleton half of such a geminate may act as a separate entity with respect to phonological constraints. A constraint that requires maintenance of a *consonant-zero* contrast at the level of the morpheme will act like DEP and MAX faithfulness constraints do in traditional OT in preventing the deletion (or insertion) of a consonant at the edge of morpheme and essentially counteracting the neutralization of the singleton-geminate contrast in cases of concatenated geminates. This constraint will not affect lexical geminates which are assumed to be single long segments rather than a cluster of two identical short ones.

(7.83) $\textsc{MaxContrast}_{C-0}$ = Maintain a consonant-zero contrast at the level of the morpheme.

To explain the action of this constraint, an example from Russian is given below. The two prefixes, *po* and *pod*, differ in terms of the presence of absence of the final consonant; that is, it is a consonant-zero contrast. If the concatenated geminate is neutralized in words where the prefix is followed by an identical stem-initial consonant, the contrast between the two prefixes is lost: *po, pod* → *po*. The constraint $\textsc{MaxContrast}_{C-0}$ requires the presence of this contrast, thus preventing the neutralization of the geminate.

(7.84) Russian: /po-dat^j/ "to hand in" - /pod-dat^j/ "to strike, to kick"

To model the Hungarian data it is necessary to postulate additional MinDist constraints. In particular, I will assume that a $\textsc{MinDist}\_C$ constraint can be further broken down into constraints that regulate contrast distinctiveness for geminate-singleton contrast followed by liquids, nasals, or obstruents. These are defined in 7.85

and 7.86. The MinDist_C constraint can be redefined as shown in 7.87. The underlying assumption is that more sonorous consonants provide a better environment for estimating the duration of the target consonant. Thus, perceptual distinctiveness of the contrast is higher before liquids than before nasals, and before nasals than before obstruents.

(7.85) MinDist$_L$ = Perceptual distinctiveness at least at the level of following liquid.

(7.86) MinDist$_N$ = Perceptual distinctiveness at least at the level of following nasal.

(7.87) MinDist$_O$ = Perceptual distinctiveness at least at the level of following obstruent.

The Hungarian data can be accounted for with the ranking shown in 7.88 (morphological boundary is indicated as |). Some constraints are omitted from this tableau for the considerations of space and because they are not ranked high enough to participate in the selection of the winning candidate.

(7.88)

	MD_N	MaxC_{C-0}	MD_L	MD_{V_V}	MaxC	Lazy
1a. atla-attla				*!		*
☞1b. atla					*	
1c. attla					*	*!
2a. atna-attna			*!	*		*
☞2b. atna					*	
2c. attna					*	*!
3a. attka-atka	*!		*	*		*
☞3b. atka					*	
3c. attka					*	*!
☞4a. at|la-at|tla				*!		*
4b. at|la		*!			*	
4c. at|tla		*!			*	*
☞5a. at|na-at|tna			*	*		*
5b. at|na		*!			*	
5c. at|tna		*!			*	*
6a. at|ka-at|tka	*!		*	*		*
6b. ☞at|ka		*			*	
6c. at|tka		*			*	*!

Output 1	Output 2
atka	atka
atna	atna
atla	atla
at|ka	at|ka
at|tna-at|na	at|na
at|tla-at|la	at|tla-at|la

Table 7.12: Variation in degemination of consonant-adjacent geminates in Hungarian.

There are only two output patterns produced by this grammar. These are listed in table 7.12. We can see that tautomorphemic geminates are always degeminated when adjacent to other consonants, while concatenated geminates degeminate next to obstruents, optionally degeminate next to nasals, and never degeminate next to liquids.

The full factorial typology of the model, which includes all the constraints discussed so far plus the morphological boundary constraint, generates 19 distinct output patterns (listed in Appendix A). In these 19 languages, both the morpheme-internal and morpheme-boundary geminates are increasingly likely to neutralize as contrast perceptibility decreases: V_V > WI > _C > WF. At the same time, neutralization in a morpheme boundary context is overall less likely than neutralization in a morpheme-internal context. Figures 7.3 and 7.4 demonstrate the implicational relationships in this model.

Figure 7.3 shows the implicational hierarchy for the contrastive outcome. We can see that maintaining the consonant length contrast in any given position morpheme-internally implies two things: (a) a morpheme-boundary consonant-length contrast will also be maintained in the same position: *at-att* implies *at|-at|t*; (b) a contrast will be maintained morpheme-internally in position of greater perceptual distinctiveness: *at-att* implies *atCa-attCa*. At the same time, maintaining a contrast on the boundary of morphemes in any given position implies maintaining a contrast on the boundary of morphemes in the position with a greater perceptual distinctiveness: *at|-at|t* implies

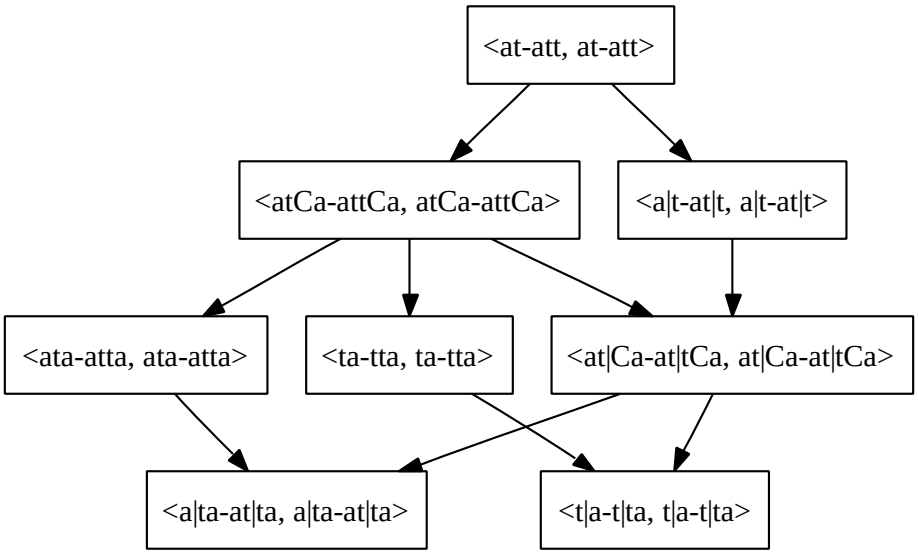

Figure 7.3: Implicational universals in the model with the morphological boundary constraint. Part 1: Contrast.

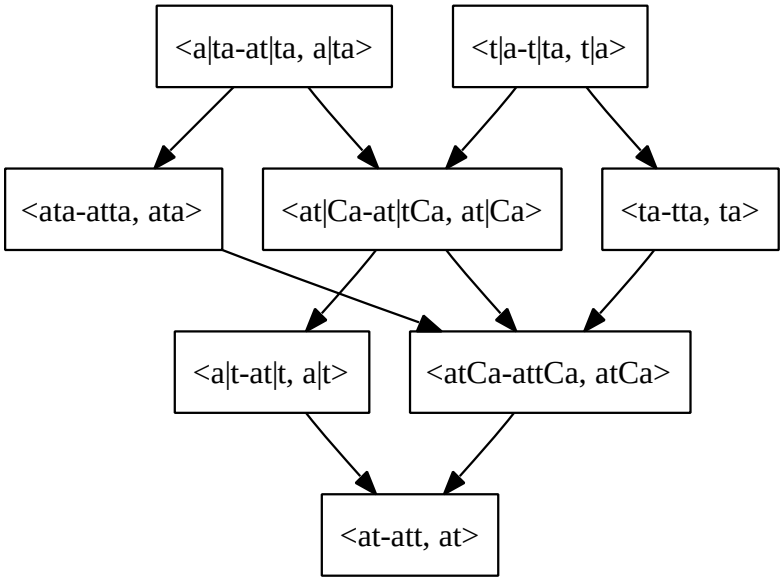

Figure 7.4: Implicational universals in the model with the morphological boundary constraint. Part 2: Neutralization.

at|Ca-at|tCa.

Figure 7.4 shows the implicational hierarchy for the neutralized outcome, and it is a reverse image of figure 7.3. Here, neutralization of the contrast in any given position on the boundary of morphemes implies (a) neutralization in the same position morpheme-internally: *a|ta* implies *ata* and (b) neutralization on the morpheme boundary in positions of lower perceptual distinctiveness: *a|ta* implies *at|Ca*.

The main result of this analysis is that geminacy on the morpheme boundary always takes precedence over geminacy morpheme-internally: if a languages allows true geminates in a particular environment, fake ones will also be allowed in the same position. If a language neutralizes fake geminates in a particular environment, true ones will also be neutralized there.

7.11 Stress effects

7.11.1 Typology of gemination and stress

The experimental evidence for perceptibility differences among consonant duration contrasts in different stress-related positions were mostly non-significant and cannot be used to motivate perceptibility-based constraints on the distribution of geminate consonants. Yet reports in the literature connecting gemination to stress are not unusual. Thurgood (1993, p. 2) lists Delaware, Somali, Egyptian Arabic, Tiwa, Karok, Goajiro, Moroccan Arabic, Luiseno, Hopi, Tzeltal, Maltese, Icelandic, Estonian, Island Carib, and Hindi-Urdu as languages where "long consonants are frequently if not exclusively preceded by a stressed vowel". Blevins (2004a) discusses cases of geminate evolution in post-tonic position in such Austronesian languages as Kelabit, Madurese, Sangir, Bugis (Buginese), Isnag, Konjo, as well as Southern Paiute and Norton-Sound Unaliq.

It is worth mentioning that in some of these examples gemination is not contrastive but rather an allophonic lengthening affecting all consonants in this position. In Diegueño consonants variably lengthen before stressed vowels (Langdon, 1970). In Urubu-Kaapor, plosives are lengthened in the onsets of stressed syllables (Kakumasu,

1986). In Island Carib consonants are lengthened in post-stress syllables, according to Taylor (1955), especially when followed by pause.

(7.89) Diegueño: /təˈkəsa:/ [təˈk:əsa:] "jaw" (Langdon, 1970)

(7.90) Urubu-Kaapor: /kaˈtu/ [kaˈt:u] "forest" (Kakumasu, 1986)

Apart from the phonetic effects of lengthening under stress, a survey of languages for which a stress-gemination connection has been reported reveals that syllable weight plays an important role in the phonology of these languages.

It has been recognized that geminate consonants play a special role in weight-sensitive systems. In particular, geminates are assigned the status of inherently *heavy* or moraic segments by moraic theory and are called upon when extra weight is required. Geminates are typically viewed as contributing a mora to the preceding syllable.

Therefore, it is not surprising that in weight-sensitive languages with a phonemic consonant length distinction, there is also a tendency for stress to co-occur with gemination, just like stress co-occurs with vowel length, whether it is because stressed syllables are required to become heavy or because stress is attracted to heavy syllables. Thus, in view of the correlation between weight-sensitivity and the reported preference for post-tonic gemination, I propose that it is the need to maintain the quantitative well-formedness of stressed syllables that is responsible for the stress-gemination connection.

The types of interaction can be divided into three categories: (1) geminates arise in post-stress environment, (2) stress is attracted to syllables with geminates, and (3) geminates in post-tonic environment are protected from degemination. Below I will discuss several representative examples of these types of behavior.

Geminates arise in post-stress position

It has been noticed that in Italian geminates exist in close connection with stress. Anderson (1984) established that the post-stress environment is relevant for three out

of four sources of geminates in Italian: (1) Latin geminates, (2) foreign borrowings, (3) gemination of single consonants, and (4) regressive assimilation. He proposed that Latin had a geminate formation process in the post-stress environment, as shown in 7.91. Foreign words were sometimes borrowed with geminate consonants already in place, but in some cases gemination occurred as part of adaptation to Italian phonology. In these cases, post-stress environment was a trigger, as shown in 7.92 and 7.93. In some words inherited from Latin with a single post-stress consonant, gemination occurred in Italian in a similar manner, as shown in 7.94.

(7.91) *síccum* (Lat.) - *sécco* [ˈsekko] (Ital.) "dry"

(7.92) *zurāfa* (Arab.) - *giráffa* (Ital.) "giraff"

(7.93) *ábacus* (Greek) - *ábbaco* (Ital.) "abacus"

(7.94) *brúto* (Lat.) - *brútto* (Ital.) "ugly"

Stress is attracted to syllables with geminates

There is a fair amount of uniformity among dialects of Arabic in the rules of stress assignment: stress is generally attracted to the heavy syllable closest to the right word-edge. The word-final syllable can be stressed only if it contains a long vowel or if it is closed by a consonant cluster or a geminate, that is, if it is superheavy or heavy considering that final consonant is extrasyllabic (examples in 7.95–7.97 from Iraqi Arabic).

(7.95) [ʃaːˈfoː] "the saw him"

(7.96) [maˈħall] "place"

(7.97) [ˈkaːtib] "clerk"

As a result, at least word-finally, geminates occur only after stressed syllables, although the reason lies in the stress rule and not in the attraction of geminates to stressed syllables. Word-internally, too, at least statistically, a connection between

stress and geminacy is conceivable since syllables closed by geminates are heavy and attract stress.

The difference between languages where segments undergo modifications to render stressed syllable heavy and languages where stress shifts to heavy syllables has been addressed in the literature; see, e.g., Morén (2001) and Smith (2005). A full account of stress and weight effects is beyond the scope of this work. However, it is important to establish that the evidence points to syllable weight as the connecting link between geminacy and stress, not the relative perceptibility of the contrast. No dedicated MinDist constraint is required to capture the connection between geminacy and post-stress position. This effect falls out from the interaction among constraints related to the weight requirements of the stressed syllables in weight-sensitive languages.

Post-stress geminates are protected from neutralization

There is also evidence that geminate consonants are protected from degemination in stressed syllables. For example, in Indo-Aryan long consonants generally shortened in the middle Indo-Aryan period in the Eastern dialects, except in Maithili, where they were preserved in stressed syllables (Jha, 1958). Old Arabic consonant length contrast was inherited by Maltese and, as mentioned in (Borg, 1997b), was retained mostly after stressed vowels. In Modern Mandaic a rule of pretonic shortening leads to the degemination of long consonants earlier in the word than the stress, as shown in 7.98 (Malone, 1997).

(7.98) Modern Mandaic:

[ˈaθθi:]	"he brought"
[aθˈi:tu]	"she brought them"

Although it is not completely clear from the source whether any post-tonic geminates are exempt from shortening or only the immediately post-tonic ones, the latter is probable since all the examples in Malone, 1997 involve the immediate post-tonic position. Finally, in Russian, variable degemination of long consonants is less pervasive in the post-stress position (Kasatkin and Choj, 1999).

7.11.2 Syllable weight and geminacy

The implicational hierarchy produced by the basic model implies that every language that allows word-final geminates must also allow geminates in all other positions, based on the fact that word-final contrast between short and long consonants was the least perceptible. This prediction goes against the observation that word-initial geminates are harder to find than word-final ones. For example, Norwegian, Swedish, Icelandic, as well as Persian, Amharic, Estonian, and Wolof, have word-final but not word-initial geminates. Here I will claim that such languages arise from the interaction of the perceptual constraints on contrast, introduced above, and constraints on the well-formedness of stressed syllables with respect to phonological weight. In particular, I am proposing that stressed syllables have a special status in some languages and thus are targeted by dedicated constraints which place certain requirements on their form. These requirements may conflict with considerations of contrast distinctiveness between singletons and geminates because geminates also have a special status with respect to weight. As discussed in section 1.3.2 of chapter 1, underlying geminates are analyzed as inherently heavy in moraic theory and as such can play an important role in augmenting the weight of the syllable. In particular, the choice between a singleton and a geminate in such weight-sensitive languages in some conditions will amount to the choice between light and heavy syllables. Since in the case of stressed syllables, syllable weight in these languages is governed by the relevant constraints, so will the distribution of geminate consonants, provided the constraints on syllable weight dominate those on contrast distinctiveness.

In the remainder of this section, I will address the typology that arises from the interaction among independently motivated syllable weight-related constraints and constraints used to model the effect of contrast dispersion. I will rely mainly on examples from Germanic languages such as dialects of Norwegian, German, Swedish, and Icelandic. In terms of the candidate forms under evaluation, I will focus on environments where the presence or absence of a geminate consonant may make a difference to the weight of the syllable. I will also adopt the standard assumption of moraic theory that underlying geminate consonants are inherently moraic and contribute this mora to the syllable for which the geminate acts as a coda. I will abstract

		Extrametricality	
		+	−
Weight-by-Position	+	CVC_{μ} CVC#	CVC_{μ} CVC_{μ}#
	−	CVC CVC#	CVC CVC#

Table 7.13: Table 7.13: Extrametricality and Weight-by-Position.

away from the somewhat controversial issue of the moraicity of onset geminates; for more discussion on this subject see Topintzi (2008), Davis (1999), Hume et al. (1997). The focus of this inquiry is intervocalic, preconsonantal, and word-final geminates.

Two parameters, Extrametricality and Weight-by-Position, will be assumed in the analysis a priori, without including them as explicit constraints. There are four possible combinations of Extrametricality and Weight-by-Position, shown in table 7.13, but only three distinct outcomes with respect to the weight of medial and final CVC syllables: (1) heavy medial CVC, light final CVC (shown in the upper left corner); (2) both heavy (shown in the upper right corner) (3) both light (lower row). I will consider the first configuration in more detail at first, and then briefly address the remaining two.

To begin with, I will consider the implications of adding a Stress-to-Weight constraint defined in 7.99. to the basic model of contrast dispersion, assuming Weight-by-Position (medial CVC is heavy) and Extrametricality (final CVC is light).

(7.99) Stress-to-Weight (STW) = Stressed syllables must be heavy.

Intervocalic geminates are generally assumed to be ambisyllabic, acting as a coda to the previous syllable and an onset to the following one and contributing a mora to the previous syllable: $C\acute{V}G_{\mu}$.GV. In contrast, the same configuration with an intervocalic singleton instead will be syllabified as $C\acute{V}$.CV, where the medial consonant is not in the position to contribute any weight to the preceding syllable. The effect of

the STRESS-TO-WEIGHT constraint on the singleton-geminate distribution in medial stressed and unstressed syllables with short vowels is shown in 7.100.

(7.100)

	STW	LAZY	MAXCONTRAST
1a. a.ta-at$_\mu$.ta		*!	
☞1b. a.ta			*
1c. at$_\mu$.ta		*!	*
2a. á.ta-át$_\mu$.ta	*!	*	
2b. á.ta	*!		*
☞2c. át$_\mu$.ta		*	*

STRESS-TO-WEIGHT only affects stressed syllables; thus, all the candidates in sub-tableau 1 of 7.100 pass unharmed. A singleton output 1b wins as a result of the LAZY constraint which prohibits consonant lengthening. If MAXCONTRAST were ranked above LAZY, the contrastive candidate 1a would be the winner. A geminate output 1c is harmonically bounded in this environment and can never surface given these constraints.

In sub-tableau 2 of 7.100 STRESS-TO-WEIGHT has an important function and far-reaching consequences. The contrastive candidate 2a allows a light stressed syllable *á* violating STW. The same problem is encountered by the singleton candidate 2b. Only a geminate output 2c satisfies STW by allowing *only* moraic geminates to close the stressed light syllables. This combination of constraints predicts *neutralization to geminates* in light stressed syllables.

Preconsonantal contrasts present a more complex situation and will behave differently depending on the syllabification and coda weight parameters adopted by the language. Depending on whether the language endorses Weight-by-Position (Hayes, 1989) which renders a single coda consonant moraic in configurations with an intervocalic consonantal cluster, such as CV́C$_1$.C$_2$V, assuming the syllabification shown here,

the syllable weight may or may not depend on gemination of the preconsonantal consonant. As tableau 7.101 shows, in Weight-by-Position languages, in both $\text{CV́C}_1.\text{C}_2\text{V}$ and $\text{CV́C}_1.\text{C}_1\text{C}_2\text{V}$, the first syllable is heavy independently of the gemination.

(7.101)

	STW	$\textsc{Lazy}_L$	MaxContrast
1a. at_μ.Ca-at_μ.tCa		*!	
☞1b. at_μ.Ca			*
1c. at_μ.tCa		*!	*
2a. át_μ.Ca-át_μ.tCa		*!	
☞2b. át_μ.Ca			*
2c. át_μ.tCa		*!	*

A single coda consonant and a coda provided by a geminate are indistinguishable in terms of their weight contribution. STW treats all the preconsonantal CVC syllables equally: none of them incur a violation. Candidates 1a–1c are not subject to STW and all of the stressed syllables in candidates 2a–2c are heavy due to the Weight-by-Position of the singleton codas and the inherent moraicity of geminate consonants.

In absolute word-final position, geminates can also be distinguished from singletons on the basis of weight. In some languages, for example, many dialects of Arabic, word-final singletons do not contribute weight to the final syllable and are usually analyzed as extrametrical. Geminates, on the other hand, render the syllable heavy, which is visible in the patterns of stress assignment: in these dialects final syllables attract stress if closed by geminates or consonant clusters. Thus, there is a contrast between final moraic geminates and final extrametrical singletons: CVG_μ - $\text{CV}\langle\text{C}\rangle$[10]. Tableau 7.102 exemplifies this situation.

[10] I am assuming that extrametricality does not apply to underlyingly moraic final consonants. This means that reference to underlying representation has to be present in the model.

(7.102)

	STW	LAZY	MAXCONTRAST
1a. a⟨t⟩-att$_\mu$		*!	
☞1b. a⟨t⟩			*
1c. att$_\mu$		*!	*
2a. á⟨t⟩-átt$_\mu$	*!	*	
2b. á⟨t⟩	*!		*
☞2c. átt$_\mu$		*	*

Unstressed syllables in 1a–1c are not subject to STW, but the contrastive candidate in 2a is ruled out since it allows a light stressed syllable *á⟨t⟩*. Such a syllable would be heavy if medial due to Weight-by-Position, but a final singleton is extrametrical and does not contribute weight. A similar fate befalls candidate 2b; however, 2c, closed by a geminate, is heavy and passes evaluation by the STW constraint.

A tableau summarizing the smaller tableaux above is shown in 7.103 (some low-ranked constraints, such as MAXCONTRAST are omitted from this tableau to save space).

(7.103)

	MD_C	MD$_{WI}$	MD$_{V_V}$	STW	LAZY
1a. a.ta-at$_\mu$.ta					*!
☞1b. a.ta					
1c. at.t$_\mu$a					*!
2a. á.ta-át$_\mu$.ta				*!	*
2b. á.ta				*!	
☞2c. át$_\mu$.ta					*
3a. ta-tta			*!		*
☞3b. ta					
3c. tta					*!
4a. at$_\mu$.Ca-at$_\mu$.tCa		*!	*		*
☞4b. at$_\mu$.Ca					
4c. at$_\mu$.tCa					*!
5a. át$_\mu$.Ca-át$_\mu$.tCa		*!	*		*
☞5b. át$_\mu$.Ca					
5c. át$_\mu$.tCa					*!
6a. a⟨t⟩-att$_\mu$	*!	*	*		*
☞6b. a⟨t⟩					
6c. att$_\mu$					*!
7a. á⟨t⟩-átt$_\mu$	*!	*	*	*	*
7b. á⟨t⟩				*!	
☞7c. átt$_\mu$					*

Although all stress options were considered in the analysis for each contextual environment, in tableau 7.103 only intervocalic, preconsonantal, and word-final contrasts are included in post-stress positions in addition to the unstressed ones, because these are the cases where a contrast between a geminate and a singleton implies a contrast between light and heavy syllables. Pre-stress cases are omitted since syllable weight in such cases does not depend on geminacy: in both CVG.GV́ and CV.CV́ the second syllable is light if open. It may or may not be heavy if a coda is available for it; however, the weight does not depend on the *preceding* consonant. Similarly, in both $CVC_1.C_2\acute{V}$ and $CVC_1.C_1C_2\acute{V}$ the weight of the second syllable does not depend on the geminacy of the preceding preconsonantal consonant.

A language derived by the ranking shown in tableau 7.103 shies away from geminates due to the effect of Lazy. Some, however, do surface in special conditions, in particular, intervocalically and word-finally following a stressed vowel (sub-tableaux 2, 7 of 7.103). This language requires that stressed syllables are minimally bimoraic, and consonant gemination provides an extra mora for open stressed syllables word-medially and for closed stressed syllables word-finally.

Due to the fact that word-medial singleton codas are moraic (Weight-by-Position) no gemination is observed in the preconsonantal position: both *át.Ca* and *át.tCa* have heavy stressed syllables; STW cannot distinguish between the two, and Lazy makes a final selection in favor of the singleton consonant.

Word-initial contrasts are included in tableau 7.103 only in unstressed positions since they do not interact with the weight of stressed syllables. Word-initially, both *tá* and *ttá* are light under the assumption adopted here that onset geminates are non-moraic. This is not a completely accurate representation of the facts, since it has been shown that in languages like Pattani Malay (Hajek and Boedemans, 2003) and Trukese (Davis, 1999; Topintzi, 2008) onset geminates behave as moraic for stress assignment and word-minima requirements. However, I believe that to consider onset geminates moraic in the same way coda geminates can be moraic is to introduce features into the model which would make incorrect typological predictions.

There are reasons to suspect that onset and coda moraicity are somewhat different phenomena. The analysis proposed here considers consonant gemination as a repair

strategy for light stressed syllables. That is, stress is fixed, but syllable weight is manipulated to satisfy a bimoraic minimum on stressed syllables. I have not come across examples of onset gemination as a repair for light stressed syllables. With respect to onset moraicity, the examples discussed in the literature appear to mainly involve cases where stress is displaced in search of a heavy syllable. That is, syllable composition remains intact but stress moves in order to satisfy the bimoraic minimum. Examples include stress assignment in Pattani Malay and Marshallese discussed in Topintzi (2008). Thus, it seems that syllables with onset geminates may attract stress to satisfy WEIGHT-TO-STRESS, but onsets do not geminate to satisfy STRESS-TO-WEIGHT.

Another reason to consider onset and coda geminates' moraicity as two quite different phenomena is the fact that languages in which word-initial geminates behave as moraic typically lack word-final geminates, and vice versa. In the rare languages where both word-initial and word-final geminates are present, to my knowledge only final ones tend to participate in weight-sensitive phenomena. Thus, both onset and coda moraicity do not appear to be available in the same language simultaneously. A full inquiry into the nature of these differences is yet to be undertaken. For now, pending additional typological data, I will assume that onset gemination is not available as a repair option for languages that impose a bimoraic minimum on stressed syllables, and thus onset geminates are considered non-moraic for this purpose.

A language represented by 7.103 uses the moraicity of geminates as *coerced* weight in the terminology of Morén (2001) in order to maintain the bimoraicity of the stressed syllables. Consonant weight (and length) is not distinctive in such languages. All other conditions being equal, a contrast between singleton and geminate is not possible in the stressed syllable because singletons after short vowels lead to light stressed syllables and are ruled out by the phonology of the language. Thus, one of the predictions of this model is that after long vowels geminates would not be found in languages with coerced weight, which typically is analyzed as a prohibition against trimoraic or super-heavy syllables. Since syllables with long vowels are already bimoraic, adding a geminate does not make them more optimal from the point of view of the STW constraint. In this case, *Lazy* would decide the outcome and rule out the candidate

with a geminate, as shown in 7.104.

(7.104)

	STW	Lazy	MaxContrast
2a. áa$_{\mu\mu}$.ta-áa$_{\mu\mu}$t$_{\mu}$.ta		*!	
☞2b. áa$_{\mu\mu}$.ta			*
2c. áa$_{\mu\mu}$t$_{\mu}$.ta		*!	*

Examples of languages of this type include Norwegian (Kristoffersen, 2011) and Icelandic (Morén, 2001; Pind, 1986). Both are reported to have Extrametricality and Weight-by-Position for medial codas, and both have geminates intervocalically and word-finally in stressed (including secondary stressed) syllables, where they occur in complementary distribution with long vowels.

In Icelandic, vowel and consonant length are in complementary distribution in stressed syllables, allowing for (C)V: syllables shown in 7.105 and (C)VCC syllables shown in 7.106 (examples are from Lorentz (1996), Pind (1986), Morén (2001)).

(7.105) *vísa* ['vi:.sa] "to show"
risa ['ri:.sa] "giant"

(7.106) *vagga* ['vak.ka] "cradle"
rissa ['ris.sa] "to scatch"
vissa ['vis.sa] "certainly"

A short vowel followed by a singleton coda is also a possible stressed syllable (7.107), providing evidence that medial syllable singleton codas are moraic due to Weight-by-Position.

(7.107) *vista* ['vista] "certainly"
fagna ['fak.ga] "to celebrate"
lasta ['las.ta] "to blame"

In monosyllables final singletons do not contribute weight, which is evidenced by the fact that long vowels are found in monosyllables closed by a short consonant: (C)V:C#, as well as in open monosyllables: (C)V:# (7.108).

(7.108) *bú* [pu:] "household"
vís [vi:s] "wise"
bók [pou:k] "book"
flak [fla:k] "wreck"

A CVCC# syllable type with a short vowel and a final geminate is also allowed while *CV:CC# is excluded. Stress is initial in Icelandic, which means word-final geminates are expected mostly in monosyllabic words, also possibly in longer words with secondary stress on final syllable.

(7.109) *viss* [viss] "certain"
flagg [flakk] "flag"
mann [mann] "human"

In Norwegian, the majority of native vocabulary inherited from Old Norse consists of mono- and disyllabic words with initial stress; in this substratum final geminates are also found in monosyllabic words after short vowels (Kristoffersen, 2011). Long vowels are allowed in open monosyllables and those closed by singletons. Thus, CVCC#, CV:⟨C⟩#, and CV:# are the possible syllable types but *CV:CC# and CVC# are not, ensuring that all monosyllabic words are strictly bimoraic.

(7.110) *natt* [natt] "night"
le [le:] "opening in fence"
fin [fi:n] "fine" (Adj.)

In native disyllables, the second syllable is typically open, while in the first stressed syllable, vowel and consonant length are in complementary distribution as in Icelandic.

(7.111) *baka* [ˈba:.ke] "to bake"
natta [ˈnat.ta] "the night"

Borrowed disyllabic words may involve final consonants. Interestingly in the case of such loanwords, final geminates are not found if stress is penultimate: *bálsam*, *cóbolt*, but we can see them in loanwords with final stress: *fagótt*, *trafíkk* (Rice, 2006).

A German dialect of Uri spoken in Switzerland may represent another example of a system with coerced consonant weight. According to Seiler (2009), in this dialect final consonants geminate (pre-pausally) after short stressed vowels (in monosyllables), which points to neutralization to geminates word-finally in stressed syllables. Medially, vowels lengthen in open syllables, which leads to alternations such as [ratt - ré:.d̥ər].[11] This conceivably would result in a complementary distribution between vowel and consonant length, as in Icelandic and Norwegian. The contrast between geminates and singletons is ruled out since geminates are found only after short vowels; in monosyllables final consonants geminate after short vowels, in polysyllables no vowel lengthening occurs before geminates and consonant clusters. Singletons are found only after long vowels.

A full factorial typology of this model includes 13 output patterns, five of which are the basic patterns discussed in the beginning of this section. The remaining seven are listed in table 7.14 (for simplicity I left out the initiality constraint from this model). As can be seen, these additional patterns represent variations of the five basic patterns where either final post-stress geminate is held constant (patterns 6 through 8) or both intervocalic post-stress and final post-stress geminates are held constant (patterns 9 through 13).

The introduction of a constraint that requires stressed syllables to be heavy can account for languages like Norwegian and Icelandic (output 9) where the implicational hierarchy based on perceptual constraints is violated: these languages allow word-final geminates but not word-initial or preconsonantal ones. However, there are other examples of gemination patterns that do not fit in this proposed hierarchy, in particular those where a true singleton-geminate *contrast* is found intervocalically and word-finally but not word-initially. Interestingly, in these languages, similarly to

[11] An intriguing question is why consonant gemination is opted for in monosyllables but vowel lengthening is chosen instead in open syllables in order to maintain the bimoraic structure of the stressed syllables.

Output 6	Output 7	Output 8	Output 9
ata-atta	ata-atta	ata-atta	ata
áta-átta	áta-átta	áta-átta	átta
ta-tta	ta-tta	ta	ta
atCa-attCa	atCa	atCa	atCa
átCa-áttCa	átCa	átCa	átCa
at	at	at	at
átt	átt	átt	átt
Output 10	**Output 11**	**Output 12**	**Output 13**
ata-atta	ata-atta	ata-atta	ata-atta
átta	átta	átta	átta
ta-tta	ta-tta	ta-tta	ta
atCa-attCa	atCa-attCa	atCa	atCa
átCa-áttCa	átCa-áttCa	átCa	átCa
at-att	at	at	at
átt	átt	átt	átt

Table 7.14: Factorial typology for languages with Extrametricality and Weight-by-Position.

the coerced geminates in Norwegian and Icelandic, geminate-singleton contrasts appear to be confined to stressed syllables. Thus, I propose that these patterns can be captured with the introduction of a constraint that requires a maintenance of *weight contrast* in stressed syllables:

(7.112) MaximizeContrast$\mu/\acute{\sigma}$ = Maintain a contrast between heavy and light stressed syllables.

Maintainability of a greater number of contrasts in stressed syllables is not an unusual phenomenon, exemplified among other things by the fact that many languages allow a greater variety of vowels in stressed syllables than in unstressed syllables (Crosswhite, 2004). Another example is contrastive aspiration in Icelandic, which in some dialects is only found in stressed syllables (Morén, 2001).

The mini-tableau in 7.113 illustrates the action of the MaxC$\mu/\acute{\sigma}$ constraint.

(7.113)

	MaxC$\mu/\acute{\sigma}$	Lazy	MaxC	STW
☞1a. á.ta-át$_\mu$.ta		*		*
1b. á.ta	*!		*	*
1c. át$_\mu$.ta	*!	*	*	

The contrastive candidate 1a allows short vowel syllables and syllables closed by geminates, thus maintaining a contrast between monomoraic (C)V$_\mu$ and bimoraic (C)V$_\mu$C$_\mu$ in stressed syllables. Non-contrastive candidates 1b and 1c induce neutralization either towards monomoraic syllables followed by singleton onsets, or towards bimoraic syllables closed by ambisyllabic geminates and are ruled out by $MaxC\mu/\acute{\sigma}$.

A tableau of the relevant contexts is shown in 7.114 and derives a language with contrastive geminates only in stressed syllables, both intervocalically and word-finally (some of the non-crucial constraints, such as MaxC and STW are omitted from this tableau to save space).

(7.114)

	MaxCμ/$\acute{\sigma}$	MD_$_C$	MD$_{WI}$	MD$_{V_V}$	Lazy
1a. a.ta-at$_\mu$.ta					*!
☞1b. a.ta					
1c. at.t$_\mu$a					*!
☞2a. á.ta-át$_\mu$.ta					*
2b. á.ta	*!				
2c. át$_\mu$.ta	*!				*
3a. ta-tta				*!	*
☞3b. ta					
3c. tta					*!
4a. at$_\mu$.Ca-at$_\mu$.tCa			*!	*	*
☞4b. at$_\mu$.Ca					
4c. at$_\mu$.tCa					*!
5a. át$_\mu$.Ca-át$_\mu$.tCa	*		*!	*	*
☞5b. át$_\mu$.Ca	*				
5c. át$_\mu$.tCa	*				*!
6a. a⟨t⟩-att$_\mu$		*!	*	*	*
☞6b. a⟨t⟩					
6c. att$_\mu$					*!
7a. ☞á⟨t⟩-átt$_\mu$		*	*	*	*
7b. á⟨t⟩	*!				
7c. átt$_\mu$	*!				*

Output 14	Output 15	Output 16	Output 17	Output 18	Output 19
ata-atta	ata-atta	ata-atta	ata	ata	ata
áta-átta	áta-átta	áta-átta	áta-átta	áta-átta	áta-átta
ta-tta	ta-tta	ta	ta	ta	ta
atCa-attCa	atCa	atCa	atCa	atCa	atCa
átCa-áttCa	átCa	átCa	átCa	átCa	átCa
at	at	at	at	at	at
át-átt	át-átt	át-átt	át-átt	át	átt

Table 7.15: Factorial typology with the MaxC$\mu/\acute{\sigma}$ constraint.

We can see that MaxC$\mu/\acute{\sigma}$ does not affect the consonant duration contrast in unstressed syllables (sub-tableaux 1, 3, 4 and 6 of 7.114). In these cases the selection of the winner will be performed by the constraints of the basic dispersion model: MinDist, MaxContrast, and Lazy. It is in stressed syllables where MaxC$\mu/\acute{\sigma}$ can make a difference (sub-tableaux 2, 5, and 7 of 7.114). Candidate 2a wins thanks to the contrast between light and heavy syllables introduced by the singleton-geminate contrast. Similarly, in 7 candidate 7a wins because a final extrametrical singleton does not contribute weight and such monomoraic syllables contrast with bimoraic geminate-final ones. In 5, however, MaxC$\mu/\acute{\sigma}$ is forced to penalize all the competing candidates equally because even in 5a there is no contrast between light and heavy syllable: medial CVC is bimoraic just as medial CVCC according to Weight-by-Position.

When the MaxC$\mu/\acute{\sigma}$ constraint is introduced into the model above, 19 different output patterns are derived: the 13 patterns above plus six additional ones. These are listed in table 7.15.

Again, the additional patterns 14 through 16 are variations of the five original basic grammars where the final post-stress contrast is present independently of the rest of the system. Output pattern 17 is a language where the singleton-geminate contrast is found only after stress: intervocalically and word-finally. This is the pattern

derived in tableau 7.114. This grammar is represented by a North Gudbrandsdal dialect of Norwegian, according to Kristoffersen (2011) the most archaic dialect which may be the closest to Old Norse in its treatment of quantity. In this dialect light (monomoraic) stressed syllables are found in disyllabic words as well as in monosyllables, together with heavy bimoraic syllables, allowing for a CV́C-CV́CC contrast medially and finally. Examples of light and heavy syllables in North Gudbrandsdal are shown in 7.115 (from Kristoffersen (2011).

(7.115) *baka* [ˈbo.ko] "to bake"
natta [ˈnat.ta] "the night"
skin [ʂen] "shine"
skinn [ʂinn] "skin"

Pattern 16 allows contrasts intervocalically, independently of stress, and word-finally in stressed syllables only. Wolof (Bell, 2003) may be an example of a language with this grammar with respect to the singleton-geminate contrast. In Wolof, the consonant duration contrast is found intervocalically and word-finally, but the latter case exists exclusively in monosyllables (a further constraint limits final geminates to monosyllabic verbs). Some examples of light and heavy monosyllables in Wolof are shown in 7.116 (from Bell (2003)).

(7.116) *def* [def] "to do"
tek [tek] "to start cooking"
bokk [bokk] "to share"
fatt [fatt] "to spoil"

Since Wolof has initial stress, final singleton-geminate contrast is expected to occur in monosyllables according to the current model, since a final syllable in polysyllabic words will not be carrying primary stress. Primary stress can be attracted to the second syllable only when the second syllable contains a long vowel but the first one does not. This happens even if the first syllable is closed by a geminate, as shown in 7.117. This example demonstrates that a consonant length contrast is possible in unstressed intervocalic position, as well as in the stressed one (7.118).

(7.117) *deggoo* [deg.gˈoo] "understanding"

(7.118) *guddi* [gˈud.di] "night"

It is difficult to say whether Wolof contrasts medial CVC and CVCC syllables in terms of weight since both single and geminate codas are light for the purposes of stress assignment in this language: only long vowels may attract stress from the default initial position. However, final singleton codas do appear to be extrametrical: the language prohibits trimoraic superheavy syllables, and words of the shape CVVGG# are not allowed; however, CVVC# words are permitted, suggesting that a final singleton is extrametrical.

Pattern 18 allows geminate-singleton contrast only after medial stressed syllables. An example seems to be an Austronesian language, Bugis (Abas and Grimes, 1995), where root-internal geminates are found only following a stressed vowel, but singletons are allowed in this position as well, creating a C-CC contrast in this environment.

Pattern 19 is a variation of pattern 18 where neutralization to geminates is obligatory word-finally after stress. This is a grammar where a contrast between geminates and singletons is found after medial stressed syllables, but word-finally only geminates are allowed after stress. A Norwegian dialect of Mid Gudbrandsdal (Kristoffersen, 2011) is an example of such a pattern: monosyllables of a CVC# structure are prohibited, although CVCC# is allowed. Thus, a bimoraic minimum is enforced in monosyllables. In disyllabic words (with initial stress) light stressed syllables may contrast with heavy stressed syllables: CV.CV vs. CVG.GV. Examples are shown in 7.119.

(7.119) *baka* [ˈbo.ko] "to bake"
natta [nˈat.ta] "the night"
skin [ʂenn] "shine"
skinn [ʂinn] "skin"

Another example of pattern 19 is found in a Swiss German dialect of Glarus (High Alemannic), where geminates are found medially and finally: according to Seiler (2009) this dialect did not participate in the process of open syllable lengthening

(OSL) but did endorse monosyllabic lengthening. As a result, in medial stressed syllables both singletons and geminates are found after short vowels, since monomoraic light syllables are permitted in this environment. Word-finally however, in monosyllables only geminates are found after short stressed vowels because vowel lengthening took place in front of singleton codas (Seiler, 2009). Examples from Seiler (2009) are shown in 7.120.

(7.120) "damage" [ˈʃad̥ə]
"shadow" [ˈʃattg̊]
"board" [b̥rætt]
"wheel" [ra:d̥]

The same situation was achieved by different means in other German dialects: in Valais and Grisons final consonants geminated in monosyllabic words with short vowels: [ratt] "wheel" (Seiler, 2009).

If MaxC$\mu/\acute{\sigma}$ is formulated in such a way that *any* moraic contrast is encouraged in stressed syllables, the model would predict that superheavy syllables must be allowed: since CVV⟨C⟩ is bimoraic and CVVGG is trimoraic, the possibility of the long vowel + geminate combination would be promoted by the MaxC$\mu/\acute{\sigma}$. However, most of the languages listed above, with the exception of Glarus dialect, prohibit trimoraic syllables, which suggest that an independent constraint against superheavy syllables would be necessary.

Implicational universals contained in this model (omitting for the moment the initiality constraint and the morphological boundary constraint) are presented in figure 7.5 and figure 7.6. Upper case A in these graphs stands for stressed vowels; lower case a stands for unstressed vowels. Figure 7.5 shows that for the most part implications are the same as in the basic contrast dispersion model, in particular where unstressed syllables are concerned: a singleton-geminate contrast word-finally implies contrast preconsonantally (for both stressed and unstressed syllables), which implies contrast word-initially, which implies contrast intervocalically (left part of the graph).

It is important to notice, however, that *stressed syllables* are *outside* this chain of

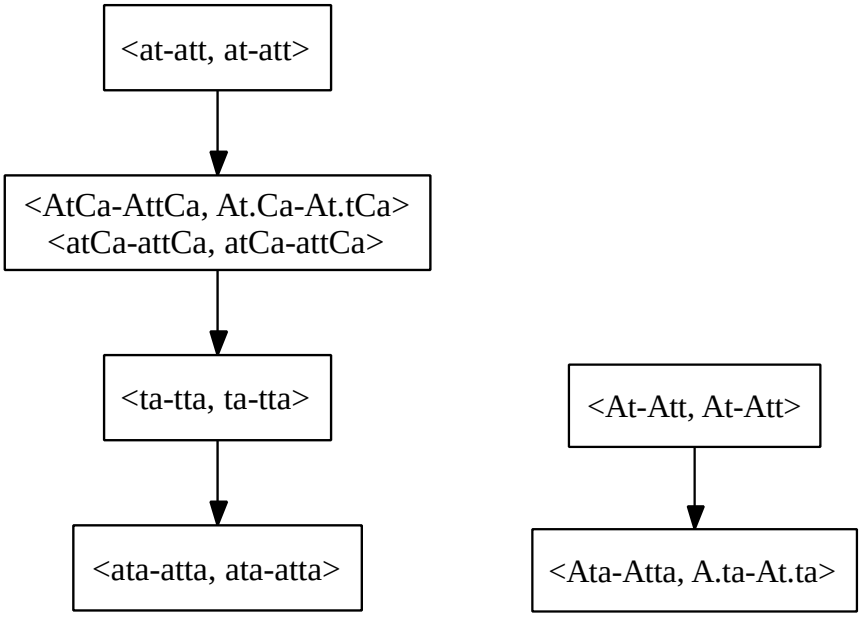

Figure 7.5: Implicational universals in the typology of syllable weight and gemination. Part 1: Contrast.

implications. Thus, contrastive gemination in stressed syllables intervocalically and word-finally can occur independently of the contrastive gemination in other positions, due to the MaxC$\mu/\acute{\sigma}$ constraint. Nevertheless, contrastive gemination word-finally after stress implies contrastive gemination intervocalically after stress (right part of the graph). Thus, an implicational relationship between final and intervocalic geminacy is maintained within each condition: in stressed and unstressed syllables.

Figure 7.6 demonstrates the implications within the system of contrast neutralization. Again, the order is very similar to that of the basic model: neutralization to singleton intervocalically implies neutralization word-initially, which implies neutralization preconsonantally, which implies neutralization word-finally (left part of the graph).

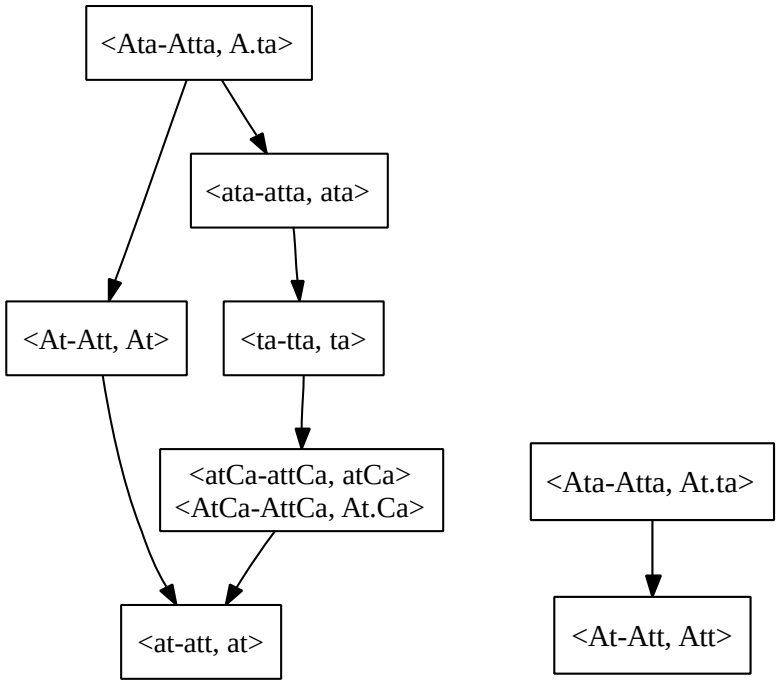

Figure 7.6: Implicational universals in the typology of syllable weight and gemination. Part 2: Neutralization.

The stressed condition is somewhat outside the loop: if neutralization to a singleton is applied to intervocalic consonants, it must also occur word-finally. There are no implicational relationships with any other context. That is, the fact that a language does not allow geminates word-initially or preconsonantally does not imply that geminates will not be allowed word-finally *in stressed syllables*.

The right portion of the graph shows that neutralization to *geminates* in stressed syllables intervocalically requires neutralization to geminates in stressed syllable word-finally. In the right conditions, this implication is equivalent to the prediction made by Kristoffersen (2011)'s analysis of the quantity systems in dialects of Norwegian: moraic expansion (obligatory bimoraicity of the stressed syllables) is impossible in medial open syllables without simultaneous expansion in monosyllabic words. In the current analysis, if gemination is obligatory after short stressed vowels in open medial syllables, making them bimoraic, it is also obligatory after short stressed vowels in monosyllables, making them equally bimoraic. Unstressed monosyllables, such as a function words, are not affected. Thus, all languages that impose a strict bimoraic minimum on medial stressed syllables are predicted to require the same of the stressed monosyllabic words. Moraic expansion through gemination in stressed monosyllables, however, can occur without concomitant obligatory bimoraicity of the medial stressed syllables: a scenario predicted by Kristoffersen (2011) as well (e.g., Mid Gudbrandsdal).

Seiler (2009) and Kiparsky (2008a) cite possible counterexamples to this prediction: languages where a bimoraic minimum is imposed over medial stressed syllables but not monosyllables. Seiler (2009) refers to Uri — a dialect of Swiss German where open syllable lengthening happened without monosyllabic lengthening. Seiler (2009) also mentions, however, that in this dialect final consonants in monosyllables became geminates, albeit only in pre-pausal forms. This may be enough, however, to posit an underlying moraic geminate as a final consonant in such words and conclude that monosyllabic moraic expansion happened due to final consonant gemination instead of vowel lengthening.

Standard Dutch and Danish are also languages where open syllable lengthening occurred without monosyllabic lengthening (Kiparsky, 2008a; Seiler, 2009). This

		Extrametricality	
		+	−
Weight-by-Position	+	CVC_μ CVC#	CVC_μ CVC_μ#
	−	CVC CVC#	CVC CVC#

Extrametricality and Weight-by-Position.

development may possibly be explained by the fact that in both of these languages final singletons are treated as moraic (for Dutch see Booij 1995 and the discussion in Kristoffersen 2011 p. 74). Thus, a Stress-to-Weight constraint cannot distinguish between CVC_μ and $CVCC_\mu$ and final preference is given to the singleton since it also satisfies the Lazy constraint. No vowel lengthening is required since CVC is already bimoraic. In addition, neither of the two languages allow geminates presumably due to a highly ranked *Lazy* constraint. Thus, gemination is unavailable as a repair for light stressed syllables, even if such a repair is required.

This takes us to the alternative scenario: referring back to table 7.13, repeated here, the upper right corner exemplifies a situation where Weight-by-Position is present (singleton codas are moraic), but Extrametricality is absent. Thus, CVC syllables are heavy medially as well as finally. In languages of this type word-final gemination would not be allowed as a repair strategy for light stressed syllables. Gemination may still be used in this way in medial stressed syllables to repair open syllables with short vowels.

A more interesting situation is depicted in the lower row of table 7.13: absence of Weight-by-Position renders both medial and final CVC light, allowing for a contrast with heavy CVGG. For languages without Weight-by-Position, the first syllable in $C\acute{V}C_1.C_2V$ is light while the first syllable in $C\acute{V}C_1.C_1C_2V$ is heavy. As tableau in 7.121 shows, if promoted, the Stress-to-Weight constraint in such languages would eliminate the contrastive candidate 1a since it allows a light medial CVC, as

well as a singleton candidate 1b. Candidate 1c is the only contender which maintains the bimoraic structure of the stressed syllables at all times, allowing only geminate codas.

(7.121)

	STW	LAZY	MAXCONTRAST
1a. át.Ca-át$_{\mu}$.tCa	*!	*	
1b. át.Ca	*!		*
☞1c. át$_{\mu}$.tCa		*	*

The main prediction of the model for languages without Weight-by-Position is that *preconsonantal* gemination should be found alongside intervocalic and word-final gemination in cases where it is required by STRESS-TO-WEIGHT or MAXC$\mu/\acute{\sigma}$ constraints. Tableau 7.122 demonstrates this for the set of relevant environments.

(7.122)

	MD_C	MD$_{WI}$	MD$_{V_V}$	STW	LAZY	MAXC
1a. a.ta-at$_\mu$.ta					*!	
☞1b. a.ta						*
1c. at$_\mu$.ta					*!	*
2a. á.ta-át$_\mu$.ta				*!	*	
2b. á.ta				*!		*
☞2c. át$_\mu$.ta					*	*
3a. ta-tta			*!		*	
☞3b. ta						*
3c. tta					*!	*
4a. at.Ca-at$_\mu$.tCa		*!	*		*	
☞4b. at.Ca						*
4c. at$_\mu$.tCa					*!	*
5a. át.Ca-át$_\mu$.tCa		*!	*	*	*	
5b. át.Ca				*!		*
☞5c. át$_\mu$.tCa					*	*
6a. at-att$_\mu$	*!	*	*		*	
☞6b. at						*
6c. att$_\mu$					*!	*
7a. át-átt$_\mu$	*!	*	*	*	*	
7b. át				*!		*
☞7c. átt$_\mu$					*	*

The scenario demonstrated by tableau 7.122 appears to be found in Swedish. Swedish has a quantity system very similar to that of Standard Norwegian: geminate weight is coerced in medial and final stressed syllables, where only geminates are possible after short vowels to maintain bimoraicity. However, Swedish does not have Weight-by-Position (Kiparsky, 2008a), and thus the prediction is that the STW constraint will select the heavy CV́GG syllable over the light CV́C syllable in preconsonantal medial stressed syllables. Indeed, Kiparsky (2008a) reports that coda gemination after short stressed vowels is common to most, possibly all, dialects of Swedish (examples from Kiparsky (2008a)):

(7.123) *vissna* [viss.na] "to wilt"
halva [hall.va] "half"
taxa [takk.sa] "rate"

If the MaxC$\mu/\acute{\sigma}$ constraint is promoted in languages without Weight-by-Position, the quantity must be contrastive in stressed medial, preconsonantal, and final syllables as shown in the tableau in 7.124.

(7.124)

	MaxC$\mu/\acute{\sigma}$	MD_$_C$	MD$_{WI}$	MD$_{V_V}$	Lazy
1a. a.ta-at$_\mu$.ta					*!
☞1b. a.ta					
1c. at$_\mu$.ta					*!
☞2a. á.ta-át$_\mu$.ta					*
2b. á.ta	*!				
2c. át$_\mu$.ta	*!				*
3a. ta-tta				*!	*
☞3b. ta					
3c. tta					*!
4a. at.Ca-at$_\mu$.tCa			*!	*	*
☞4b. at.Ca					
4c. at$_\mu$.tCa					*!
☞5a. át.Ca-át$_\mu$.tCa			*	*	*
5b. át.Ca	*!				
5c. át$_\mu$.tCa	*!				*
6a. at-att$_\mu$		*!	*	*	*
☞6b. at					
6c. att$_\mu$					*!
7a. ☞át-átt$_\mu$		*	*	*	*
7b. át	*!				
7c. átt$_\mu$	*!				*

The model without Weight-by-Position generates 25 output patterns. One of them allows contrast between singletons and geminates intervocalically and preconsonantally in stressed syllables. Word-finally the contrast is neutralized. This is the kind of distribution that we find in Maltese.

Thus, the main consequence of introducing the STRESS-TO-WEIGHT constraint and the MAXCONTRAST$\mu/\acute{\sigma}$ constraint into the model is the ability to generate languages with word-final and sometimes preconsonantal geminates but not word-initial ones. This is because the new constraints give a special status to stressed syllables and weight-based contrasts within the stressed syllables. The moraic nature of geminate consonants also plays an important role. Thus, the implicational relationship *word-final* $\rightarrow$ *preconsonantal* $\rightarrow$ *word-initial* is broken in stressed syllables. The implicational hierarchy in unstressed positions remains intact.

Languages with geminacy conditioned by stress are found in Germanic family: dialects of German, Norwegian, and Swedish. There are other examples of languages where final geminates are not accompanied by word-initial ones, including Estonian, Persian, Hungarian, Wichita, Amharic, and some dialects of Arabic, e.g., Gulf Arabic. A closer look at the stress and quantity systems of these languages would be required in order to establish whether they are predicted by the current model. There are some indications, however, that stress is relevant at least in some of them. For Amharic, Leslau (1997) notes that "the syllable preceding a geminated syllable is likely to be stressed" (p. 429). In Estonian, only stressed syllables condition all three consonantal quantities; in unstressed syllables reduction to two is observed (Prince, 1980). In Persian, stress is typically final, thus providing an environment for word-final geminates. Moreover, final geminates are realized only in prevocalic position in Persian. Mahootian (1997) also reports that geminates in native Persian vocabulary are frequently subject to neutralization and are maintained mostly in words of Arabic origin.

A similar situation is exemplified by Wichita, where intervocalic, consonant-adjacent, and word-final geminates have been reported, but not word-initial ones (Garvin, 1950; Rood, 1975, 1996). However, descriptions of this language suggest that geminates play only a marginal role in the phonology of Wichita. Only three

Minimal Distinctiveness	MinDist$_{_C}$
	MinDist$_{WI}$
	MinDist$_{V_V}$
Maximize Contrast	MaxContrast$_{L}$
	MaxContrast$_{WI}$
	MaxContrast$_{C-0}$
	MaxContrast$\mu/\acute{\sigma}$
Minimize Effort	Lazy$_{L}$
Syllable Weight	Stress-to-Weight

Table 7.16: Constraints included in the complete model.

phonemes are allowed as geminates: [nn], [ss], and [tsts]. The geminate nasal is an allophone of the flap singleton and the only geminate found in the word-final position. The phonemic status of the geminates is unclear since no minimal pairs are given in any of the descriptions I consulted. Moreover, Rood (1975) does not include [length] among the distinctive features of Wichita consonants.

7.12 Complete model

The complete model of geminate typology presented here includes the constraints summarized in table 7.16. The MinDist constraints relevant to the discussion of variability in the Hungarian degemination are omitted from this model. They were proposed based on typological observations only, and their validity was not tested experimentally.

A full tableau including all the relevant candidates and the full set of constraints is too large to include here. The factorial typology ranges from 64 to 132 output patterns, depending on how the parameters are set for Weight-by-Position and Extrametricality, and depending on whether the concatenated geminates are considered moraic in the same way lexical geminates are. The output patterns cannot be listed here so I will limit the discussion to the implicational relationships contained in the

models. [12] The T-orders are useful precisely because they reveal the key predictions of the proposed set of constraints in a concise manner. Listing the dozens of possible languages predicted by constraint set would be impossible to understand by a human and would not serve the purpose of understanding the predictions.

The combination of the sub-models discussed above in sections 7.10.2, 7.10.3, and 7.11 produces an implicational structure that represents a simple additive combination of the implications in the sub-models. Figure 7.7 shows the implications among the neutralizing outputs in the model with Weight-by-Position and Extrametricality. Moraicity of fake geminates does not matter in this case since codas are always heavy independently of whether they are part of a geminate and whether the geminate is true or fake.

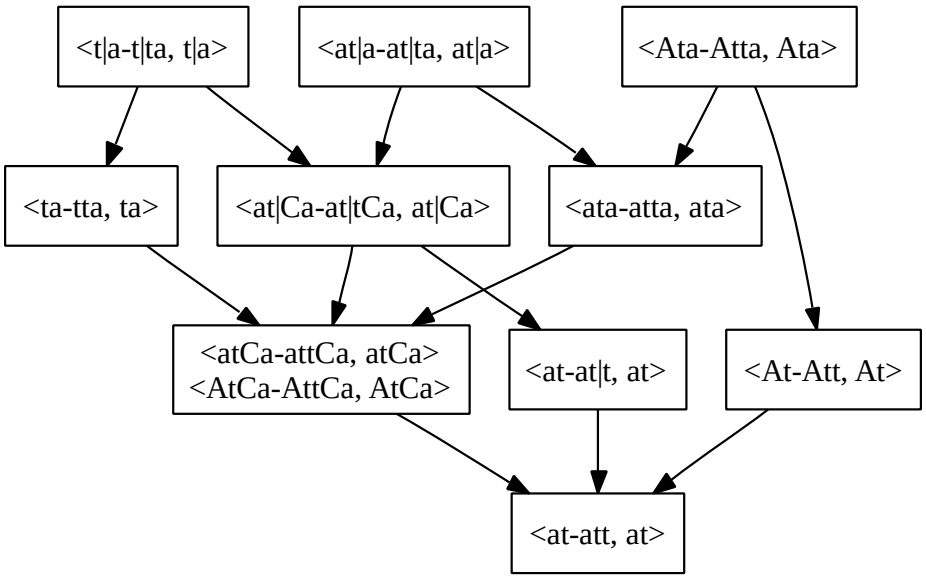

Figure 7.7: Implicational universals in the complete model. Part 1: Neutralization to singleton.

It can be seen that, as in the basic model, neutralization in the higher perceptibility environment, such as initial or intervocalic, implies neutralization in the lower perceptibility environment. This holds both within the categories of true and fake

[12] The files used to generate the factorial typology and the T-order graphs are available upon request.

geminates (vertical line stands for morphological boundary). For example, neutralization of intervocalic fake geminates *at|a* implies neutralization of preconsonantal fake geminates: *at|Ca*.

As in the model with the morphological boundary factor, neutralization on the boundary of morphemes implies neutralization of true geminates in the same environment. For example, neutralization of intervocalic fake geminates *at|a* implies neutralization of intervocalic true geminates: *ata*.

As in the model of syllable weight and geminacy for languages with Weight-by-Position and Extrametricality, we can see that neutralization of intervocalic and final geminates in post-stress position is somewhat outside of the loop of implications. Intervocalic neutralization after stress implies final neutralization after stress: $Ata \rightarrow At$ (upper case "A" stands for stressed vowels) and neutralization after stress implies neutralization in unstressed syllables: $At \rightarrow at$.

As discussed in section 7.11 systems with coerced consonant weight opt for non-contrastive gemination in stressed syllables, where neutralization to geminates in medial syllables implies neutralization to geminates in final syllables. This implication is preserved in the complete model, as shown in figure 7.8.

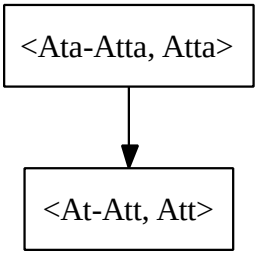

Figure 7.8: Implicational universals in the complete model. Part 2: Neutralization to geminate.

Finally, the implicational relationship among the contrastive outputs that do not involve the post-stress context are exactly the same as shown in figure 7.3 in section 7.10.3, reproduced here as figure 7.9. We can see that for both true and fake geminates maintaining a contrast in any given position implies maintaining a contrast in the position with a greater perceptual distinctiveness: e.g., *at-att* implies *atCa-attCa* and

at|-at|t implies *at|Ca-at|tCa*. In addition, maintaining the consonant length contrast in any given position morpheme-internally implies maintaining a contrast in the same position on the boundary of morphemes: *at-att* implies *at|-at|t*.

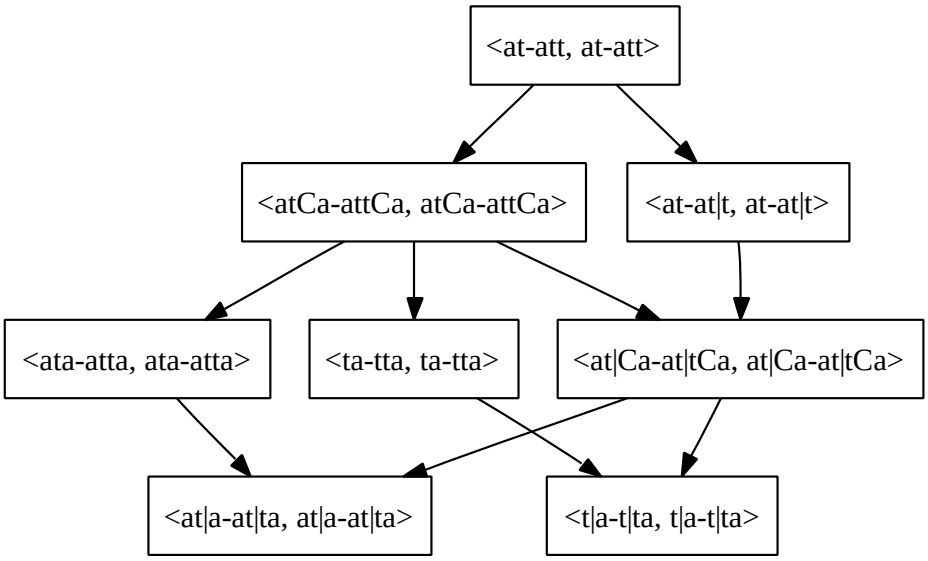

Figure 7.9: Implicational universals in the complete model. Part 3: Contrast.

7.13 Manner of articulation

It has been proposed that manner of articulation of the consonant is another factor in the typology of consonant duration contrast (Kawahara, 2006, 2007; Kawahara et al., 2011; Podesva, 2002). The hypothesis that perceptual distinctiveness of the contrast varies with the manner of articulation and/or voicing of the consonant was tested here. The values of the transformed β coefficients for the short-long identification curves fitted for each manner of articulation are reproduced in table 7.17.

The order of the coefficient values suggests that perceptual distinctiveness of the contrast decreases in the following order: l > n > s > d > t. This allows us to hypothesize that if inventories of phonemic contrasts relied primarily on the perceptual distinctiveness, [l n s] would be the most likely to participate in the singleton-geminate contrast, or perhaps sonorants and fricatives in general.

Condition	β coefficient
t	34.32
d	22.81
s	17.92
n	17.34
l	16.61

Table 7.17: β coefficients for different manners of articulation.

Results of the typological surveys available to date contradict this expectation in some respects, although it is important to note that there is also a considerable lack of consistency among the sources themselves. Some suggest that obstruents, in particular voiceless stops, are the most common geminates, while sonorant consonants resist gemination (Kawahara et al., 2011; Podesva, 2002). Others point out that nasals, nevertheless, do appear extremely frequently as geminates across languages: Jaeger (1978, p. 321) wrote "The most frequent type of geminate or long consonant in the world's languages is clearly the nasal geminate". Finally, the third view is that there is no common cross-linguistic pattern with respect to consonants chosen as geminates — Blevins (2004a, p. 179): "It is reasonable to speculate as to whether there are any implicational relationships relating to sonority which hold of geminates. The answer appears to be no". Blevins (2004a) gives examples of languages which limit their geminate inventories to nasals, as well as those which limit their inventories to obstruents.

In the present survey of circa 30 languages for which information about the types of geminating consonants was available, nasals did stand out as an extremely frequent choice for gemination. In fact, all of the languages in the survey did contain nasal geminates. It was also observed that certain types of consonants were frequently absent from the inventories even as singletons. This applied in particular to affricates, more so to voiced ones. Voiced fricatives are fairly rare, as well as, to a lesser degree, voiced stops. This skewed distribution can have an effect on the typology of geminate inventories. For example, the scarcity of voiced geminates may be partly due to the

Stops		Fricatives		Affricates					
Vcd	Vcl	Vcd	Vcl	Vcd	Vcl	N	L	R	Y
0.9	0.9	1	0.9	1	1	1	0.96	0.7	0.7

Table 7.18: Proportion of geminates across different manners of articulation.

avoidance of voiced obstruents in general.

In terms of the ability to geminate, more gaps in the inventories are found among rhotics and glides. Table 7.18 reports a proportion of the number of times a certain manner of articulation was found as a geminate in one of the languages included in the survey to the number of times if was used in these languages (either as geminates or singletons). For example, if ten languages had [s] in their inventories but only five of them had a contrast between a single and a geminate [s] the proportion for this consonant would equal 0.5.

While most of the values range between 0.9 and 1, rhotics and glides stand out with a value of only 0.7. The only consonant type found in absolutely every language in this sample and also allowable as a geminate in all of them, is nasal.[13]

However, this method of estimating the relative difference among manners of articulation in terms of their ability to enter the phonemic length contrast is not very reliable. The sample of languages is likely to be biased in one way or another, and in any case, is not large enough. Therefore it suffers from low sensitivity and the resulting values are very close to each other. Apart from the fact that rhotics and glides appear to be the least common geminates, it is hard to say whether there is any difference among the rest of the manners.

Present experimental results based on the perceptibility facts suggest that [s] should be a more common geminate than voiced and voiceless stops because of the higher perceptibility of the short-long contrast in [s] than in stops. In contrast to this expectation, typological data reported in Podesva (2002) include a whole set of languages disallowing voiceless fricative geminates while voiceless stop geminates are

[13]Maddieson (2008) mentions one language, Noon, which does not allow nasal geminates.

permitted. The relative scarcity of fricative geminates crosslinguistically may be due to factors other than perceptual distinctiveness. Podesva (2002) proposes, following Kirchner (2000), that geminate fricatives require greater articulatory precision to create and maintain for a period of time a narrow channel between the articulators. Greater precision requires greater effort, and thus fricative geminates are avoided in geminate inventories. He also introduces an explicit *SonGem constraint, banning sonorant geminates from phonological inventories based on the relatively low occurrence of such phonemes in the survey he conducted and synchronic evidence from some Austronesian languages. Podesva (2002)'s sample is nevertheless rather generous when it comes to nasal geminates. Only one language, !Xóõ, permits geminate stops but not nasals. However, this is a language where gemination, according to Traill (1985), is "stylistically restricted" — it occurs only with expressive emphasis, and is accompanied by devoicing. It does not appear to be contrastive.

Thus, while nasals appear to stand out among the consonants of different manners in their ability to enter in the singleton-geminate contrast, sonorants in general, including glides, laterals, and rhotics, are in a minority when it comes to gemination. Podesva (2000) proposes an explanation based on the relative acoustic similarity between sonorants and vowels. A boundary between two acoustically similar segments is less easily detectable perceptually. Difficulty in detecting the boundary leads to difficulty in estimating the duration of the segments. If this proposal is correct, nasals may have achieved a comparatively improved perceptual distinctiveness due to the fact that they are the least sonorous consonants within the class of sonorants. Their acoustic realization also contains anti-formants which may help cue the transition from vowels to nasals. However, not only nasals, but the lateral liquid as well, emerged as ones of the most perceptually distinct singletons and geminates in the present experiment. According to Podesva (2000), sonorants are expected to perform worse than stops and fricatives, with nasals perhaps faring a bit better than liquids. This indeed was the result obtained in experiments by Hansen (2012); Kawahara (2006, 2007); Kawahara et al. (2011). Kawahara (2007) found that all sonorants, including nasals, laterals, and glides, showed a higher degree of confusability between

singletons and geminates than voiceless stops and fricatives.[14]

Aoyama (2000) proposed that the higher frequency of a phonological contrast may lead to a sharper perceptual boundary. He established that geminate consonants were more frequent in Finnish than in Japanese and demonstrated that the perceptual boundary between singletons and geminates was sharper for Finnish than Japanese listeners. In addition, this quantity contrast was mastered earlier by Finnish than Japanese children. Similarly, in the present study, Italian listeners showed higher sensitivity to the length contrast in [l] than other participants, possibly due to the fact that [l] is one of the two most common geminating consonants in this language, although another very common geminate, [t], was not affected in the same way. The language-specific differences in the frequency of geminate phonemes in Arabic (the language of the experiment) may have contributed to the outcome of the experiment. However, the frequency data from Wehr 1971 deflects this possibility.

To summarize, the fact that such diverging results were obtained from experiments very similar to the one reported here shows that more research is needed, preferably involving a greater variety of languages, to establish whether there is a universal order in the perceptual discriminability of duration among different manners of articulation or whether there is language-specific variation.

Contradictory experimental results and a disparity between perceptual indications and typological data imply that there are factors other than perceptual distinctiveness that affect geminate inventories across languages. One possibility is to take an evolutionary approach (Blevins, 2004a) and to search for the answer among the sound changes that participate in the creation of geminate consonants. Blevins (2004a) uses a sound change argument to explain the differences among languages in terms of a preference for sonorant geminates or obstruent geminates. Blevins (2004a) shows that in Gilbertese and Manam, which limit their geminate inventory to nasals, only nasal codas are allowed, and geminates resulting from morpheme concatenation will inevitably be nasals. In Ojibwa, which limits its geminate inventory to obstruents, historical laryngeal-obstruent clusters assimilated to give rise to obstruent geminates.

[14]Results of Obrecht (1965), however, showed a very sharp perceptual boundary between single and geminated intervocalic [n] for Arabic listeners, compared to [b] and [s].

However, there is also the possibility that asymmetries in the phenomena and processes related to geminate evolution could skew the resulting inventories. For example, in languages which place some restrictions on the type of codas allowed, nasal codas are quite common. Similarly, assimilation in consonant clusters is likely to proceed in a certain direction. That assimilation is typically regressive is soundly grounded in perception and has been argued for convincingly by Ohala (1990). CV transitions provide considerably more reliable cues to consonantal place feature than VC transitions, therefore C_2 in VC_1C_2V is less likely to be misperceived and hence acts more frequently as a trigger rather than a target of assimilation. Jun (1995) further established on the basis of a typological survey of 17 languages that in manner assimilation liquids and glides do not act as triggers as often as stops, fricatives, and nasals. Moreover, within the latter group stops were overwhelmingly more common as triggers of assimilation, acting in this capacity in all the languages surveyed. Jonstra (2003) showed that in child speech cluster reduction, Cl, Cr, or Cw clusters rarely reduce to the second member of the cluster, that is, liquid or glide (0 to 21%). Second place nasal segments in Cn and Cm clusters survived reduction more often than liquids and glides (23 to 42%), while in s+stop clusters stops were preserved in 80 to 96% of the cases. These results suggest that some typological patterns in geminate inventories (e.g., preference to stop and nasal geminates) may be due at least partially to differential success rates in the preservation of the second consonant clusters for different manners of articulation and differences in their ability to act as triggers of assimilation. The fact that liquids and glides rarely trigger assimilation and are often omitted during cluster reduction may explain the scarcity of geminate liquids and glides.

This line of reasoning, though, only takes us so far, for it does not explain the reported frequency with which sonorant gemination in particular is blocked or repaired in synchronic phonologies. Kawahara et al. (2011) describes several examples: blocking of sonorant gemination in Selayarese (Podesva, 2000, 2002) and Ilokano (Hayes, 1989), stopping of sonorant geminates in Berber, and avoidance of sonorant geminates in Japanese.

In an alternative scenario, we may consider the possibility that geminate inventories are indeed governed by perceptibility restrictions as reported in Kawahara (2007) and Hansen (2012) and the contradictory results of the present investigation represent an experimental artifact. One possible reason why this could be so is the fact that non-words were used in the current experiment, which did not sound like real words in the native language of the participants. Thus, the stimuli may have been perceived in a more *non-speech* like manner than the stimuli used in Kawahara (2007) and Hansen (2012). Psychological literature on perception of duration suggests that the duration of filled intervals (intervals with sustained acoustic energy, e.g., beeps or tones) is perceived with higher accuracy than the duration of empty intervals (silences flanked by clicks or tones) (Rammsayer and Lima, 1991; Wearden et al., 2007). This may explain the fact that the contrast perceptibility in *continuants* in this experiment was higher than the contrast perceptibility in stops. However, experiment reported in Kawahara et al. (2011) used non-speech stimuli and did not demonstrate the pattern of responses consistent with the results of the present experiment, suggesting that the non-speech explanation is not the answer. Thus, it remains a question why the results of the experiment reported here differ so drastically from the results of Kawahara (2007), Kawahara et al. (2011) and Hansen (2012).

Diverging experimental results and lack of consistency in the typological patterns discourage the introduction of MinDist constraints on geminate sonority into the phonological model of geminate typology. In view of the current results, the question of sonority as a factor in geminate inventories continues remains unsolved.

7.14 Between-language frequency

Typological generalizations about languages are not limited to statements about what is possible and what is not or implicational relationships like "if phenomenon X exists in the language, so does phenomenon Y". Often they include information about how rare or frequent certain configurations are. If the frequency distribution is non-random, phonological theory should be able to account for quantitative facts in linguistic distribution as well as qualitative ones.

Within-language variation and related frequency effects have been addressed in Anttila 1997, 2002, 2008 and Boersma and Hayes 2001; for a review see Anttila 2012. In particular, Anttila 1997 and Anttila 2008 capture within-language variation with a partial ranking approach: within the grammar of a language some constraints are unranked and every input-output evaluation randomly chooses a ranking between such constraints. This approach does not only capture the fact that one and the same language can vary between two or more possible outputs for the same input. It can also be extended to make predictions about the expected frequency of each of the possible outputs. It is, in fact, a very common situation that some variants are attested more frequently than others in free variation.

The way frequency predictions are derived from partially ranked grammars is based on the fact that the winning output is not necessarily derived by a single and unique ranking of the constraints. Typically, multiple distinct rankings converge on the same output. Assuming that each ranking can be chosen with equal probability at the moment of evaluation, the probability of a particular *output* can be calculated in the following way. If the number of all possible rankings in the grammar is R and the number of rankings that derives a particular output is r then, the frequency f of such output is predicted to be r/R. The ratio f between the number of rankings that favor an output and the number of all possible rankings is referred to as an r-volume in Riggle (2010).

This approach to within-language frequency effects can be extended in a very straightforward manner to between-language frequency, as noticed by Coetzee (2002). Of course, when a phonological analysis is tested on typological material it is hardly done on the basis of only one type of input. Several input forms are subjected to various rankings of the proposed constraints and each ranking derives an output for each input. The resulting output patterns demonstrate the application of constraints and their rankings across a variety of linguistic material. The frequency of output patterns can be derived in the same fashion as the frequency of a single output.

Coetzee (2002) tests this method of predicting between-language frequency on the example of a well-attested correlation between rounding and backness in the crosslinguistic distribution of vowels. To summarize, rounding is much more likely to occur

on back vowels across languages, and front rounded vowels are more frequently found in languages that also allow back rounded vowels. Coetzee (2002) calculates the expected frequency distribution based on the traditional OT analysis, which posits two markedness constraints to capture the distribution: one against front rounded vowels and another one against back unrounded vowels. The resulting frequency prediction is far from the observed one. Coetzee (2002) concludes that the method is not appropriate for modeling between-language frequency and notes that this is a characteristic problem such frequency calculations face. With a typical OT violation pattern, a fairly uniform frequency distribution is likely to arise. Strongly non-uniform, skewed distributions, however, are difficult to model. It is clear that some kind of ranking bias has to be introduced into the model in order to capture such unbalanced frequency distributions.

Coetzee (2002) introduces such bias with the help of *preference constraints* which state the preferred ranking between pairs of other constraints. In such a way, the probability of certain rankings is directly manipulated through preference constraints. Another way to introduce a statistical bias into the model is to augment it by *redundant* constraints — copies of constraints already in the grammar (Riggle, 2010). By careful calibration of the type and number of redundant constraints the predicted frequency distribution can be taken much closer to the observed one, as shown in Riggle (2010), although this approach also has its limitations.

In the remainder of the sections, I will apply the r-volume approach to calculate the expected frequency of the language types in the basic model and demonstrate the redundant constraints method, which I call the *inflation* approach. Finally, I would like to compare this with a new method: deriving frequency using volumes of convex regions (c-volume approach). This method is based on grammar where the candidates are evaluated by weighted constraints, not unlike Harmonic Grammar, instead of ranked constraints of classical OT. As will be shown shortly, the c-volume approach is significantly more restrictive than the inflation method. It does not rely on such arbitrary devices as need-based constraint inflation. The quantitative predictions are derived from the structure of the grammar: constraints, candidates, and their violation patterns. The proposed method of output selection in weighted

constraint systems also provides a way to evaluate the typological predictions of the model, an equivalent of the factorial typology of standard OT models. This approach represents a natural extension of the weighted constraints approach to phonological theory and frequency predictions, just as factorial typologies and r-volumes do in standard OT.

Table 7.19 reproduces the output patterns derived from the basic model of contrast dispersion applied to geminate distribution across a number of contextual environments. This table also contains rough frequency estimations for each language type. These estimations are based on the data reported in Maddieson (1984) and the survey of 45 languages listed in section 7.5. According to the data reported in Maddieson (1984), about 3.5% of the languages have geminates, although the actual number may be higher. Kraehenmann (2001) noticed that some of the geminating languages were not reported as such in Maddieson (1984)'s survey possibly due to omissions in the original sources. Thus, I will approximate the geminating languages at 5%, represented here by the 45 languages in the present survey.

It is obvious that many languages had to be left out of this estimation since they did not fit into the five types predicted by the basic model (this is also the reason why the percentages do not sum up to 100%). However, the quantitative success of a more complex model is difficult to evaluate due to two reasons: (1) there exists no phonological database large and detailed enough to make the distinctions necessary to evaluate the predictions of a more complex model, and (2) in a model with a large number of possible output patterns, the calculation of the number of rankings that derive each pattern becomes too computationally expensive. Thus, without claiming that the numbers used here are representative of the actual frequency distribution, I will use them for expositional purposes to demonstrate the technique.

To calculate the predicted frequency based on the r-volume technique, the number of constraint rankings deriving each patters has to be known. This number can be calculated, but it is more convenient to estimate it using the *sampling approach* (Riggle, 2010), in which a number of rankings is randomly selected out of the space of all possible permutations and used to estimate the probability of each pattern. The frequency distribution obtained after 10,000 permutations of the constraints in the

Type	Grammar	Output pattern	Estimated Frequency
1	No geminates	ata ta atCa at	95%
2	Intervocalic geminates	ata-atta ta atCa at	2.2%
3	Intervocalic and word-initial geminates	ata-atta ta-tta atCa at	0.9%
4	Intervocalic, word-initial, and preconsonantal geminates	ata-atta ta-tta atCa-attCa at	0.1%
5	Intervocalic, word-initial, preconsonantal, and word-final geminates	ata-atta ta-tta atCa-attCa at-att	0.5%

Table 7.19: Estimated frequency of the language types in the basic model.

Type	Grammar	Estimated	Predicted
1	No geminates	95%	50%
2	Intervocalic geminates	2.2%	16%
3	Intervocalic and word-initial geminates	0.9%	8%
4	Intervocalic, word-initial, and preconsonantal geminates	0.1%	5%
5	Intervocalic, word-initial, preconsonantal, and word-final geminates	0.5%	20%

Table 7.20: Predicted frequency using the r-volume technique.

basic model is shown in table 7.20.

The order of predicted frequency roughly follows that of the estimated one, except that the overall proportion of geminating languages is too large and in addition the language type 5 is predicted to be rather more frequent than in the estimation.

To correct the predicted frequency distribution for a better fit to the estimated frequencies we can apply the inflation technique by introducing "redundant" copies of the constraints into the model to produce a statistical bias towards certain output types. By doing this we magnify the effect of certain constraints and diminish the effect of other constraints by comparison. Table 7.21 presents the results of 10,000 randomly selected rankings for a system with 16 tokens of MinDist$_{_C}$, 8 tokens of MinDist$_{WI}$, 4 tokens of MinDist$_{V_V}$, 2 tokens of Lazy, and only one MaxContrast.

This model produces a better fit to the estimated distribution: the overall skew

Type	Grammar	Estimated	r-volume	Inflation
1	No geminates	95%	50%	60%
2	Intervocalic geminates	2.2%	16%	22%
3	Intervocalic and word-initial geminates	0.9%	8%	10%
4	Intervocalic, word-initial, and preconsonantal geminates	0.1%	5%	4%
5	Intervocalic, word-initial, preconsonantal, and word-final geminates	0.5%	20%	3%

Table 7.21: Predicted frequency using the Inflation technique.

towards non-geminating languages is improved and language type 5 is no longer predicted to be overly frequent. However, to continue to fine-tune the frequency predictions more redundant constraints will have to be added and even then the perfect distribution is likely to be unattainable. Moreover, since the number of redundant constraints can be chosen more or less arbitrarily, based only on the targeted frequency pattern, this model is not very constrained, which limits its predictive power.

Finally, I will consider the frequency estimation based on a weighted constraint approach, similar to Harmonic Grammar (HG) (Coetzee and Pater, 2010; Pater, 2009; Potts et al., 2010). In such a grammar, unlike in OT, constraints are assigned weights rather than ranks, and candidate evaluation is based on the sum of the weights of the violated constraints. Tableaux 7.125-7.126 demonstrates the principle.

(7.125)

/dog/	IDENT-VOICE[2]	*CODA-VOICE[1]	
a. ☞ dog		*	1
b. dok	*		2

(7.126)

/dog/	IDENT-VOICE[1]	*CODA-VOICE[2]	
a. dog		*	2
b. ☞ dok	*		1

The numerical value in square brackets after the constraint name is the weight of the constraint. The last column in the tableau sums up the total weight of the violated constraints for each candidate. The candidate with the highest total violation weight loses. Thus, final devoicing is achieved by assigning a *higher weight* to the *CODA-VOICE constraint, while in standard OT it is achieved by ranking *CODA-VOICE over IDENT-VOICE.

This demonstration shows that HG can perform at least as well as standard OT. The mathematical proof that weighted constraints models can produce at least the same patterns as the traditional OT, and sometimes more, is an immediate consequence of Robbiano's characterization theorem for admissible monomial orderings (Robbiano, 1986), together with the fact that the method of selecting candidates in traditional OT corresponds, in mathematics, to a monomial ordering called reverse lexicographic. [15]

Most of the current explorations of the weighted constraints approach focus on finding a single weight vector $\mathbf{w} = (w_1, \ldots, w_n)$, where each w_i is the weight of a constraint, that would derive a desired pattern. Establishing whether such a weight vector exists can be done through solving a system of linear inequalities (Potts et al.,

[15] Thanks to Giulio Caviglia for pointing this out.

2010). However, this approach is somewhat limited. To fully explore the typological implications of the proposed constraints in traditional OT, one needs to consider all possible rankings of these constraints. Similarly, to fully explore the implications of weighted constraints, the space of all possible weight vectors has to be considered.

This may seem to present a problem: even if we limit ourselves to only positive or negative numbers, the weight for each constraint can be selected from anywhere between zero and infinity. However, instead of counting how may weight vectors derive a certain output, we can first normalize the space from which the weight vectors are selected and then measure the volume of the region consisting of all weight vectors deriving the same output.

As shown in figure 7.10, to every constraint, we can associate a dimension in the space of all possible weight vectors. Given constraints C_1 and C_2 we associate to them the variables w_1 and w_2 and consider the weight space $\mathbf{W}$ defined as:

$$\mathbf{W} = \{\mathbf{w} = (w_1, w_2) | w_1 \text{ and } w_2 \text{ are non-negative real numbers } \}.$$

To normalize $\mathbf{W}$ it is enough to fix a positive radius and consider all vectors in $\mathbf{W}$ whose Euclidean norm (i.e. $\sqrt{w_1^2 + w_2^2}$ and more generally for an n-dimensional space $\sqrt{w_1^2 + \cdots + w_n^2}$) is smaller than or equal to such radius.

The figure below visualizes a model with two constraints and two candidates shown in figure 7.11. The circular dotted line delineates the regions within which the weight vectors (w_1, w_2) may be chosen: w_1 along the horizontal dimension associated to C_1 and w_2 along the vertical dimension associated C_2.

We can see that when $w_2 > w_1$ (i.e. the weight of C_2 is greater than the weight of C_1), candidate A wins. When the weight of C_2 is smaller than the weight of C_1, candidate B wins. In fact, the two triangular areas, subdividing the two-dimensional normalized space, correspond to the regions occupied by the two possible winners, A and B. The proposal is that the relative magnitude (volume, or more precisely Lebesgue measure) of these regions corresponds to the frequency of the associated output. It is important to notice that the ratio between any two of such volumes is completely independent of the radius chosen to normalize the space $\mathbf{W}$.

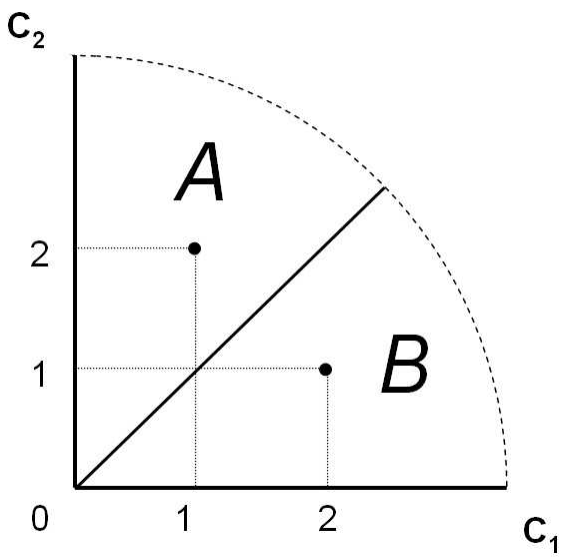

Figure 7.10: Two-dimensional model of weighted constraints.

	$C_1[1]$	$C_2[2]$	
a. ☞ A	*		1
b. B		*	2

	$C_1[2]$	$C_2[1]$	
a. A	*		2
b. ☞ B		*	1

Figure 7.11: Weighted constraints.

This proposal makes probabilistic sense in the same way the r-volume approach works for standard OT. In a partially ranked grammar (or a grammar without any a priori ranking) every time the outputs are evaluated the ranking is selected presumably at random; thus, every ranking has an equal probability of being selected.

With weighted constraints, at every evaluation time a weight is randomly assigned to each constraint. Each vector of weights is viewed as a point in the available multidimensional normalized space, and it has an equal chance of being selected. A point (i.e. a weight vector) falling within one of the regions into which the normalized weight space is subdivided corresponds to a list of weights which select the output associated to that region.

The larger the area that corresponds to an output, *the higher the probability* that a randomly selected point in the multidimensional space will fall within this area. Thus, a greater region corresponds to a greater frequency.

Based on this hypothesis, to be able to predict the relative frequencies of the outputs and output patterns, we must first find the equations of the regions subdividing the normalized weight space and then compute the volumes of such areas (*convex regions*). These two tasks are difficult, both theoretically and computationally. Fortunately, the method of sampling can be applied here as well. An algorithm implemented in Macaulay2 (Grayson and Stillman) goes through a number of cycles, each time randomly choosing a vector of weights in the normalized weight space and assigning it to the constraints in order to determine a winner. The resulting frequency distribution is an approximation (increasingly close, depending on the number of iterations) of the distribution based on the precise volume of the convex regions. Table 7.22 reports the results of this simulation (weights, with non-negative integral entries, selected in a sphere of radius 50, about 14,000 cycles).

We can see that the frequency distribution provided by the estimation of the convex regions is similar to that of the inflation model. In particular, it does not overestimate the frequency of language type 5, as the r-volume approach does. This shows that in the particular scenario presented here, the c-volume method of predicting the relative frequency of the language types generated by the weighted constraints

Type	Grammar	Estimated	Inflation	c-volume
1	No geminates	95%	60%	51.5%
2	Intervocalic geminates	2.2%	22%	28%
3	Intervocalic and word-initial geminates	0.9%	10%	13%
4	Intervocalic, word-initial, and preconsonantal geminates	0.1%	4%	5%
5	Intervocalic, word-initial, preconsonantal, and word-final geminates	0.5%	3%	2.6%

Table 7.22: Predicted frequency using the c-volume technique.

model is as successful as the inflation model but without the drawbacks of the latter. The c-volume method is preferred over the inflation approach since it achieves a similar distribution without introducing redundant constraints.

Independently of the empirical success of this approach in modeling the frequency data in the geminate typology, I believe that the view it takes of typology and variation in theories of weighted constraints, including HG, is a natural extension of the ideas contained in such theories. The relative success of this method can be evaluated by applying it to a variety of phonological phenomena for which sufficient quantitative data are available or will become available in the future.

Another contribution of this approach concerns the geometry of the convex regions into which the normalized weight space is partitioned. A partially ranked grammars view of variation in OT holds that variation arises via optional re-ranking of selected constraints. A similar effect can be achieved with weighted constraints. In this new setting the geometry of the space itself may give an insight into within-language

variation by suggesting that adjacent regions are the ones most likely involved in within-language variation. The re-ranking of selected constraints finds its analogue in the restriction of the normalized weight space in order to include only the selected neighboring regions. This hypothesis needs to be tested in the future.

7.15 Concluding remarks

The research discussed in this dissertation represents a first attempt towards a comprehensive overview of the positional typology of geminate-singleton contrasts. Experimental results and typological observations reported here support the view that contextually-driven differences in the perceptibility of consonant duration contrast play an important role in shaping the crosslinguistic distribution of geminate consonants. It is also demonstrated that stress and syllable weight factors, and their interaction with the perceptibility constraints, introduce additional patterns into the typology, those not attainable by the perceptibility account alone.

Much remains to be done in the areas of phonetics and phonology of geminates and their context. The present dissertation illuminates several directions in which future research is to be undertaken. More detailed experimental data are required in order to understand the interaction between the consonant type and the type of context in determining the perceptibility of the contrast. Thus, experimental data need to be collected for a greater variety of consonants in different contextual positions. The effect of the neighboring consonant's degree of sonority on the perceptibility of the durational contrast has not been tested experimentally yet, although typological data are strongly suggestive of the significance of this factor. The exact nature of the influence of the broader contextual environment, such the following or preceding word, has on the word-initial and word-final durational contrasts awaits to be examined as well. The more general question of the relationship between phonological weight and phonetic length also remains a fascinating subject. These are only a few directions in which future research can be developed. In addition, the controversial results concerning sonority effects on the perceptibility of duration demand a second look.

Among the theoretical contributions of this dissertation are further evidence for

constraints on contrast in phonological theory, additional evidence for the moraic view of geminate consonants, and an extension of the weighted constraint approach to linguistic typology with a novel application to variation and between-language frequency.

Appendix A

Factorial typology with the Morphological factor

Output 1	Output 2	Output 3	Output 4	Output 5
ata	ata-atta	ata-atta	ata-atta	ata-atta
ta	ta	ta-tta	ta-tta	ta-tta
atCa	atCa	atCa	atCa-attCa	atCa-attCa
at	at	at	at	at-att
at|a	at|a-at|ta	at|a-at|ta	at|a-at|ta	at|a-at|ta
t|a	t|a	t|a-t|-ta	t|a-t|-ta	t|a-t|-ta
at|Ca	at|Ca	at|Ca	at|Ca-at|tCa	at|Ca-at|tCa
a|t	a|t	a|t	a|t	a|t-at|t

Output 6	Output 7	Output 8	Output 9	Output 10
ata	ata	ata	ata	ata-atta
ta	ta	ta	ta	ta
atCa	atCa	atCa	atCa	atCa
at	at	at	at	at
at|a-at|ta	at|a-at|ta	at|a-at|ta	at|a-at|ta	at|a-at|ta
t|a	t|a-t|-ta	t|a-t|-ta	t|a-t|-ta	t|a-t|-ta
at|Ca	at|Ca	at|Ca-at|tCa	at|Ca-at|tCa	at|Ca-at|tCa
a|t	a|t	a|t	a|t-at|t	a|t-at|t

Output 11	Output 12	Output 13	Output 14	Output 15
ata	ata	ata	ata	ata-atta
ta-tta	ta-tta	ta-tta	ta-tta	ta
atCa	atCa	atCa	atCa	atCa
at	at	at	at	at
at|a	at|a-at|ta	at|a-at|ta	at|a-at|ta	at|a-at|ta
t|a-t|-ta	t|a-t|-ta	t|a-t|-ta	t|a-t|-ta	t|a-t|-ta
at|Ca	at|Ca	at|Ca-at|tCa	at|Ca-at|tCa	at|Ca-at|tCa
a|t	a|t	a|t	a|t-at|t	a|t

Output 16	Output 17	Output 18	Output 19
ata-atta	ata-atta	ata-atta	ata-atta
ta-tta	ta-tta	ta-tta	ta
atCa-attCa	atCa	atCa	atCa
at	at	at	at
at|a-at|ta	at|a-at|ta	at|a-at|ta	at|a-at|ta
t|a-t|-ta	t|a-t|-ta	t|a-t|-ta	t|a-t|-ta
at|Ca-at|tCa	at|Ca-at|tCa	at|Ca-at|tCa	at|Ca
a|t-at|t	a|t-at|t	a|t	a|t

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