The phonetics of metrical prominence and its consequences on segmental phonology

by

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Submitted to the Department of Linguistics and Philosophy
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Abstract

Only very few phonological processes are reported to be conditioned by stress. There are two major patterns of stress-sensitive processes: segments are lengthened under stress, and vowels become louder. Two other phonological patterns are reported in the presence of stress, although they don’t seem to enhance prominence of the stressed position: the preservation of segmental contrast and the enhancement of acoustic properties of the releases in stress-adjacent consonants. The main question of this dissertation is why there are so few segmental processes that show sensitivity to stress. Why are the major segmental processes affecting consonants (e.g. place assimilation, nasalization and voice neutralization) not sensitive about whether their trigger or target is in a stressed position?

The analysis of prosodic conditioning presented here has three components: First every stress-conditioned process is enforced by a markedness constraint requiring the perceptual prominence of a metrically strong position. Languages use two strategies to implement this prominence: increasing the duration of the stressed position, or increasing the perceptual energy of the stressed vowel. Second, increasing the loudness of the stressed vowel has side-effects on the realization of stress-adjacent stop releases, which result from the subglottal mechanisms used to produce the increase in loudness. These side-effects constitute the small class of stress-conditioned segmental alternations which are not directly enhancing the prominence of the stressed position. Third, both the effects of prominence requirements and the side-effects of prominence enhancement on the phonetic realization of segments in stressed positions may affect the perceptual distinctiveness between contrasting sounds in stressed positions: if the perceptual distinctiveness between contrasting sounds is decreased in a stressed position, contrast neutralization might arise. If the perceptual distinctiveness between contrasting sounds is increased in a stressed position, stress-conditioned contrast preservation might arise. Contrast preservation in stressed positions is therefore not an effect of Positional faithfulness; it emerges as the indirect consequence of prominence enhancement.

The set of segmental features which may be targeted by stress-sensitive processes is extremely limited since it is restricted to those features which can be affected by one of three processes: duration, loudness and effects of raised subglottal pressure on stop releases.

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As it always happens - at least this is what I am told - towards the end of a dissertation one faces the choice either to conclude, skipping over a few final touches, or to postpone and graduate the year after. I chose to stop here. There are many promising directions in which I want to push the issues addressed in this dissertation: I would rather start working on them right now. I hope the patient reader will excuse me.
al nonno Franco
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Chapter 1

Preface

This dissertation develops a novel approach to the analysis of stress-conditioned segmental alternations, which derives prosodic conditioning solely from the grammatical pressure that segments within stressed positions be perceptually prominent. The analysis incorporates a new grammar of metrical prominence with analyses of contrast neutralization and contrast preservation based on phonetic cues and perceptual distinctiveness of surface contrasts (Flemming, 2004, 2006). The central claim of this dissertation is that there are only three phonological processes which can be conditioned by the presence, or by the absence of stress. The first two sets of processes are triggered by markedness constraints enforcing the prominence of metrically strong positions: the durational prominence of the stressed domain and the perceptual energy of the stressed vowel. The third set of processes arises from the restricted acoustic side-effects of increasing the prominence of a stressed vowel: these processes result from the modulations of the subglottal pressure level, and the tensing of the vocal folds which are necessary in order to increase the loudness of the stressed vowel. No other process is predicted to be sensitive to stress. The grammar of prosodically conditioned processes is therefore not determined by the special status attributed to privileged positions: prosodic conditioning arises from the grammatical pressures imposed by the need to generate louder vowels and longer stressed units. Phonological processes which have been analyzed as cases of positional privilege are an extremely restricted set of processes which arises either as the direct consequence of prominence enhancement, or as the indirect consequence of implementing the perceptual prominence on the stressed vowel.

1.1 Stress conditioning

Two interactions are observed between word stress and segmental properties: first, certain phonological processes are conditioned by the presence of stress, (1); second, the placement of word stress can be conditioned by segmental properties, (2). This dissertation focuses on the first type of interaction, although phenomena of prominence-sensitive stress attraction are also discussed, and they can be accounted for by the same grammar.

(1) Stress-conditioned consonant lengthening in South Greenlandic (Bye and deLacy 2008: 8)

/awata-t/ [aw'atat] 'kayak bladder' (Pl.)
/nuka-t/ ['nuk:at] 'sibling' (Pl.)
Prominence-conditioned stress-assignment in Javanese (Gordon, 2006: 168)

a. /badan/ [ba'dan] 'body'
   /padat/ [pa'dat] 'compact'

b. /kampal/ [ko'mpal] 'gather'
   /taka/ [ta'ka] 'come'

The term *stress-conditioned segmental alternation* is used in this dissertation to refer to segmental processes whose distribution is sensitive to the location of stress, and which are restricted to apply in a stressed position.

The empirical observation which emerges from the study of the cross-linguistic typology of stress-conditioned segmental alternations is that possible instantiations of these alternations are extremely restricted. There are two major patterns of stress-sensitive processes: first, segments are lengthened under stress; second, vowels become louder. Two other phonological patterns are reported in the presence of stress, although they don’t seem to enhance prominence of the stressed position. These patterns are first, the preservation of segmental contrast in the vicinity of stress; second, the enhancement of the acoustic properties of the releases in stress-adjacent consonants. Releases of stress-adjacent obstruents may be realized as affricates, or they are produced with a longer frication component of the burst, with a slight aspiration, or described as louder than bursts of non stress-adjacent consonants. It is surprising fact that a large number of phonological features never participate in stress-conditioned processes.

The very restricted nature of stress-conditioned phonological processes is problematic for the standard analysis of the interaction between stress and segmental processes.

The resistance of segmental features within a stressed syllable or a stressed foot to undergo phonological processes has been accounted for as an effect of positional privilege (Selkirk, 1994; McCarthy and Prince, 1995; Alderete, 1995; 1999a,b; Beckman, 1995, 1997, 1998; Casali 1996, 1997). The manifestation of this positional privilege is the requirement that segments in prominent positions be “preferentially faithful to the feature specifications of their underlying counterpart” (Positional Faithfulness; Beckman, 1998:8). The family of Positional Faithfulness constraints is the grammatical expression of the positional privilege which protects any feature occurring in a strong positions. The Positional Faithfulness constraint proposed by Beckman to account for the preservation of contrast in stressed positions is given in (3).

(3) \text{IDENT-}\delta(F) \text{ (Beckman, 1998:131)}
Output segments in a stressed syllable and their input correspondents must have identical specifications for the feature F.

A mismatch emerges from the comparison between the typology of stress-conditioned processes and a Positional Faithfulness account of these processes, posing two serious challenges to this approach.

First, Positional Faithfulness is not able to restrict the set of features which can be targeted specifically by stress-sensitive phonological processes. Only very few phonological processes are blocked from occurring in stressed positions, e.g. place assimilation and voicing assimilation, are not blocked from occurring in stressed positions. In fact most phonological processes are not reported to be conditioned by stress. Second, the preservation of segmental contrast is also attested in stress-adjacent segments which are not contained within the stressed syllable. If these were effects of Positional Faithfulness, they would surprisingly occur outside the focus of Positional Faithfulness constraints, e.g. (4).
This dissertation presents a very different model of the grammar of stress-conditioning. The very general idea behind the proposal is that the study of stress conditioning starts from the analysis of the different strategies languages use to mark the rhythmic prominence of a metrically strong position. Specifically, a theory of stress-conditioning should begin by answering the following questions:

a. What are the ways to manifest the prominence of a metrically strong position?

b. What are the phonetic correlates of stressed positions?

c. What are the aerodynamic mechanisms needed to produce these correlates?

d. Do these mechanisms indirectly affect segments in the vicinity of the prominent position?

Three major claims are developed in this dissertation. First, stressed-conditioned segmental alternations are enforced on stressed positions by two grammatical pressures requiring the perceptual prominence of these positions. Perceptual prominence is realized through the duration of the stressed position, through the perceptual energy of the stressed vowel, or through both. The second claim is that stressed positions are not privileged positions, i.e. no grammatical constraint protects features in these positions from alternations, more than features outside of them (contra Positional Faithfulness). Finally, phonological processes which have been analyzed as cases of positional privilege are limited to the direct consequences of prominence enhancement, or to the indirect consequences of implementing the perceptual prominence on the stressed vowel.

1.2 Outline of the analysis

A main component of the analysis developed in this dissertation are prominence requirements. These requirements are grammatical pressures which trigger stress-conditioned segmental alternations in metrically strong positions which are not perceptually prominent enough. All stress-conditioned processes therefore result in the enhancement of prominence-related phonetic properties of the targeted segment. The nature of these processes is restricted to a very small set of all possible phonological processes, since only two strategies can be used to increase perceptual prominence, increasing durations or loudness, the set of processes that are sensitive to the position of word stress is restricted to a very small set of all possible phonological processes, (5).

(5) Prominence requirements on stressed positions

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. if stressed, be long</td>
<td>[p-'ak:-a] &gt; [p-'ak-a] , where [ak:] is longer than [ak]</td>
</tr>
<tr>
<td>b. if stressed, be loud</td>
<td>[p-'ak-a] &gt; [p-'ak-a] , where [a] is louder than [a]</td>
</tr>
</tbody>
</table>
A small set of processes is not enforced by the requirements in (5); these processes result in the enhancement of the acoustic properties of the releases in stress-adjacent consonants. An example of this kind is reported for Maori in (6).

(6) Maori stress-conditioned affrication (Bauer, 1993:521-22)

/piu/ [pç(i)u] 'swing'
/iti/ ['itsi], [itçi] 'small'
/karanga/ ['kxereŋe] 'call'

It is argued that these processes arise as the side-effect of enhancing the loudness of the stressed vowel, (5)b. In order to increase the loudness of the stressed vowel, subglottal pressure has to be increased. Changes in subglottal pressure are slow to produce (ca. 300ms; Rothenberg, 1968): although it is possible to slightly increase the rate of change, this requires a significant increase in effort. Increasing subglottal pressure on a vowel is therefore liable to result in increased subglottal pressure during neighboring segments also. The effects of subglottal pressure increases, though predominantly affecting the loudness of the target vowel (Titze and Sundberg, 1992), but they are not strictly local: they also modulate the acoustic realization of the neighboring consonants. Acoustic properties of consonants’ releases are mostly affected by the modulation of subglottal pressure, since oral pressure behind the release is significantly higher in stress-adjacent consonants than in non-stress-adjacent consonants. Examples of attested side-effects of these modulations are listed in (7).

(7) Side-effects of loudness enhancement on stress-adjacent stop releases:
   a. Increased loudness (higher intensity), e.g. Farsi (Samareh, 1970)
   b. Increased sharpness (steeper intensity slope), e.g. Italian (Giavazzi, 2009)
   c. Increased frication noise, e.g. Maori (Bauer, 1993)
   d. Increased aspiration, e.g. Maori (Bauer, 1993)

The third main claim of this analysis of metrical conditioning is that prominence requirements and side-effects of loudness increases may indirectly affect the distribution of segmental contrast in stressed positions and in stress-adjacent segments. If the alternations triggered in the presence of stress decrease the distinctiveness of a contrast, contrast neutralization might arise. If on the other hand the alternations triggered in the presence of stress increase the distinctiveness of an otherwise weak contrast, a pattern of contrast preservation might arise. Phonological processes which have been analyzed as cases of positional privilege are thus limited to the following: they are either direct consequences of prominence enhancement, or indirect consequences of implementing the perceptual prominence on the stressed vowel.

The account of prosodic conditioning developed in this dissertation is extremely restrictive. The set of segmental features which may be targeted by stress-sensitive processes is limited since it is restricted to those features which can be affected by one of three processes: duration, loudness and effects of raised subglottal pressure on stop releases.
1.3 Organization of the dissertation

The dissertation is organized as follows. Chapter 2 lays out the conceptual outline of the analysis, beginning from a schematic typology of metrically conditioned processes and a broad outline of the phonetically-based analysis developed formally in Chapters 5-7. Previous studies of prosodically conditioned processes are summarized here, and the advantages of the present account are laid out. Chapter 2 also lays out the formal properties and assumptions of Dispersion Theory (Flemming 2004, 2006), in which the formal analysis is cast. Chapter 3 illustrates a thorough typology of stress-conditioning, introducing the phonological patterns which are analyzed in the form of case studies in the following chapters. In Chapter 4 the phonetic bases of the formal analysis are introduced, as well the system of constraints which gives rise to prosodic conditioning. The case studies of the different manifestations of prosodic conditioning are developed in Chapters 5-7. Chapter 5 begins by analyzing the phonological processes which are directly triggered by prominence requirements holding of stressed positions, and their side effects. The case studies of stress-conditioned lengthening in Guelavía Zapotec is presented as an instantiations of the grammatical requirement on durational prominence. Prominence-sensitive stress-assignement in Javanese illustrates the grammatical pressure to maximize the perceptual prominence of stressed vowels. The side-effects of prominence enhancement on stress-adjacent segments give rise to consonantal alternations; the case study of Maori affrication shows how these effects are triggered. Chapter 6 of this dissertation addresses languages in which prominence enhancement or side-effects of stress affect the distribution of segmental contrast. The case studies of Zabiče Slovene and Copala Trique develop the analysis of this segmental pattern. Finally, Chapter 7 presents experimental evidence to the claim that prominence enhancement and side-effects of stress affect the phonetic realization of stress-adjacent segments. The chapter presents the acoustic analyses of two languages in which the position of stress affects the distribution of consonantal contrast, Italian and Finnish. A perceptual experiment documents that the side-effects of stress on the realization of adjacent consonants affect the perceptual distinctiveness of segmental contrast. A formal analysis of Italian palatalization and Finnish assimilation in presented, which derives the stress-conditioned distribution of these processes from the specific effects of stress on the perceptual distinctiveness between stress-adjacent consonants. It is shown that the restriction of these to non-stress-adjacent stops in not an effect of positional privilege, but an indirect effect of stress on the phonetic realization of these segments. Chapter 8 concludes.
Chapter 2

Introduction

2.1 The typology of prosodically conditioned processes

The interaction of stress and segmental alternations gives rise to four broad patterns of phonological processes. Segmental contrast may be neutralized in unstressed position, but preserved within a stressed position \((a)\). The mirror image of these processes is also attested \((b)\): contrasts may be neutralized in stressed positions, and preserved outside of them. Finally, certain non-neutralizing phonological alternations are attested exclusively within a stressed position \((c)\), or blocked exclusively in stressed positions \((d)\). The brief description of these four classes immediately suggests that there will be a great variety of prosodically conditioned processes. The heterogeneous and somewhat contradictory nature of the patterns in \((a–d)\) suggests that the application of any conceivable phonological pattern may be conditioned by the position of stress in a given language. In this section we illustrate a typology of these processes, and show that this is not the case. A look at the specific nature of the neutralizing, and non-neutralizing processes which are found in the vicinity of stress reveals that they are extremely restricted.

It is shown that although stress-conditioned processes can be divided into four very distinct classes, the outcomes of these processes in the languages in which they are attested are extremely restricted. Segmental duration may be conditioned by stress; in vowels, height is almost exclusively affected by stress, and the processes targeting consonantal features in stressed position modify mostly the properties of the consonants release. Furthermore, only very few phonological processes are blocked from occurring in stressed positions, e.g. place assimilation and voicing assimilation, are not blocked from occurring in stressed positions. The restricted nature of these processes poses problems for previous accounts. In previous accounts, (Positional Faithfulness; Beckman, 1995, 1997, 1998; Casali, 1996, 1998) the preservation of segmental contrast is claimed to arise from Positional Faithfulness constraints which protect segmental features in stressed position. If Positional Faithfulness constraints were determining the preservation of contrasts in stressed positions, we would expect to find that the application of any process can be stress-conditioned, i.e. blocked in a stressed position. This is not the case: we show that only a small and internally uniform set of the possible neutralizing and non-neutralizing processes are blocked in stressed positions. Furthermore, previous analyses of prosodic conditioning (Positional Faithfulness; Beckman, 1998) claim that stressed positions are privileged positions which generally resist phonological processes. Instead, in spite of this resistance, there are a great number of phonological processes which target specifically these positions. For instance, vowel contrasts can be neutralized in stressed vowels, and
stress adjacent consonants undergo non-neutralizing phonological processes. Smith (2002) develop-
ops a theory of those phonological processes which are restricted to stressed positions, a model of
Positional Augmentation.

Most of the processes belonging to the classes (b) and (c) above can be accounted for in Smith’s
model. In section 2.4 we discuss the differences between our account and Smith’s; it is shown that
although the two accounts are not incompatible, ours presents considerable advantages. Unlike
Smith’s account, the present model predicts the existence of a small number of consonantal feature
crashes which are preserved in the vicinity of stress. Furthermore, in contrast to models of
prosodic conditioning which rely on the notion of positional privilege, it can account for stress-
conditioned contrast preservation which is found outside of the stressed syllable. The comparison
with Positional Augmentation is put off until section 2.4; until then the focus of the presentation is
on the discrepancy between the predictions of Positional Faithfulness and the typology of attested
processes.

Stress conditioned neutralization processes (a) and (b) are the focus of work by Beckman (1998),
Crosswhite (1999), deLacy (2001) and Vaysman (2009). Non-neutralizing stress conditioned seg-
mental alternations on the other hand are well documented in Smith (2002), Gonzalez (2003),
deLacy (2006) and Bye and deLacy (2008). This work presents both analyses and comprehensive
surveys of these processes. The languages described in this section, as well as the case studies
analyzed in the following chapters draw on these surveys as their primary source of data.

2.1.1 Schematic outline

The goal of this section is to give a general outline of the data: its organization into parts is
made on descriptive grounds and should thus be understood as being pre-theoretical. The more
detailed description, and analysis of most of these processes is developed in the following chapters.
We present first an overview of the contrast neutralizing processes which are blocked in stressed
positions (pattern a), the neutralizing processes triggered exclusively in stressed positions (pattern
b) are presented next. Following are the presentations of stress-conditioned processes which don’t
yield contrast neutralization: processes which are restricted to stressed positions (c) and processes
which are characteristic of non-stressed positions (d).

2.1.1.1 Contrast neutralization in stressless position

Languages with stress-based neutralization processes typically neutralize contrasts in stressless
positions, and preserve them in stressed positions. This pattern is attested in a great variety of
languages, and it may involve the neutralization of both consonantal and vocalic contrasts.

In Italian (Flemming, 1993; Miglio, 1997; Crosswhite, 1999) and Catalan (Recasens, 1986,
1991; Hualde, 1992; Prieto, 1992; Beckman, 1998), for instance, there is a process of neutralization
between tense and lax unstressed vowels, (1).

(1) Vowel Neutralization in Standard Italian:
a. Lax/tense vowel contrast in stressed syllables:
   [fɛr.to] 'sure'
   [pes.ka] 'fishing'
b. Neutralization in unstressed syllables:
   [fɛr.ta.'men.te] *[fɛr.ta.'men.te] 'surely'
Similarly a consonantal contrast may be preserved in a stressed position, but neutralized in an unstressed position, as it happens for instance for the fortis-lenis consonant contrast in Copala-Trique (Hollenbach, 1977, 1984), (2). Other languages which exhibit this pattern of neutralization are Finnish, in which assimilation in verbs is blocked in a stressed position, and Italian, in which velar palatalization in the inflection of nouns and adjectives is blocked in a stressed position. These three languages are the subject of case studies.

(2) Consonant neutralization contrast in San Juan Copala Trique
(Hollenbach, 1977: 36)
   a. Fortis(lenis contrast in stressed syllables
      [a.'ga?] 'metal'
      [da.'ka] 'crest' (of bird)
   b. Neutralization in unstressed syllables
      [go.'pa] *[ko.'pA] 'goblet'

The result of this first neutralization pattern is that the set of contrasting sounds which is found in a stressed position is greater than the set of contrasts in an unstressed position, (3).

(3) \# contrasts_{stressed} > \# contrasts_{unstressed}

Every process in this class causes the neutralization of a featural contrast. Certain features are preserved in stressed positions, whereas they tend to be targeted by phonological processes in stressless positions. A small set of features are targeted by these neutralizing processes. The neutralization of vowel contrasts targets the height specification of the vowel first. Cross-linguistically, neutralizing processes in stressless positions result in vowel raising, whereas no raising is attested in stressed positions in vowel neutralizing languages. Neutralizing processes in the consonantal domain target a subset of laryngeal and manner features. Cross-linguistically, neutralizing processes in stressless positions target the features [±voice] (e.g. Copala Trique), [±continuant] (e.g. Copala Trique, Finnish) and [±strident] (e.g Italian). Obstruents which are not adjacent to a stressed vowel may become fricatives and/or be voiced.

2.1.1.2 Contrast neutralization in stressed position

Contrast neutralizing processes may also be restricted to stressed positions. Like the neutralizing processes in stressless positions, they can target both vocalic and consonantal featural contrasts, e.g Zabiče dialect of Slovene (Rigler, 1963; Crosswhite, 1999; Smith, 2002), (4), Tbatulabal (Aion, 2003).

(4) Vowel neutralization in Zabič Slovene
(adapted from Crosswhite, 1999: 43)
   a. Short vowels in unstressed syllables
      high i i u
      mid e a o
      low a
   b. Short vowels in stressed syllables
      mid e a o
      low a
An example of a consonantal contrast which is preserved in unstressed positions but neutralized in stress-adjacent consonants comes from St₂át’imcets (Lillooet Salish; Caldecott, 2009). This language has a laryngeal contrast between glottalized and plain resonants, but the contrast is neutralized in post-tonic position, (5).

(5) Laryngeal neutralization in St₂át’imcets: the suffix /-min?/
(data from Caldecott, 2009:64, transcribed into IPA)
/tʃ?iq-min?/ [tʃ?iqmin?] ‘Come and get it!’
/ʔiwa?-mín-af/ [ʔiwa?mínaʔ] ‘S/he want with him/her.’

The result of this second neutralization pattern is that the set of contrasting sounds which is found in a stressed position is smaller than the set of contrasts in an unstressed position, (41).

(6) \# contrasts\_stressed < \# contrasts\_unstressed

The neutralization of contrast in stressed vowels targets the height dimension of the vowel, but unlike vowel neutralization in unstressed vowels, it results in vowel lowering and not vowel raising.

A comprehensive view of both patterns of vowel neutralization reveals that although the first one is a process of vowel raising, and the second one of lowering, they yield very similar results. Cross-linguistically in stressed positions low vowels are preserved and non-low vowels are lowered. In Chapter 3 we show that the neutralizing process in St₂át’imcets also yields a comparable result.

As with the first neutralization pattern, very few features are targeted in this neutralization pattern, namely vowel height and a subset of laryngeal features. For instance, there is no attested case of stress-conditioned neutralization which targets place features or manner features.

### 2.1.1.3 Non-neutralizing processes restricted to stressless positions

The phonological process which is most frequently described as occurring exclusively in unstressed positions is the reduction of stressless vowels, which may result in vowel neutralization of vowel contrast in this position, as seen e.g. in (1). Consonant lenition is a further process which is frequently documented in non stress-adjacent consonants. In a thorough study of lenition, Honeybone’s (2003) claims that unlike processes which are restricted to stressed positions, which are specifically enforced in these positions, cross-linguistically consonant lenition is never favored in specific environments; it may be blocked in certain positions, such as stressed positions. Lavoie (1996, 2001) and Kirchner (1998), present surveys documenting the interaction between consonantal alternation and unstressed positions. They describe the frequent lenition between unstressed vowels. Among the languages that have stress-sensitive lenition are for instance West Tarangan and Somali (approximantization), Old English and Senoufo (voicing), and Kupia (spirantization and flapping), (7).

/tsaʔu/ [tsaʔu] ‘leg’

---

1Cases of metaphony under stress found in Romance languages could be counter-examples to this generalization, as they are cases of apparent vowel raising in a stressed position. Metaphony could also result as a side-effect of vowel lengthening under stress, and therefore not be a direct case of vowel raising under stress. This dissertation does not develop an analysis of metaphony.
The set of features which are targeted by these non-neutralizing processes are the same ones which are targeted in neutralizing processes which are restricted to stressless positions, namely vowel height and a subset of manner and laryngeal features, [±voice], [±continuant] and [±strident].

2.1.1.4 Non-neutralizing processes restricted to stressed positions

The most frequently documented processes within this class involve the stress-conditioned durational enhancement of segments in stressed positions: stressed vowel lengthening and lengthening of consonants in either pre- or post-tonic position. Examples of these processes drawn from very different languages are presented below in (8) through (10). They are presented in fuller detail as case studies in subsequent chapters.

(8) Vowel lengthening in Gualavia Zapotec (Jones and Knudson, 1977:172)
/beser/ [bɛˈsɛ:ɾ] 'bee'

(9) Post-tonic consonant lengthening in Kuuku-Ya ?u (Thompson, 1976)
/katʃin/ [kaˈtʃin] 'yamstick'

(10) Pre-tonic consonant lengthening in Urubu-Kaapor (Kakumasu, 1968:399)
/nupatá/ [nu.papaˈtá] 'he will hit'

The second group of processes in this class doesn't target segmental duration. The increase of the loudness of stressed vowels, compared to unstressed vowels, is extremely widespread. Stressed vowels can be lowered, or they can be produced with a greater intensity, or both. A subset of manner and laryngeal and manner features of stess-adjacent consonants are also targeted in some languages, [±continuant], [±strident], [±spread glottis]. Cases of occlusivization and affrication of the plosive release of a stop consonant are reported in the literature, as well as the increased presence of aspiration and slight affrication in pre-tonic consonants. This process is described for instance for New York City English Liverpool English (Carr, 1999) and Silacayoapan Mixteco (North and Shields, 1977), (11). The two latter processes are described for instance for Yuman, (12), and Maori, (13).

(11) Aspiration in Silacayoapan Mixteco (North and Shields, 1977: 22)
/tàà/ [tʰàà] 'man'

(12) Occlusivization in Yuman (Langdon, 1975: 223, 231):
Proto-Yuman /*w/ becomes /v/ in a subset of Yuman languages

<table>
<thead>
<tr>
<th>Language</th>
<th>Change</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paipai</td>
<td>No change</td>
<td>[ʔu′wa]</td>
</tr>
<tr>
<td>Mojave</td>
<td>*/w/ → /v/</td>
<td>[ʔa′va]</td>
</tr>
</tbody>
</table>

(13) Affrication in Maori (Bauer, 1993: 521-22)
/karanga/ [kxrəŋa] 'call'

We distinguish therefore between stress-conditioned processes which involve a durational enhancement and those processes which target the same set of consonantal features as the neutralizing processes, a subset of manner and laryngeal features.
2.1.2 The empirical observation: a very restricted set of processes

The data presented above instantiate four classes of stress-conditioned processes. A very simple yet striking observation shall be made about the processes which are found in these classes: their possible instantiations are extremely restricted. Segmental duration and very few phonological features may be conditioned by stress. Vowel height is almost exclusively affected by stress, or at least significantly more often than backness and rounding. Cross-linguistically, vowel height contrasts are eliminated before backness and rounding contrasts (Barnes, 2002; Flemming, 2005).

The table in (14) illustrates which of the standard SPE (Chomsky and Halle, 1968) consonantal features are targeted by the individual processes, as a function of whether the segments occur in a stressed or unstressed position, and which ones are never affected by stress. The processes targeting phonological features in stressed position modify mostly the properties of the consonants’ release. Strikingly, a large number of phonological features never participate in stress-conditioned processes.

(14) Consonantal features affected by stress

<table>
<thead>
<tr>
<th>Feature class</th>
<th>Feature</th>
<th>Stressed position</th>
<th>Stressless position</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laryngeal</td>
<td>[±spread glottis]</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>[±constricted glottis]</td>
<td>✓</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>[±voice]</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Manner</td>
<td>[±continuant]</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>[±strident]</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>[±delayed release]</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>[±nasal]</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>[±lateral]</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Place</td>
<td>[labial]</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>[coronal]</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>[dorsal]</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>[radical]</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Previous analyses of stress-conditioned processes rely on the central claim that stressed positions, like other positions in the word (e.g. segments in the root, segments within the first syllable of the word), have special positional privileges. The positional privilege attributed by Positional Faithfulness to stressed positions predicts these positions will resist phonological processes, and therefore also resist contrast neutralization. The restricted nature of the processes reviewed in the previous section poses significant problems for previous accounts of prosodic conditioning based on this account. First, it is not the case that these positions in general resist neutralization: neutralizing processes are found in these positions, which target both vocalic and consonantal features. Second, only very few phonological processes are blocked from occurring in stressed positions. Since the number of phonological features which may be affected by stress is as restricted
as we have seen, many phonological processes which target the large set of remaining features, e.g. place assimilation and voicing assimilation, are not blocked from occurring in stressed positions. In fact, most phonological processes are not reported to be influenced by stress.

The main argument of this dissertation arises from the observation of the great discrepancy between the predictions of Positional Faithfulness and the attested cases of prosodic-conditioning. In the remainder of this chapter, and in the following chapters, we show that the grammar of prosodically-conditioned processes is not determined by the special status of privileged positions. Instead, prosodic conditioning arises from grammatical pressures to realize stress through auditory prominence. These grammatical pressures only target the auditory properties of stressed vowels and stress-adjacent consonants, and only those which can affect the perceptual prominence of the stressed position.

The processes presented in the previous section can be summarized with three very general observations. First, vowels with higher F1, and therefore greater sonority (Parker, 2002) tend to appear in stressed nuclei. Second, the releases of stress-adjacent obstruents are frequently realized as affricates, slightly aspirated, or described as louder than bursts of non stress-adjacent consonants. Third, stressed vowels and stress-adjacent consonants have longer durations than segments which are not stress-adjacent.

The analysis of these patterns, which is outlined in the next sections and developed formally in later chapters, accounts for the range of stress-conditioned phonological processes as arising from conditions on metrical prominence in a language, and on its implementation. In next section we sketch the conceptual outline of the analysis, looking closely at the grammatical triggers of the types of processes which are found in prominent positions.

2.2 Dispersion Theory: a sketch

The analysis of stress-conditioning is developed within the Dispersion Theory of Contrast (Flemming, 1995, 2004, 2006, 2008), which formalizes the role of perceptual distinctiveness in the grammar. The analysis is cast in Flemming’s (2006) model of the phonological grammar, which is divided into three subcomponents: Inventory, Realization and Evaluation of Surface Contrasts (henceforth ESC).

Distinctiveness constraints (MINDIST) are the formal tool through which properties of contrasts are evaluated, as opposed to isolated forms. These constraints account for the preference for more distinct contrasts over weaker contrasts.

The inventory:

MINDIST constraints apply to phoneme inventories, where they interact with the preference to maximize the number of contrasting sounds (MAXIMIZE CONTRASTS: the number of contrasting sounds in an inventory is derived from the relative ranking between these two constraints. Sounds are represented in this framework as being located in a multidimensional perceptual space. The perceptual distinctiveness evaluated by MINDIST constraints is the distance between sounds along a given perceptual dimension (e.g. F1 or [duration]). The location of a sound on a dimension is specified in the inventory.

---

2 This section provides a sketch of the Dispersion Theory of Contrast, and obviously does not do justice to the work of Edward Flemming. The interested reader should consult Flemming (1995, 2004, 2006, 2008), which provide a transparent exposition.
Consider for instance a language in which long and short vowels are contrastive in the inventory. Both vowels are specified for a duration target in the inventory:

<table>
<thead>
<tr>
<th>Inventory Segment</th>
<th>[duration]</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>1</td>
</tr>
<tr>
<td>V:</td>
<td>2</td>
</tr>
</tbody>
</table>

This inventory is derived by the ranking below:

\[
\text{MINDIST}=[\text{duration}]:1 \gg \text{MAXIMIZE CONTRASTS} \gg \text{MINDIST}=[\text{duration}]:2
\]

**The Realization:**

This component maps strings of segments drawn from the inventory onto their phonetic realizations. Stress assignment is included in this component, and prominence requirements are active in this component.

The phonetic realization emerges from the ranking of correspondence constraints requiring faithful realization of the perceptual targets of the input segments and markedness constraints, such as articulatory effort constraints and prominence requirements.

**The Evaluation of surface contrasts:**

MINDIST constraints also apply in the ESC, where they evaluate the surface realization of contrasts and penalize those candidate contrasts that are not adequately distinct, yielding their neutralization. We adopt the strictest possible relation between the constraint ranking of the Inventory, and the one in the Evaluation, namely one of identity.

### 2.3 Schematic outline of the account

The central claim of this dissertation is that stress conditioned processes are exclusively driven by a grammatical pressure to maximize the auditory prominence of metrically strong positions. There is no effect of Positional Faithfulness on stressed positions. We argue that every stress-sensitive process results in the enhancement of prominence-related phonetic properties of the targeted segment. Unlike previous formal approaches to prosodic conditioning, we predict that the set of phonological processes which are predicted to be sensitive to the position of word stress is restricted to a very small set of all possible phonological processes. These can be of two kinds: (i) processes which maximize prominence of a stressed position; (ii) processes which arise as side effects of prominence enhancing processes. The operative grammatical constraints in stress conditioning are formulated as Optimality Theoretic constraints (Prince and Smolensky 1993, 2004; OT). They are either constraints which enforce metrical prominence, or constraints which regulate the phonetic implementation of metrical prominence. The constraints which enforce metrical prominence are projected from a hierarchy of perceptual prominence, and they refer to auditory features. This claim has important consequences for the phonology of prominent positions. Beckman (1998) and deLacy (2001) refer to the set of prominent positions, which contains phonetically strong and psycho-linguistically strong positions, (15), as a homogeneous class, which pattern the same in the
phonological grammar.

(15) Privileged positions (Beckman, 1998; Smith, 2002)

- Phonetically strong positions
  - Stressed syllables
  - Syllable onsets
  - Long vowels
- Psycho-linguistically strong positions
  - Initial syllables
  - Roots

We argue instead that the phonology of these positions is heterogeneous. The phonological grammar of stressed positions is determined by a set of constraints which exclusively enforce the prominence of metrically strong positions.

In the following two sections, we show that the restrictiveness of prosodically conditioned processes is understandable if we claim that these processes exclusively arise from the action of markedness constraints which evaluate the auditory prominence of stressed positions. In other words, we don't treat stressed positions as privileged positions for featural contrast, and therefore remove the assumption that faithfulness constraints can specifically refer to features within them. The formalization of the analysis is developed in Chapter 4 and in the case studies of Chapter 5 and Chapter 6. Experimental evidence in support of this account is presented in the two case studies analyzed in Chapter 7. The advantages of this analysis are discussed in §2.4, where previous proposals are summarized and discussed.

2.3.1 Grammatical requirements on metrically strong positions

We argue that prosodic conditioning arises solely from grammatical pressures on the realization of prominence of stressed domains. This argument rests on the proper identification of the different pressures which act on these positions, and on the correct definition of prominence, when applied to stress. These are the building blocks are presented here.

The definition of stress which is at the core of this thesis is the one proposed by Liberman (1975) and Liberman and Prince (1977), and which is a central claim in Hayes' (1995) metrical stress theory, namely that stress is the linguistic manifestation of rhythmic structure. A stressed domain of a prosodic word is a metrically strong position within the word. The location of the stressed domain in the word is a language-specific property. Note that we are using here the term stressed domain to refer to the stressed position, and not stressed syllable. In the next chapter we define the extent of this domain as the interval which includes the stressed vowel and all consonants up to, but not including the post-tonic vowel. We provide evidence for this domain over the syllable as the locus of stress. For the purpose of this conceptual analysis, it is sufficient to say that the stressed domain is the phonological unit on which constraints on metrical prominence may act.

Two auditory properties contribute to the perceptual prominence of a stressed domain: its total duration and the total perceptual energy (Gordon, 1999, 2006) of the stressed vowel. Segments within the stressed domain can therefore be required to be longer than their unstressed counterparts, and longer than adjacent stressless domains.

A stressed vowel can be required to have a greater total perceptual energy than its unstressed counterpart, and a greater total perceptual energy than its surrounding vowels. Duration and
total perceptual energy are two auditory dimensions. The durational prominence of the stressed domain can be enhanced by lengthening the duration of the segments within the domain. The total perceptual energy of the vowel is function of its intensity and its duration, it can be enhanced by increasing the intensity, the duration, or both. Languages may also differ in the relative importance of duration and energy which they assign to the realization of metrical prominence. In some languages (e.g. Italian; Farnetani and Kori, 1986; Payne, 2005) segments within a stressed domain have a greater duration than segments in a stressless domain, and stressed vowels have a greater perceptual energy than stressless vowels. In some languages (e.g. Finnish; Suomi et al., 2003; Suomi and Ylitalo, 2004) on the other hand, metrical prominence is exclusively expressed by the increased duration of segments within the stressed domain.

A distinction is drawn between two broad requirements which may hold of the stressed domain of a prosodic word: its paradigmatic and syntagmatic auditory prominence. Paradigmatic prominence refers to the prominence of the stressed domain compared to the prominence of its unstressed counterpart. Syntagmatic prominence refers to the prominence of the stressed domain compared to the prominence of the unstressed domains surrounding it. Languages may differ in whether they show effects of syntagmatic prominence. In a language in which syntagmatic requirements are active, not all stressless domains are equal: stressless domains which are immediately adjacent to stress are even less prominent than stressless domains which are not stress-adjacent. An example of this requirement may be flapping in English and other languages, which is most frequent applied in immediately post-tonic stressless positions. In some languages, stressless domains are not reported to be internally differentiated: the split is only between stressed and stressless domains.

The operative grammatical constraints in stress conditioning are markedness constraints which are projected from these auditory dimensions, and enforce the durational prominence of the stressed domain, $D_{dur}$, or the perceptual energy of the stressed vowel, $V_{Energy}$. The limitation of energy effects to the stressed vowel and durational effects to the entire stressed domain is due to the empirical observation that stress-conditioned segmental alternations only yield increased loudness of the stressed vowel, never of the entire domain. For instance, there are to our knowledge no attested cases of fricativization of obstruents within the domain. Duration and perceptual energy are auditory dimensions, which project a fixed hierarchy of constraints on prominence. For instance, a domain with a duration of 200ms. will always be more prominent along the durational dimension, than a domain of length 100ms., (16)a. This fixed ranking of prominence projects to a ranking of the relative markedness constraint, (16)b. Similarly, a vowel whose total perceptual energy is 1.5 energy units will always be more prominent along this dimension than a vowel whose total perceptual energy is 1, and less prominent than a vowel whose energy is 2, (17)a. Again, the fixed ranking of prominence projects to a ranking of the relative

3Gordon (2006) observes that the perceptual energy of the entire rhyme conditions the placement of stress in languages with weight-sensitive stress. There seems thus to be an asymmetry between the alternations which are attested in a stressed position, where only the energy of the stressed vowel seems to be altered, and the sensitivity of certain languages to the energy of the entire rhyme, when it comes to the placement of stress. Since the focus of this dissertation is mostly the interaction between stressed positions and segmental alternations, we adopt the view that loudness requirements refer to the stressed vowel. A more thorough analysis of weight-sensitive stress systems is needed to assess the exact focus of these metrical constraints.
markedness constraint, (17)b.

(16) Example: Partial scale of durational prominence and constraints
   a. $\hat{D}_{\text{dur}}=200\text{ms.} > \hat{D}_{\text{dur}}=150\text{ms.} > \hat{D}_{\text{dur}}=100\text{ms.}$
   b. $\hat{D}_{\text{dur}}\geq 100\text{ms.} \Rightarrow \hat{D}_{\text{dur}}\geq 150\text{ms.} \Rightarrow \hat{D}_{\text{dur}}\geq 200\text{ms.}$

(17) Example: Partial scale of vowel prominence and constraints
   a. $\hat{V}_{\text{Energy}}=2 > \hat{V}_{\text{Energy}}=1.5 > \hat{V}_{\text{Energy}}=1$
   b. $\hat{V}_{\text{Energy}}\geq 1 \Rightarrow \hat{V}_{\text{Energy}}\geq 1.5 \Rightarrow \hat{V}_{\text{Energy}}\geq 2$

Stress conditioned phonological processes are exclusively driven by these two grammatical pressures to maximize the auditory prominence of metrically strong positions ($\hat{D}_{\text{dur}}\geq X$ and $\hat{V}_{\text{Energy}}\geq X$). We will refer to these processes as the direct effects of prominence requirement. The increase of the durational prominence and of the total energy of the stressed vowel are determined by the interaction of these grammatical pressures with segmental markedness and faithfulness constraints in the grammar. In some languages both prominence requirements are operative, in other languages only one of them is active in the grammar and triggers phonological processes. The full description of the two auditory dimension, and the construction of the relative perceptual scales is presented in Chapter 4; the formal analysis of these processes is developed in Chapter 5.

Whereas the phonological processes triggered by the constraints in (16) yield the durational increase in the stress domain, phonological processes triggered by the constraints in (17) may have side-effects on the realization of segments which are adjacent to the stressed vowel, but not necessarily contained within the stressed domain. In the following section we introduce the ways in which increasing the total perceptual energy of the stressed vowel can affect the realization of stress-adjacent consonants. We argue that these effects are extremely limited, and that they give rise to the only other kind of processes which is sensitive to stress.

We have focused in the section on phonological processes which are enforced in stressed positions. We have not discussed processes which are favored in unstressed position. This is in keeping with Honeybone's (2003) and Bye and deLacy's (2008) proposal that consonant lenition and vowel reduction are never favoured in specific environments, but they may be blocked in certain positions, such as metrically prominent domains. Unlike their accounts, in which positional faithfulness constraints that block lenition in prosodically prominent environments are of crucial importance, this account eliminates faithfulness to the contents of stressed positions. Neutralizing and non-neutralizing phonological processes which are restricted to unstressed positions are not banned from stressed positions because of their privileged phonological status, but because they would be prominence reducing.

2.3.2 Side-effects of prominence requirements

Increasing the duration of the stressed domain simply results in lengthening the duration of one, some or all segments in the stressed domain. Increasing the total perceptual energy of the stressed vowel on the other hand can carry consequences for the realization of segments other than the stressed vowel itself. There are three ways in which the energy of the vowel can be enhanced: by lengthening the vowel, by lowering it and finally by increasing its loudness without either lengthening or lowering. The occurrence of these phonological processes is conditioned by the relative ranking of constraints on prominence with faithfulness constraints.
If $V_{\text{Energy}} \geq X$ constraints are ranked higher than faithfulness constraints to vowel height and vowel duration, (18)a, there will be variation between lengthening and lowering stressed vowels in order to reach the required energy level\(^4\). This pattern is attested cross-linguistically either as a non-neutralizing phonological process, or as a neutralizing process, e.g. in Zabiče Slovene, (4).

The second possible ranking, (18)b, blocks vowel lowering. It therefore requires that the total energy of a stressed vowel that is below the required level be increased by either increasing its duration or by increasing its loudness, or both. This pattern is very frequent across languages: stressed vowels are frequently lengthened, and short vowels may become long, yielding either length neutralization or not, e.g. Gualavía Zapotec, (8).

Under the third and fourth possible ranking of these constraints, (18)c-d, vowel lengthening is blocked by a high-ranked faithfulness constraint. The stressed vowel is therefore made more perceptually prominent by increasing its loudness, and possibly by lowering it. Many of the languages showing this pattern have contrastive vowel length. Either no lengthening is possible in these languages, or not enough lengthening to achieve the required level of prominence in the stressed vowel, e.g. Maori, (13).

(18)  
\begin{align*}
\text{a. } & V_{\text{Energy}} \geq X \gg \text{IDENT } V_{\text{dur}}, \text{IDENT } V_{\text{height}} \\
\text{b. } & \text{IDENT } V_{\text{height}} \gg V_{\text{Energy}} \geq X, \text{IDENT } V_{\text{dur}} \\
\text{c. } & \text{IDENT } V_{\text{dur}} \gg \text{IDENT } V_{\text{height}}, V_{\text{Energy}} \geq X \\
\text{d. } & \text{IDENT } V_{\text{dur}}, \text{IDENT } V_{\text{height}} \gg V_{\text{Energy}} \geq X
\end{align*}

Languages in which metrical requirements on the energy level of the stressed vowel are solely, or mainly satisfied, through an increase in its intensity level, are languages in which side-effects of this prominence requirement can be found. No faithfulness constraint protects the basic loudness level of the vowel; limitations to the possible increases in loudness are effects of markedness constraints penalizing high levels of subglottal pressure. The loudness of a vowel is augmented with an increase of the subglottal pressure level centered on the stressed vowel, and the tensing of the vocal folds (Sluijter and van Heuven, 1996). The modulation of pressure has to take place also during the articulation of stress-adjacent segments. The side-effects of increasing subglottal pressure are mostly visible on stress-adjacent stops. They increase the loudness of the release and result in greater frication noise.

These are side-effects of a prominence requirement, namely the grammatical pressure to enforce the perceptual prominence of a stressed vowel. They do not increase the energy level of the vowel per se, but enable increases of the vowel’s energy level. In Chapter 4 we derive the domain within which these effects are expected to be found. We refer to them as effects which are indirectly triggered by prominence.

Two properties of these side-effects are crucial to the proposal of this thesis. First, they are restricted to the few possible phonetic effects of a subglottal- and thus oral pressure increase on the realization of stress-adjacent obstruents, (19). The domain in which they are predicted to be found corresponds to the region within which subglottal pressure is increased, which is centered around the stressed vowel.

\(^4\)We present here a simplified picture of the interaction between prominence constraints and IO-correspondence. In the formal analysis of these processes in the following chapters, we adopt a system of scalar faithfulness to vowel height and vowel duration, which penalizes different thresholds of deviation from the input duration and height targets. This system predicts that both lengthening and lowering can be used to increase prominence.
a. Side-effects of subglottal pressure increase on stress-adjacent consonants:
- Increased loudness of the stop release
- Increase loudness of the frication noise
- Increased sharpness of the burst at the stop release

b. Side-effects of vocal fold tensing on stress-adjacent consonants:
- Increased VOT

Second, increasing the vowel’s loudness entails some effect on the realization of the neighboring obstruent. These side-effects are predicted to be strongest in those languages in which increasing the vowel intensity is the major strategy to increase its energy level, as in languages with the grammars in (18) c and d.

The side-effects associated with the sub-glottal pressure increase and vocal fold tensing during the production of stress-adjacent consonants are responsible for the stress-sensitive alternations which do not increase the prominence of the stressed position, e.g. affrication in Maori. The phonological processes which are sensitive to the position of word stress are therefore restricted to a very small set. These can be of two kinds: (i) processes which are driven in order to maximize prominence; (ii) processes which arise as side effects of prominence enhancing processes, which affect the phonetic realization of stress-adjacent obstruents.

Chapter 4 illustrates the aerodynamic mechanisms which give rise to the phonetic properties of the side-effects in (19). The formal definition of the effort constraints is also provided in this chapter. Chapter 6 develops the formal analysis of this class of processes through the presentation of two case studies from Maori and Copala Trique. Two further case studies, of Italian palatalization and Finnish assimilation are developed in Chapter 7, with experimental evidence for this account.

2.3.3 Predicted typology of stress-sensitive processes

The previous two sections laid out the building blocks of the present account. This section illustrates the typology of stress-conditioned processes, which is predicted from the few possible interactions between stress and segmental structure. The tables in (20) illustrate the typology of the processes which are predicted to be specifically sensitive to the presence, or absence of stress. The table reports the grammatical triggers of processes in stressed positions, the processes which are predicted to be triggered by them (top), or blocked (bottom), and the phonological features which these processes target. Finally, for every predicted process we report the effects of these processes on the auditory prominence of the stressed position. Table (21) illustrates the features which are predicted to not be affected by the presence or by the absence of stress, since they cannot be targeted either by direct constraints on prominence, or by its side-effects.

(20) Predicted interactions between stress and segmental structure
(Stressed positions)

a. 
### b.

<table>
<thead>
<tr>
<th>Grammatical pressure</th>
<th>Phonological process</th>
<th>Targeted feature</th>
<th>Effect</th>
<th>Attested cases (examples)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_{dur} \geq X$</td>
<td>V lengthening</td>
<td>$\pm$long</td>
<td>D duration</td>
<td>Gualavá Zapotec (Jones and Knudson 1977) Tübatulabal</td>
</tr>
<tr>
<td></td>
<td>C lengthening in D</td>
<td>$\pm$long</td>
<td>D duration</td>
<td>Urubu-Kaapor (Kakumasu, 1986) Kuuku-Ya'fu (Thompson, 1976)</td>
</tr>
</tbody>
</table>

| $V_{Energy} \geq X$ | V lowering           | $\pm$high      | ↑V energy | Zabiče Slovene (Rigler, 1963) |
| V lengthening       | $\pm$long            | ↑V energy      | Gualavá Zapotec (Jones and Knudson 1977) |
| increased V intensity | n/a                   | ↑V energy      | Dutch (Sluijter and van Heuven, 1996), Italian (Albano Leoni et al., 1995) |
| glottalization      | $\pm$constricted glottis | ↓V energy | St’át’ilmcets (Caldecott, 2009) |
| creaky voice        | $\pm$constricted glottis | ↓V energy | Gualavá Zapotec (Jones and Knudson 1977) |
| V nasalization      | $\pm$nasal           | ↓V energy      | Guaraní (Beckman, 1998) |

### c.

<table>
<thead>
<tr>
<th>Effort ( C ) &amp; $V_{Energy} \geq X$</th>
<th>Phonological process</th>
<th>Targeted feature</th>
<th>Auditory effect</th>
<th>Attested cases (examples)</th>
</tr>
</thead>
<tbody>
<tr>
<td>affrication in voiceless stops</td>
<td>$\pm$delayed release</td>
<td>$\pm$strident</td>
<td>none</td>
<td>Maori (Bauer, 1993)</td>
</tr>
<tr>
<td>louder stop release</td>
<td>n/a</td>
<td>none</td>
<td>Farsi (Samareh, 1977), Italian (Giavazzi, 2009)</td>
<td></td>
</tr>
</tbody>
</table>

Given the restricted number of grammatical pressures which can act on stressed positions, it is predicted that, duration aside, the only consonantal features which can be targeted by stress-sensitive processes are the laryngeal and manner features in (20). Some processes are predicted to be penalized by metrical requirements in stressed positions. Any feature whose realization competes with the phonetic implementation of metrical prominence is predicted to be potentially targeted under stress. For instance, glottalization and creakiness ((20)b) have been shown to decrease the intensity of the stressed vowel (Gordon and Ladefoged, 2001; Lyon, 2007). A similar decrease of vowel intensity is caused by the nasalization of vowels (Maeda, 1993). The features targeted by the side-effects of stress, are also limited to the small set of manner and laryngeal features in (20)c. Phonological processes triggered by the effort constraint Effort C do not have any effect on the perceptual prominence of the stressed domain, or of the stressed vowel.

All place features, and the laryngeal and manner features in (21) are predicted to never be affected by stress. The predictions of this account are restricted even further: not all phonological processes targeting the features in (20) are predicted to be stress-sensitive, only those which arise from the side-effects of stress (compare (20)c and (21)). For instance, there is no language which has the same process of voicing assimilation as Russian, with the only difference that in this lan-
guages the assimilation process is sensitive to the presence or absence of stress. Similarly, there is no documented case of a language in which, as in Senoufo, some plain consonants become ejectives, but in which, unlike in Senoufo, ejectivization is restricted to the stressed position.

(21) Unpredicted interactions between stress and segmental structure

<table>
<thead>
<tr>
<th>Phonological process</th>
<th>Targeted feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>voicing assimilation</td>
<td>±voice</td>
</tr>
<tr>
<td>ejectivization</td>
<td>±constricted glottis</td>
</tr>
<tr>
<td>C nasalization</td>
<td>±nasal</td>
</tr>
<tr>
<td>labialization</td>
<td>labial</td>
</tr>
<tr>
<td>coronalization</td>
<td>coronal</td>
</tr>
<tr>
<td>dorsalization</td>
<td>dorsal</td>
</tr>
</tbody>
</table>

The prominence based approach to prosodic conditioning outlined here greatly restricts the possible interactions between stress and segmental structure to those triggered by prominence constraints and those arising from their side-effects. It formalizes the idea that there are no effects of Positional Faithfulness in stressed positions but only a limited set of processes which are promoted by grammatical pressures on the realization of prominence of stressed positions. Chapter 3 presents the full typology of stress-conditioned processes, showing that the factorial typology in (20) is not only restrictive, but also adequate.

An important property of this account is that process promotion and process inhibition (Honeybone, 2003) in stressed positions are a unified set of phenomena that all reflect a preference for the auditory prominence of stressed positions. Phonological processes are blocked where they would result in the violation of higher-ranked prominence requirements.

The positions within which stress-conditioned processes are predicted to occur are of two kinds: the stressed domain, the stressed vowel with its immediately adjacent segments. Since the stressed vowel always lies within the stressed domain, both prominence-triggered processes, (20)a and (b), target the stressed domain. The second position is crucially distinct from previous proposals. We predict that phonological processes triggered by side-effects of subglottal pressure increase on stress-adjacent segments, i.e. processes in (20)c, will only be found in those stress-adjacent segments which lie within the range of subglottal pressure increase. These processes are predicted to occur in immediately stress-adjacent segments, independently of their prosodic constituency, and possibly also in segments immediately preceding and following the stress-adjacent ones. The boundaries of this region are strictly linked to the region in which subglottal pressure fluctuates in response to a pressure to increase the perceptual energy of the stressed vowel. Although the experimental evidence needed in order to precisely delimit this region still needs to be gathered, Chapter 4 presents a more detailed discussion of this point.

2.4 Comparison with previous analyses

In the previous sections we outlined the prominence based analysis of prosodic conditioning that is developed in this dissertation. Much of the data presented in the sections above is of the type often accounted for with Positional Faithfulness and Positional Augmentation. This section reviews a Positional Faithfulness account of the data and shows that there are two main problems with this account. First, an analysis of prosodic conditioning that is not phonetically grounded overgenerates. Previous accounts of prosodic conditioning propose Positional Faithfulness constraints which
could in principle refer to any feature. This predicts many more cases of prosodically conditioned processes than are actually attested. The proposed account provides a better fit to the typology. As we saw in the previous sections, not all features can be targeted by specifically stress-sensitive processes, only those which are either targeted by prominence-enhancing processes, or those which are targeted indirectly by the side-effects of prominence enhancement. Second, an analysis which is not phonetically grounded over- or underpredicts, the extent of stressed domains within which featural content is protected by Positional Faithfulness constraints. Stress-conditioned processes arising from the side-effects of prominence requirement occur stress-adjacently, independently of syllabic boundaries. An analysis which treats the stressed syllable as the locus of positional privilege undergenerates the set of possible patterns (Beckman, 1998; Smith, 2002); an analysis which in the other hand extends the Positional Faithfulness domain to the main stressed foot (Anttila, 2006) overgenerates the type of processes which can be conditioned by stress. The phonetic underpinnings of stress conditioning provide a basis for predicting what type of phonological processes can and cannot be affected by stress, and where these processes occur.

This section begins with a presentation of Positional Faithfulness in its earlier formulations (Beckman, 1998), §2.4.1. Smith's (2002) integration of Positional Augmentation constraints to the set of positional constraints operating in stressed positions is reviewed in §2.4.2. Finally, advantages of the present account over the two past frameworks, along with the problems outlined above are discussed, §2.4.3.

2.4.1 Positional Faithfulness

The resistance of segmental features within a stressed syllable or a stressed foot to undergo phonological processes has been accounted for as an effect of Positional Faithfulness (Selkirk, 1994; McCarthy and Prince, 1995; Alderete, 1995; 1999a,b; Beckman, 1995, 1997, 1998; Casali 1996, 1997), which generally states that segments in prominent positions are required to be “preferentially faithful to the feature specifications of their underlying counterpart” (Beckman, 1998:8). Beckman adopts a set of Positional Faithfulness constraints, not dissimilar to Selkirk’s formulation of PARSE(F) constraints, that penalize the occurrence of corresponding segments in privileged positions which do not have identical specifications for [F]. The family of Positional Faithfulness constraints are the grammatical expression of the positional privilege which protects any feature occurring in a strong positions, (15). In the case of stress-conditioned blocking of contrast neutralization, the strong domain is the stressed syllable\(^5\). The Positional Faithfulness constraint proposed by Beckman to account for the preservation of contrast in stressed positions is given in (22).

\[(22) \text{IDENT-}\sigma(F) \quad \text{(Beckman, 1998:131)}\]

Output segments in a stressed syllable and their input correspondents must have identical specifications for the feature F.

This constraint belongs in the family of non-positional Faithfulness (IDENT(F)) of McCarthy and Prince (1995), and universally dominates it, (23).

\[(23) \text{Stressed syllable faithfulness sub-hierarchy} \quad \text{IDENT-}\sigma(F) \gg \text{IDENT}(F)\]

\(^5\)Anttila (2006) extends the domain targeted by Positional Faithfulness constraints to the material within the main stressed foot; the problems arising from this extension are discussed in §2.4.3
When some markedness constraint or constraints (M) intervene in the ranking in (23) stress-conditioned neutralization arises. M is any kind of alternation-favoring markedness constraint. The ranking of M in the midst of the featural faithfulness constraints, (24), crucially above the context-free faithfulness constraint, is responsible for generating the stress-sensitive positional asymmetry. The featural contrast will be maintained within the stressed syllable and neutralized elsewhere.

(24) Positional asymmetries
\[ \text{IDENT-}^\delta(F) \gg M \gg \text{IDENT}(F) \]

The tableaux in (25) show the Positional Faithfulness analysis of a stressed conditioned vowel neutralization process like the one found in Standard Italian, (1), for three hypothetical inputs.

(25) Positional Faithfulness and the positional neutralization of stressless vowels.

<table>
<thead>
<tr>
<th></th>
<th>/tɛpo/</th>
<th>IDENT-(\text{\delta}(V \text{ height}))</th>
<th>*LAX MID</th>
<th>IDENT(V height)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>tɛpo</td>
<td>*!</td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>b.</td>
<td>tɛpo</td>
<td></td>
<td>*</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>/tɛpo/</th>
<th>IDENT-(\text{\delta}(V \text{ height}))</th>
<th>*LAX MID</th>
<th>IDENT V height</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>tɛpo</td>
<td></td>
<td></td>
<td>*!</td>
</tr>
<tr>
<td>b.</td>
<td>tɛpo</td>
<td></td>
<td>*</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>/tɛpo/</th>
<th>IDENT-(\text{\delta}(V \text{ height}))</th>
<th>*LAX MID</th>
<th>IDENT(V height)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>tɛpo</td>
<td></td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>b.</td>
<td>tɛpo</td>
<td></td>
<td>*</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>/tɛpo/</th>
<th>IDENT-(\text{\delta}(V \text{ height}))</th>
<th>*LAX MID</th>
<th>IDENT(V height)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>tɛpo</td>
<td></td>
<td></td>
<td>*!</td>
</tr>
<tr>
<td>b.</td>
<td>tɛpo</td>
<td></td>
<td>*</td>
<td></td>
</tr>
</tbody>
</table>

The relative ranking of markedness and faithfulness constraints in (25) derives the blocking of vowel neutralization in stressed syllables. The markedness constraint rules out the candidate with a lax mid vowel when the vowel is stressless, (iii)b, yielding the neutralization of lax and tense mid vowels, (iii) vs. (iv). The high ranked Positional Faithfulness constraint IDENT-\(\text{\delta}(V \text{ height})\) blocks the neutralization of stressed vowels. Positional Faithfulness can therefore account for the neutralization of vowel contrast that is restricted to stressless syllables. This analysis relies on two assumptions: first, the blocking of neutralization processes is restricted to segments that are contained in the stressed syllable, second, any feature within a stressed syllable may be targeted by Positional Faithfulness constraints.

As we saw in the previous sections, the challenge for this analysis lies in its inability to restrict the set of features which can be targeted specifically by stress-sensitive phonological processes. Beckman’s analysis does not make any prediction about what features should and should not show stress-conditioning. An account based on Positional Faithfulness does not distinguish between the kind of processes in (20) and those in (21). For example, the blocking of neutralization between oral and nasal vowels in stressed syllables is attested, most famously in Guaraní (Gregores and
Suárez, 1967; Hulst and Smith, 1982; Piggott, 1988, 1992; Beckman, 1998; Walker, 1998; Thomas, 2009; among others). I don't know however of any case in which the nasalization of consonants is blocked in a stressed syllable but neutralized elsewhere. Similarly, I don't know of any language in which the voicing contrast among stops is neutralized by voicing assimilation in stressless syllables but it is preserved in stressed syllables. Positional Faithfulness predicts that all of these cases could arise from the action of Positional Faithfulness constraints in stressed syllable, (26).

(26)  
   a. Stress conditioned consonant nasalization?
   tálanka → tálanga  
   tankála → *tangála  
   b. Stress conditioned voicing assimilation?
   kátégsa → kátégza  
   kágseta → *kágzeta

Positional Faithfulness was proposed to account for the resistance of a broad class of strong positions to undergo phonological processes, the stressed syllable being only one of them. In the specific case of stressed positions, the processes which were analyzed originally are cases of vowel reduction and vowel neutralization. Although this analysis can account for the distribution of some patterns, it over-generates the target features, and it over-and under-generates the domain.

2.4.2 Positional Augmentation

Smith (2002) develops Beckman’s model of positional privilege to account for the phonological processes which are triggered by grammatical requirements holding of strong positions (M/str), such as stressed syllables of roots, (15). Phonological requirements holding of strong positions are enforced by positional markedness constraints relativized to the strong position in question (e.g. M/str; M/ROOT).

The author notes that not any phonological requirement may hold of these positions, only those which call for the enhancement of perceptually prominent characteristics of sounds within the strong position, and are thus cases of positional augmentation. The restrictions on the nature of these requirements are set by a number of constraint filters which make use of perceptual and articulatory information to screen the freely constructed M/str constraints. The requirement that all M/str constraints must be positional augmentation constraints is enforced by the Prominence Condition, (27), a constraint filter that excludes non-prominence-enhancing M/str constraints.

(27)  
   Prominence Condition (Smith, 2002:6)
   Markedness constraints specific to strong positions are included in CON only if the general markedness constraints from which they are built call for the presence of perceptually prominent properties.

Phonological requirements that hold specifically within strong positions are analyzed by means of M/str constraints ranked as shown in (28).

(28)  
   Positional augmentation ranking with M/str constraints
   (Smith, 2002:16)
   M/str ≫ F ≫ M

34
The augmentation constraints that are predicted to operate on the strong position stressed syllable, M/\hat{\sigma}, are listed in (29).

(29) \textbf{HEAVY}\sigma /\hat{\sigma}:
For all syllables x, if x is a \hat{\sigma}, then x has more than 1 mora.
*\textbf{PEAK}/X /\hat{\sigma}:
For all syllables x, if x is a \hat{\sigma} and a is the nucleus of x, then a does not have a sonority level X.
\textbf{ONSET} /\hat{\sigma}
For all syllables x, if x is a \hat{\sigma}, then x has an onset.
*\textbf{ONSET}/X /\hat{\sigma}:
For all syllables x, if x is a \hat{\sigma}, then the onset of x does not have a sonority level X.
\textbf{HTONE} /\hat{\sigma}:
For all syllables x, if x is a \hat{\sigma}, then a tone-bearing unit associated with x bears high tone.

The tableau in (30) shows the analysis of stress-conditioned vowel lowering in Zabič Slovene, (4), with the augmentation constraint *\textbf{PEAK}/X /\hat{\sigma}.

(30) Lowering of high vowels in stressed syllables (hypothetical input) (adapted from Smith, 2002:93)

\begin{center}
\begin{tabular}{|c|c|c|}
\hline
/túka/ & *\textbf{PEAK}/HIV/\hat{\sigma} & IDENT[high] \\
\hline
a. túka & *! & \\
\hline
b. tóka & * & \\
\hline
\end{tabular}
\end{center}

In (30), the high ranked positional augmentation constraint rules out candidate (a) which contains a stressed vowel whose sonority level violates the prominence requirement. Positional augmentation can account for most phonological processes which are attested specifically in stressed positions, §2.1.1.2 and §2.1.1.3, such as stressed vowel lengthening (\textbf{HEAVY}\sigma /\hat{\sigma}), post-tonic lengthening (\textbf{HEAVY}\sigma /\hat{\sigma}) and vowel lowering (*\textbf{PEAK}/X /\hat{\sigma}). This analysis of augmentation is similar to the account of the same processes which is developed in this thesis. The two prominence enhancing markedness constraints \textbf{D}_{dur} \geq X and \textbf{V}_{\text{Energy}} \geq X operate in a way which is comparable to the constraints in (29). There are however two challenges for this approach. First, Smith's substantive filters predict that only prominence-enhancing processes will be triggered by the presence of stress. They don't predict the existence of those phonological processes which are triggered by the side-effects of prominence enhancement, (20)c, since they do not increase the prominence of the stressed syllable. We could assume that cases like the affrication of pre-tonic obstruents (e.g. Maori) enhances the prominence of the transition into the stressed vowel, and is therefore triggered by an additional positional augmentation constraint, which we can name \textbf{LOUDBURST ONSET}/\hat{\sigma}. Although this assumption would extend Smith's model to account for the existence of side-effects of stress in pre-tonic position, it would not predict that these processes can occur stress-adjacently, independently of syllable boundary (e.g. in the onset of a post-tonic syllable). The account fails to predict the existence of a small number of consonantal feature contrasts which are preserved in the vicinity of stress (e.g. in Copala Trique, Italian and Finnish).

Second, the theory of Positional Augmentation is not a theory of contrast preservation in a stressed position. The blocking of neutralizing processes in strong positions is analyzed by Smith
as arising from the action of a second set of positional constraints, namely a version of Beckman’s Positional Faithfulness constraints, $F/str$. Unlike in Beckman’s analysis, in which as we saw faithfulness to any feature is predicted to be possible in strong positions, Smith’s constraints are subject to a licensing filter, (31). The Feature Licensing condition rules out formally possible but unattested Positional Faithfulness constraints for phonetically strong positions ($\Phi/str$) such as the stressed syllable. The formulation of this filter builds on Steriade’s (1993, 1995, 1997, 1999) Licensing by Cue Hypothesis: a phonetically strong position can only have a special faithfulness relationship with a feature for which that position possesses salient cues. The phonetic prominence of a stressed syllable is a function of its duration, amplitude, and/or pitch: these properties all increase the perceptibility of vowel features. Positional Faithfulness constraints targeting the stressed syllable are therefore restricted to vowel features: the filter excludes all positional faithfulness to consonantal features.

(31) Feature Licensing Condition (Smith, 2002:76)

In a constraint of the form $\text{IDENT}[\text{Feat}] / \Phi/str$, the following condition must be met:

$\Phi/str$ must possess salient cues for the perception of $\text{Feat}$.

The filter proposed by Smith greatly restricts the number of predicted effects of positional faithfulness to features in stressed positions. It does however fail to predict the existence of a small number of consonantal feature contrasts which are preserved in the vicinity of stress, §2.1.1.2. The author acknowledges that contrast preservation in Copala Trique poses a challenge for the validity of this filter (Smith, 2002:76), in fact not only Copala Trique, but the of neutralization of consonantal features in Italian and Finnish is also problematic. Even more so, given that these effect are found outside of the strong positions stressed syllable.

2.4.3 Advantages of phonetic grounding

This section summarizes the main problems of the accounts sketched above, and the advantages of the present approach over them.

In Smith’s account of prosodic conditioning, two separate constraints enforce prominence requirements on stressed syllables. The existence of both triggering and blocking of phonological processes in these positions requires two somewhat contradictory constraint families. To account for the resistance of stressed syllables to undergo phonological processes, a constraint must penalize the unfaithful mapping between input and output segments in these positions. To account for the triggering of augmentation processes in stressed syllables, a constraint must require the unfaithful mapping between input and output segments in stressed syllables.

The first problem of any account which does not consider the acoustic underpinnings of stress, on the stressed vowel and the adjacent segments is unable to predict the exact nature of the small set of vocalic and consonantal processes which are conditioned by the presence of stress.

The account developed in this dissertation eliminates Positional Faithfulness from the grammatical pressures determining prosodic conditioning. It separates stress-conditioned processes into two classes, both enforced by markedness constraints. On one hand there are effects which are triggered by prominence requirements ($\bar{D}_{dur} \geq X$ and $\bar{V}_{Energy} \geq X$), which enforce the perceptual prominence of the metrically strong domain. On the other hand, there are acoustic side-effects of the enhancement of prominence on the stressed vowel, which have been neglected from previous accounts. The extremely restricted nature of the acoustic effects of stress-adjacent segments limits
the realm of stress conditioned processes in a very precise way which corresponds to set of actually attested processes. The blocking of processes and the triggering of processes in stressed positions are solely triggered by these pressures, which are not contradictory, but dependent one from the other. Similarly, the formal mechanisms through which contrast neutralization can sometimes be blocked in stressed position, and sometimes be triggered, are grounded in the acoustic implementation of prominence on stressed or stress-adjacent segments. Chapter 4 develops the formal structure on the model.

The second problem of these accounts lies in the definition of the stressed syllable as the only metrically strong position. As we have seen in the previous sections, a number of stress-conditioned processes are attested in stress-adjacent segments which are not contained within the stressed syllable. In a subset of the Italian lexicon for instance, the contrast between velar stops and palato-alveolar affricates before high front vowels is preserved only in the onset of an immediately post-tonic syllable. If this were an effect of Positional Faithfulness, it would surprisingly occur outside the focus of Positional Faithfulness constraints. A very similar effect in the distribution of Finnish assimilation has been taken by Anttila (2006) as evidence that the privileged domain should be extended to the main stressed foot (IDENT-'F(F)). The tableaux in (32) shows the schematic analysis of Finnish assimilation with this constraint.

(32) Finnish assimilation in verbs (adapted from Anttila, 2006:13)

<table>
<thead>
<tr>
<th>/vetä-i/</th>
<th>IDENT-'F(±strident)</th>
<th>*TI</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. ε</td>
<td>(vé.ti)</td>
<td>*</td>
</tr>
<tr>
<td>b. (vé.sí)</td>
<td>*!</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>/paranta-i/</th>
<th>IDENT-'F(±strident)</th>
<th>*TI</th>
<th>TERNARY</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. (pá.ran).ti</td>
<td>*!</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. (pá.ran.sí)</td>
<td>*!</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. ε</td>
<td>(pá.ran.sí)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The Positional Faithfulness analysis can account for a number of the problematic cases if the domain of positional privilege is extended to the main stressed foot. This move however has major consequences on the predicted factorial typology of Positional Faithfulness effects. Beckman’s challenge of restricting the set of features which can be targeted by stress-conditioned processes is greatly increased here, since the existence of IDENT-'F(F) constraints predicts all sort of non-attested cases of Positional Faithfulness to any feature within the stressed foot.

The phonetically grounded analysis developed in this dissertation has a major advantage over these accounts, in terms of predictive power. Prominence triggered processes are predicted to occur within a stressed domain such as the stressed syllable, or the stressed interval, but a second class of processes is also predicted, namely the processes which are indirectly triggered by stress. The analysis of the side-effects of stress on stress-adjacent segments is independent from prosodic constituency, since it solely relies on the concept of string adjacency. These effects are predicted to occur within the domain which is affected by the increase of subglottal pressure. This contains immediately adjacent segments, be they in the stressed syllable, in the stressed foot, or in neither. Chapter 4 discusses the limits of both domains.
2.5 Summary

This chapter has laid out the overview of this dissertation, introducing the research question of this dissertation and sketching the account which is developed in the following chapters.

The chapter begins with a very simple observation that can be made about the processes which show sensitivity to the position of stress, namely that their possible instantiations are extremely restricted. Segmental duration may be conditioned by stress, vowel height, and the processes targeting consonantal features in stressed position modify mostly the properties of the consonants’ release. It is a surprising fact that a large number of phonological features never participate in stress-conditioned processes. It is shown that the very restricted nature of stress-conditioned phonological processes is problematic for the standard analysis of the interaction between stress and segmental processes. Accounts of metrical conditioning which are built on the concept of positional privilege either over-generate, or under-generate the predicted typology of stress-sensitive processes; they also cannot account for stress-conditioned phonological patterns which are found outside outside the focus of positional privilege. The outline of a novel approach to the question of why stress-conditioned processes are so restricted was presented, which tackles the problem from a very different perspective.

The next chapters develop the proposal: Chapter 3 presents a detailed typology of stress-sensitive processes, from which the empirical observation of restrictiveness emerges. Chapter 4 formalizes the ingredients of the model which was outlined schematically here.
Chapter 3

A typology of prosodically conditioned processes

3.1 Introduction

This chapter illustrates an extended typology of phonological processes which can be conditioned by the presence or by the absence of stress. The data summarized in the overview of the previous chapter is presented here in more detail, and more data is added to it. The aim of the chapter is to provide further cross-linguistic evidence to the claim that stress-conditioned processes are of a very restricted nature. They are of two kinds. The first class of processes is triggered by the need to satisfy grammatical constraints requiring the auditory prominence of metrically strong positions. The grammatical pressures driving these processes are the requirement to increase the duration of the stressed domain (D_{dur} ≥ X), and the requirement to increase the perceptual energy of the stressed vowel (V_{Energy} ≥ X). The second class of processes arises from the side-effects of implementing the prominence of the stressed vowel: they result from the side-effects of increasing the subglottal pressure level during the articulation of stress-adjacent segments. The claim, which was outlined in the previous chapter, is very restrictive: according to it no other process may be conditioned by stress. This claim is substantiated here through the demonstration that these, and only these three kinds of processes are documented to exist cross-linguistically.

The goal of the chapter is to present the cross-linguistic distribution of the data: its organization into parts is understood as being pre-theoretical. The chapter is structured like the schematic survey of the previous chapter, namely into the four broad patterns of phonological processes which arise from the interaction of stress and segmental alternations. Section 3.2 discusses non-neutralizing phonological alternations which are attested exclusively within a stressed position; section 3.3 those which are blocked exclusively in stressed positions. Segmental contrasts which are neutralized in unstressed position, but preserved within a stressed position are presented in §3.4. The mirror image of these processes, namely contrasts which are neutralized in stressed positions and preserved outside of them are presented in §3.5.

The literature on prosodically conditioned segmental processes implicitly does not restrict the range of different word-internal prosodic units within which segments show a stress-conditioned distribution. References to the stressed syllable (Beckman, 1998; Smith, 2002), or the main stressed foot (Anttila, 2005; Vaysman, 2009) are used to account for different cases of prosodic conditioning. For this reason, the terms “prominent” and “metrically strong” positions are used to describe differ-
ent units depending on the phenomenon under analysis. The following overview purposely does not touch upon the issue of defining the domain of stress, and thus the domain of stress-conditioning. It includes processes which occur in a wide variety of prominent and non-prominent positions, identifying them for each relevant language. The set of stress-sensitive domains argued for in this thesis is introduced and defined in Chapter 4.

This chapter mainly draws on surveys in previous work on stress-conditioning as its primary source of data: Beckman (1998), Crosswhite (1999), deLacy (2001, 2006), Smith (2002), Gonzalez (2003), Bye and deLacy (2008), and Vaysman (2009), as well as the grammars of the individual languages.

3.2 Non-neutralizing processes restricted to stressed positions

Phonological processes restricted to prominent positions are of two kinds, ones which increase the duration of segments within the position, and others which have been described as changes of “magnitude” (Lavoie, 2001) in either the stressed vowel or in consonants in the vicinity of stress. These processes target other segmental features in the stressed domain. These processes are also often referred to as fortition processes, to distinguish them from lenition processes, which are found in stressless positions. Bye and deLacy observe (2008:1) that although there is “a tacit agreement among phonologists and phoneticians about the prototypical use of the term fortition”, in the phonetic dimension the term does not refer to a single unified phenomenon but instead to both changes in duration and qualitative changes. Similarly, in phonology, the term is often used to refer to the categorical effects of such adjustments in duration and magnitude. Since many different processes fall under this broad denomination, we divide them in this section into durational processes (§3.2.1) and non-durational processes (§3.2.2).

3.2.1 Durational processes

This label groups together those phonological processes which involve stress-conditioned durational changes in segments within a stressed domain. Both vowel lengthening and consonant lengthening are attested, they are presented in the following two sections.

3.2.1.1 Vowel lengthening

The lengthening of stressed vowels has been mostly studied in relation to languages with an iambic stress system (e.g. Hayes, 1995), which have the tendency to mark the quantitative contrast within the foot by lengthening the vowel of the stressed syllable. Two examples of this process are illustrated in (1).

(1) Iambic lengthening (examples)
   a. Kashaya (Bye and deLacy, 2008:16; data from Buckley 1994:172)
      /mo.mu.li.i'e.du.ce.du/  [(mo.'mu:).(li.,c'e:).(du.,ce:).du]
      'keep running all the way around'
   b. Central Alaskan Yupik (Bye and deLacy 2008: 17)
      /qa.ja.ni/  (qa.'ja:).ni
      'in his own kayak'
Prince (1990) and Hayes (1995) argue that this type of phonological lengthening is typically not found in languages with trochaic stress. There have been however reports of 'trochaic lengthening' in the literature (e.g. /CVCVCVCV/ → [(CV:CV)(CV:CV)]). Hayes (1995:84) claims that some of these cases are phonetic and not phonological (e.g. Swedish, cf. Bruce; 1984). Of the others, almost all turn out to have lengthening in the main-stressed syllable only. Examples are Icelandic (Hayes, 1995), Mohawk (Michelson, 1988; Mellander, 2003), Selayarese (Mithun and Basri, 1986; Mellander 2003); Guelavia Zapotec (Jones and Knudson 1977; González, 2003), Popoloca (Veerman-Leichsenring, 1991; González, 2003), and Kambera (Klamer, 2004; van der Hulst and Klamer, 1996). These languages have been described as having phonetically lengthened vowels, and not a process of phonological lengthening such as the one found in iambic systems (Bye and deLacy, 2008).

Standard Italian has also been analyzed as having trochaic feet (den Os and Kager, 1986; Sluyters 1990). Stressed vowels in open syllables are longer than unstressed vowels (see D’Imperio and Rosenthal, 1999), (2).

(2) Phonetic lengthening in St. Italian (D’Imperio and Rosenthal, 1999)
   a. Lengthening in penultimate stressed syllables:
      /la.vo.ro/ [la.(‘vo:).ro] ‘work’
   b. Lengthening in antepenultimate stressed syllables:
      /ta.vo.lo/ [(‘ta:vo).lo] ‘table’

There is a lot of discussion in the literature on the exact nature of vowel lengthening in Italian. D’Imperio and Rosenthal argue that the lengthening of antepenultimate stressed vowels in Italian is a phonetic correlate of stress and it is fundamentally different from the lengthening of penultimate stressed vowels, which, they claim, is phonological. The authors claim that lengthening in penultimate stressed syllables, (2)a, is due to a grammatical requirement that these syllables form a bimoraic foot (Prince, 1990). A stressed antepenultimate vowel, (2)b, on the other hand, is grouped with the penultimate syllable to form a disyllabic (and bimoraic) foot. Since the foot containing a stressed antepenultimate vowel is bimoraic, there is no pressure to lengthen a stressed antepenultimate vowel. Increases in the duration of an antepenultimate vowel are therefore associated with the phonetic realization of stress, but are not represented phonologically. McCrary (2004) presents a different analysis of lengthening in penultimate vowels. She presents results from acoustic studies which arguing that penultimate vowel lengthening is not phonetically distinct from lengthening in antepenultimate vowels.

A similar pattern is found in regional varieties of Italian. Mazzola (1976) describes the dialect of Mistretta (Sicily) as having a complementary distribution of /VCV/ sequences with regard to vowel length. These are realized as [VCV] or [V:CV] depending on whether the first vowel is stressed or unstressed. This language also has a regular process of vowel reduction: it has a five vowel system, /i, e, a, o, u/, which reduces to three vowels /i, a, u/ ([i, e, u]), in unstressed syllables. The prosodic contexts in which reduction is blocked coincide with the contexts of phonetic lengthening, i.e. the nucleus of a stressed syllable. The vowel reduction pattern in this language is presented again in §3.4 as a case of contrast preservation in stressed positions.

   a. /VCV/ → [V:CV]
      /mori/ [‘mo:ri] ‘he dies’
      /veni/ [‘ve:.ni] ‘you come’
Stressed vowel lengthening is also found in Guelavia Zapotec (Otomanguean, Mexico), (4). This language has one stress per word, usually in the penultimate syllable, and it has a contrast between lenis and fortis consonants. The oral vowels /i, e, i, a, u, o/ are short when unstressed and they are lengthened when they are stressed, if they precede a lenis consonant, (4)a, or when they are at the end of the word, (4)b (Jones and Knudson, 1977).

(4) Guelavia Zapotec open oral vowels (Jones and Knudson, 1977: 172)

<table>
<thead>
<tr>
<th>Language</th>
<th>Language family</th>
<th>Position</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guelavia Zapotec</td>
<td>Otomanguean, Mexico</td>
<td>main V</td>
<td>Jones and Knudson (1977), González (2003), Bye and deLacy (2008)</td>
</tr>
<tr>
<td>Standard Slovenian</td>
<td>Slavic, Slovenia</td>
<td>main V</td>
<td>Petek et al. (1996)</td>
</tr>
</tbody>
</table>
These languages represent, together with the languages in the next section, the first pattern of prosodic conditioning, namely the set containing those phonological processes which are triggered in metrically strong positions by the grammatical pressure to enhance the duration of the stressed domain \( (D_{\text{dur}} \geq X) \). One of these languages, Guelavia Zapotec, is the subject of a case study in Chapter 5: it is a language in which the action of the prominence constraint is well exemplified, since it presents the joint presence of vowel lengthening, and consonant lengthening within the stressed position. For this reason the language is also described in the next section, which presents an overview of consonantal lengthening restricted to stressed positions.

### 3.2.1.2 Consonant lengthening

This section is divided into two parts. The first one presents the more frequent pattern of post-tonic lengthening, the second one cases of consonant lengthening in pre-tonic position. González (2003), which represents the most thorough available survey of stress-conditioned consonantal alternations, distinguishes between consonant lengthening and gemination. Lengthening refers to the cases in which there is a positive durational difference between consonants in stressed-and stressless positions but there is no change in the syllabic status of the input; gemination refers on the other hand to those cases in which the lengthening process gives rise to two hetero-syllabic consonants. Both processes are labeled here as lengthening; the syllabic status of the individual segments is reported as described in previous literature.

**Post-tonic lengthening**

Cases of lengthening and gemination in post-tonic position are frequently documented. Guelavia Zapotec (Otomanguean; Jones and Knudson, 1977), which we have introduced in the context of vowel lengthening, also shows a process of stress-conditioned lengthening restricted to the post-tonic position. This language has a contrast between fortis and lenis consonants; fortis consonants are lengthened following a stressed vowel and word-finally. Fortis stops and nasals are also reported to lengthen after a stressed vowel before /j,w/ and before a voiced consonant (Jones and Knudson, 1977; Gonzalez, 2003). A complete account of the interaction of vowel and consonant lengthening in Guelavia Zapotec is given as a case study in Chapter 5.


<table>
<thead>
<tr>
<th>Case</th>
<th>Example</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>/cpakaʔ/ [cçek.kaʔ]</td>
<td>'my tadpole'</td>
</tr>
<tr>
<td>b.</td>
<td>/nagin/ [nag.ɕiŋ]</td>
<td>'it is sweet'</td>
</tr>
<tr>
<td>c.</td>
<td>/nit/ [nitʰ]</td>
<td>'sugar cane'</td>
</tr>
<tr>
<td>d.</td>
<td>/cápinaʔ/ [caʔ.ɲi.naʔ]</td>
<td>'my pine tree'</td>
</tr>
</tbody>
</table>

A similar process of post-tonic lengthening is found in Kuuku-Yaˈu (Pama-Nyungan; Thompson, 1976). In this language main stress falls on the rightmost long vowel if there is one, otherwise on the initial syllable; secondary stress always falls on the initial syllable. A consonant is geminated when it follows a short main-stressed vowel, (7)a, (Thompson, 1976; McGarrity, 2003; Bye and deLacy, 2008). Consonants following short secondary-stressed vowels do not undergo gemination, (7)b. The interaction of consonant lengthening and stress assignment in Kuuku-Yaˈu is the subject of a case study in Chapter 5.
Post-tonic lengthening in Kuuku-Ya?u (Bye and deLacy, 2008:7)

a. /pama/ [páma] 'Aboriginal person'
   /kacinpinta/ [káci:nptan] 'female'

b. /mija:nina/ *[mija:nina] 'show himself'

South Greenlandic Inuktitut (Inuit; Ulving, 1953) is a further example of a language with post-tonic lengthening (Bye and de Lacy, 2008). Main stress in this language is morphologically or lexically determined, and it always falls within a two-syllable window at the right edge of the Prosodic Word. The initial syllable of the word always bears secondary stress. Consonants geminate following a penultimate main stressed vowel, (8)a, but no gemination takes place in secondary stressed syllables, (8)b.

Post-tonic lengthening in South Greenlandic
(Bye and deLacy 2008: 8)

a. /awata-t/ [awá:at] 'kayak bladder' (Pl.)
   /nuka-t/ [ndik:at] 'sibling' (Pl.)

b. /iqalukat/ [iald'k:at] *[iqqald'k:at]
   'polar cod' (Pl.)

The table in (9) provides a longer list of languages in which post-tonic lengthening is documented in stressed positions.

Post-tonic consonant lengthening

<table>
<thead>
<tr>
<th>Language</th>
<th>Language family</th>
<th>Reference</th>
</tr>
</thead>
</table>

Like the lengthening of stressed vowels, post-tonic lengthening is triggered in stressed position by the grammatical pressure enforcing the durational prominence of metrically strong positions (\(D_{dur} \geq X\)). The formal analysis of this pattern is developed through the analysis of case studies
in Chapter 5. The next section introduces the second subset of stress-conditioned consonantal lengthening, namely pre-tonic lengthening.

**Pre-tonic lengthening**

In some languages pre-tonic consonants are longer than pre-atonic consonants. In a subset of these languages differences in duration can be reduced to differences in aspiration noise between these two position. These languages, among which are American English and Mexican Spanish, are discussed in §3.2.2. There are however a few languages in which pre-tonic lengthening is described as general consonant lengthening or consonant gemination before a stressed vowel. In Urubu-Kaapor (Tupi-Guarani; Kakumasa, 1986) for example, oral stops /p, t, k, kʷ, ʔ/ lengthen in the onsets of primary stressed syllables (González, 2003:48), (10). Lengthening is not attested in secondary-stressed syllables, (10)b, or in primary-stressed syllables whose onset is a nasal, an approximant or a fricative, (10)c.

(10) Pre-tonic lengthening in Urubu-Kaapor (Kakumasa, 1986: 399-401)

a. /katu/ [ka.'tu] 'it is a good'
   /kaʔa/ [ka.ʔ:a] 'forest'

b. /nupā́ta/ [nu. pa.'t:a] 'he will hit'

c. /ixa/ [i.'fa] 'it is a fact'

A very similar process of pre-tonic lengthening is found in Tukang Besi (Malayo-Polynesian; Donohue, 1991; Bye and deLacy, 2008). The difference between this language and Urubu-Kaapor is that more consonants preceding the primary stressed vowel are lengthened in Tukang Besi, in addition voiceless stops, (11). Word-initial consonants and consonants preceding a secondary stressed vowel are not lengthened.

(11) Pre-tonic lengthening in Tukang Besi (Donohue, 1991:34; data from Bye and deLacy, 2008:10)

/to-paŋ/ [top:xáŋa] 'cut-branch'
   [mč:š:i] 'far'
   [pom:óʔe] 'suck it'
   [mɔtut:ũru] 'sleepy'
   [mɔtum:ũru] 'hungry'

If a consonant qualifies for gemination the addition of pronominal suffixes or prefixes can affect the occurrence of gemination, (12).

(12) Pre-tonic lengthening and stress shift (Donohue, 1991:35)

/paŋa/ [paŋ:ά] 'branch' /to-paŋa/ [top:áŋa] 'we cut branches'

Pre-tonic lengthening poses a problem to moraic theories of metrical conditioning: since the weight of a syllable is determined by the weight of its rhyme, lengthening in the onset does not contribute to the weight of the stressed syllable. Chapter 4 proposes an analysis of this pattern which departs from its previous account in Bye and deLacy (2008). It is argued that lengthening before a stressed vowel is not enforced by durational requirement on the duration of the stressed position, rather, it is triggered in order to increase the auditory prominence of the stressed vowel. The grammatical
constraint which triggers this process in therefore distinct from the one which triggers stress-durational enhancement in stressed positions \( \hat{D}_{dur} \geq X \). It is the markedness constraint which enforces the total perceptual energy of the stressed vowel \( \hat{V}_{Energy} \geq X \). This account of pre-tonic lengthening takes a cue from the literature on the acoustic effect of frication noise or silence on the perceived loudness of a following vowel (Delgutte and Kiang, 1984; Delgutte, 1997; Wright, 2004). The differences between Urubu-Kaapor and Tukang Besi are discussed in this chapter. This model predicts that only obstruent should be lengthened in pre-tonic position, as they maximally increase the perceived loudness. The lengthening of a wider range of consonants which is found in Tukang Besi is a less expected instantiation of this pattern. Both languages are the subject of case studies in Chapter 5.

3.2.1.3 Summary
This section has presented the set of non-neutralizing phonological processes which are restricted to stressed positions, and involve the durational enhancement of segments within the stressed position. These processes are divided into vowel and consonantal lengthening. We have claimed that these processes arise from the action of the two prominence requirements which act on stressed domains, introduced in Chapter 2. Vowel lengthening and post-tonic lengthening are enforced by a requirement on the durational prominence of the stressed domain \( \hat{D}_{dur} \geq X \). Pre-tonic lengthening on the other hand is triggered in order to maximize the perceived loudness of the stressed vowel, by a constraint enforcing the prominence of the stressed vowel \( \hat{V}_{Energy} \geq X \).

The formalization of both constraints, and the mechanisms which enforce these processes, are given in Chapter 4. The formal analysis of these processes is developed in Chapter 5 with studies of the individual languages.

3.2.2 Non-durational processes
The label groups together those phonological processes which cannot be reduced to the enhancement of segmental duration within the stressed domain. Since most reported non-durational vocalic processes cross-linguistically result in patterns of contrast neutralization, they are discussed in §3.4 and §3.5. This section is about stress-conditioned consonantal processes. The range of phonological features targeted in the processes described here is restricted. As introduced in Chapter 2, stress-adjacent consonants undergo a limited set of processes: they may show a stress-conditioned alternation of laryngeal features such as aspiration and glottalization, or alternations of a single feature, stridency. Voicing alternations are most frequently restricted to stressless positions, they are therefore discussed in §3.3.

The cross-linguistic generalization which will emerge from this survey provides empirical support for the claim put forward in Chapter 2. Stress-sensitive phonological processes can be grouped in exactly two sets: those which are directly triggered by grammatical requirements of metrical prominence \( \hat{D}_{dur} \geq X \) and \( \hat{V}_{Energy} \geq X \), and those which arise from the side-effects of implementing the prominence of the stressed vowel. The first set of durational processes was reviewed in the previous sections of this chapter. This section is a cross-linguistic survey of the remaining non-neutralizing processes documented in the literature on stress-conditioning. It is shown that they correspond to the phonological processes which arise from the side-effect of prominence requirement. The aerodynamic mechanism which gives rise to these alternations is discussed in detail in Chapter 4.
3.2.2.1 Stridency, occlusivization and loudness of the burst

González dedicates a section of her survey to the processes which can be grouped under the label *fortition*. It is used to indicate a decrease in consonant sonority, and thus those processes which increase the consonantal character of the targeted consonants (Vennemann, 1988). The fricativization of approximants, the occlusivization of fricatives, the affrication of stops, and the stress-conditioned increased intensity of the plosives’ releases are considered by González (2003) as instances of fortition because they involve a decrease in sonority (see also Lavoie, 2001). Although the term *fortition* is not used here, this section covers these processes. The reasons behind the avoidance of this term is that in the present model these processes are not actively triggered in the grammar by metrical requirements, they’re therefore not direct cases of phonetic enhancement. They result from the small number of side-effects of the aerodynamic mechanisms often used in order to increase the prominence of the stressed vowel.

Bauer (1993) describes a process of stress-conditioned consonantal alternation in the phonology of Maori (Austronesian). The phonetic correlates of Maori word stress affect the realization of both vowels and consonants. Stressed vowels are reported to be lengthened and to have falling pitch. Consonants in the onset of stressed syllables are enhanced:

“These features [the realization of a stressed vowel, MG] are often accompanied by emphatic onset, which consists of a slight pause preceding the stressed syllable, and the appropriate one of the following: aspiration or affrication of stops; preglottalization of vowels; stronger friction for fricatives; longer contact for /r/; closer approximation for /w/; lengthening for nasals. These features of stress may also be accompanied by increased loudness" (Bauer, 1993:545)

Maori has three stop consonants, /p, t, k/, all of which are reported to have a variable degree of aspiration; aspiration increases with loudness and stress, Biggs (1969). According to Bauer (1995:512), affrication is more frequent than aspiration in the onset of a stressed syllable; /p/ and /t/ are affricated mostly before high front vowels, /k/ mostly before /a/.

(13) Maori stress-conditioned affrication (Bauer, 1993:521-22)

/piu/ [p̃琪u] 'swing'
/iti/ [i̯tsi], [i̯t̯ɕi] 'small'
/karanga/ [k̯ɕ réŋə] 'call'

Chapter 5 presents the mechanisms through which the side-effects of stress can give rise to the described alternations in the phonetic realization of pre-tonic stops. The analysis of prosodic-conditioning in Maori is developed in a case study in Chapter 6.

A further, more controversial case of stress-conditioned fortition is the one found in the historical development of the Yuman language family (Hokan; Wares, 1968; Munro, 1972; Langdon, 1975; Lavoie, 2001). I present here Langdon and Munro’s analysis of these processes, since it appears to account for the systematic similarities among the different processes across these languages.

In a subset of the Yuman languages (Mojave, Maricopa and Yuma), Proto-Yuman */w/ underwent a fortition to */v/ in immediately pre-tonic position, (14)a. A further process of fortition is found in the same three languages, namely the fricativization of */j/ to */θ/ in pre-tonic position.

1For a different, almost “reversed” account of these processes I refer the reader to Wares (1968) and González (2003).
(Kroeber, 1943; Langdon, 1975), (14)b. The direct comparison between the development of these consonants in different prosodic conditions (pre-tonic and pre-atomic) is not possible since the data is not available. We therefore rely on the description in assuming that /*w/ and /*j/ did not become fricatives in pre-atomic position in the relevant languages.

(14) Fortition in Yuman (Langdon, 1975: 223, 231)
   a. house  no change  Walapai  [ʔwáʔ]
                no change  Paipai  [ʔuwá]
                */w/ → */v/  Mojave  [ʔavá]
                */w/ → */v/  Maricopa  [avá ?]
   b. tooth  no change  Cocopa  [iːjá]
                */j/ → */d/  Mojave  [iːdóʔ]

Farsi is also described as showing stronger stop releases in the onset of pre-tonic consonants; specifically /ʔ/ is produced with an "emphatic and vigorous" plosion (Samareh, 1977:17) and González (2003).

González (2003:63-74) reports a wider set of similar processes which occur in pre-tonic position. We report them in the table in (15).

(15) Stridency, occlusivization and burst enhancement in pre-tonic position

<table>
<thead>
<tr>
<th>Language</th>
<th>Language family</th>
<th>Process</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Northern Colombia</td>
<td></td>
<td>Lavoie (2001)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Kirchner (1998)</td>
</tr>
<tr>
<td>Maori</td>
<td>Austronesian, New Zealand</td>
<td>/p,t,k/ → affricate/-V</td>
<td>Biggs (1969)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Bauer (1995)</td>
</tr>
<tr>
<td>West Tarangan</td>
<td>Austronesian, Indonesia</td>
<td>/w,j/ → [g,dj]/ -V</td>
<td>Nivens (1992)</td>
</tr>
<tr>
<td>Farsi</td>
<td>Indo-Iranian, Iran</td>
<td>/ʔ/ → louder release/-V</td>
<td>Samareh (1977)</td>
</tr>
<tr>
<td>Proto-Yuman</td>
<td>Hokan, Mexico, California</td>
<td>/v/ → /p/, /j/ → δ/-V</td>
<td>Wares (1968)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Langdon (1975)</td>
</tr>
</tbody>
</table>

Although the phonological processes in this class are documented exclusively in pre-tonic position, similar effects of stress on the realization of post-tonic obstruents are also found. In Chapter 7 we provide experimental evidence for the presence of burst enhancement in post-tonic obstruents in Italian. We argue that this side-effect of stress conditions the distribution of velar palatalization in the language, see also §3.4.

3.2.2.2 Aspiration

Stop consonants in the vicinity of stress are often characterized by a stronger aspiration than their unstressed counterparts. The main sources of data for the survey of the stress-conditioned distribution of aspiration are Steriade (1997), Lavoie (2001), Silverman (2003) and González (2003).

Post-aspiration

In Maori post-aspiration of obstruents in pre-tonic position is reported to alternate with affrication. In other languages it is described as the phonetic presence of more aspiration noise, often transcribed as /Cʰ/.
A better known case of post-aspiration in the onset of a stressed syllable is the aspiration of voiceless stops and /tf/ in English. In London English, the voiceless stops /p/, /t/, /k/ are often realized with heavy post-aspiration before a primary-stressed vowel, (16)a; in the case of /t/ often with affrication (also in New York City English and Liverpool English), Carr (1999), (16)b.

(16) Stop aspiration/ affrication in English (Carr, 1999: 153-6)
a. London English cup of tea /]\h^b\lambda?p\h^b\psi's\h^b\nu[\n b. New York City English tin /][ts\h

In an acoustic analysis of consonants in different prosodic positions, Lavoie (2001) reports longer durations of onset consonants in stressed syllables in Mexican Spanish and American English (see also Umeda, 1977; Turk, 1992). In English these differences mostly arise from an increased aspiration noise in pre-tonic position, compare /p/ and /k/ vs. /s/ in (17). Differences are greatest word-medially, since word-initial stops are slightly aspirated independently of the position of stress.

(17) Average American English consonant durations by position
(adapted from Lavoie, 2001: 110)

<table>
<thead>
<tr>
<th></th>
<th>Pre-stress</th>
<th>Non-Pre-stress</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial</td>
<td>Medial</td>
</tr>
<tr>
<td>/p/</td>
<td></td>
<td></td>
</tr>
<tr>
<td>closure duration</td>
<td>115</td>
<td>118</td>
</tr>
<tr>
<td>aspiration noise</td>
<td>73</td>
<td>60</td>
</tr>
<tr>
<td>picker</td>
<td>42</td>
<td>58</td>
</tr>
<tr>
<td>depose</td>
<td></td>
<td></td>
</tr>
<tr>
<td>/k/</td>
<td></td>
<td></td>
</tr>
<tr>
<td>closure duration</td>
<td>112</td>
<td>116</td>
</tr>
<tr>
<td>aspiration noise</td>
<td>57</td>
<td>50</td>
</tr>
<tr>
<td>cocoa</td>
<td>55</td>
<td>66</td>
</tr>
<tr>
<td>macaque</td>
<td></td>
<td></td>
</tr>
<tr>
<td>/s/</td>
<td></td>
<td></td>
</tr>
<tr>
<td>total duration</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>super</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A further case of post-aspiration in pre-tonic position is documented in Silacayoapan Mixteco (Otomanguean; North and Shields, 1977; González, 2003). The phonological word is formed from a disyllabic root called a couplet. Although several syllables can follow or precede the couplet, word stress always falls on the first syllable of the couplet. /t/ may be “slightly aspirated” couplet initially, and therefore aspirated in pre-tonic position, (18)a. Outside the couplet /t/ undergoes lenition to /\d/, (18)b; /t/ is preserved in post-tonic position but it is not aspirated, (18)c.

(18) Aspiration of /t/ in Silacayoapan Mixteco
(North and Shields, 1977:22-26)
a. /(t\d\h)/  [t\h\d\h] 'man’
b. /(v\d\c\d\h)/  [v\d\c\d\h] 'it rain comes’
c. /(n\d\t\d\h\i\h)/  [n\d\t\d\h\i\h] ‘broken’

Farsi voiceless stops /p, t, k/ and /tf/ are also reported to have a stronger aspiration in the onset of a stressed syllable than in other positions (Samareh, 1977:24; cf. González, 2003:100).

A more complete list of the languages exhibiting stress-conditioned post-aspiration of stops is provided in the table in (19). It is worth noticing, that although aspiration in general may be conditioned by stress, there are no reported case of post-aspiration in post-tonic consonants. As it appears from the following section, the same asymmetry is found in the distribution of stress-
conditioned pre-aspiration, which is never reported in pre-tonic position.

(19) Increased post-aspiration in pre-tonic position
(adapted from González, 2003:98)

<table>
<thead>
<tr>
<th>Language</th>
<th>Language family</th>
<th>Process</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>English</td>
<td>Germanic, England</td>
<td>C → Cʰ/̄V</td>
<td>Collins and Mees (1990)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Carr (1999)</td>
</tr>
<tr>
<td>American English</td>
<td>Germanic, USA</td>
<td>C → Cʰ/̄V</td>
<td>Lisker and Abramson (1967)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Lavoie (2001)</td>
</tr>
<tr>
<td></td>
<td>Zealand</td>
<td></td>
<td></td>
</tr>
<tr>
<td>German</td>
<td>Germanic, Germany</td>
<td>Stronger aspiration ̄V</td>
<td>Kohler (1997)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Alber (2001)</td>
</tr>
<tr>
<td>Farsi</td>
<td>Indo-Iranian, Iran</td>
<td>Stronger aspiration ̄V</td>
<td>Samareh (1977)</td>
</tr>
<tr>
<td>Silacayopan</td>
<td>Otomanguean, Mexico</td>
<td>/t/ → tʰ/̄V</td>
<td>North and Shields (1977)</td>
</tr>
<tr>
<td>Mixteco</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Squamish</td>
<td>Central Salish,</td>
<td>C → Cʰ/̄V</td>
<td>Kuipers (1967)</td>
</tr>
<tr>
<td></td>
<td>British Columbia</td>
<td>(non-glottalized plosives)</td>
<td></td>
</tr>
</tbody>
</table>

Pre-aspiration

Pre-aspirated stops are rare in the world’s languages (Silverman, 2003). Whereas prosodically conditioned post-aspiration occurs in the onset of stressed syllables, pre-aspiration is found across languages in the immediately post-tonic position. Unlike post-aspiration, which is reported to be enhanced by the presence of stress, the reported cases describe pre-aspiration as being preserved in the vicinity of stress, not generated by stress-effects in these contexts. The preference for pre-aspiration in this context is likely to arise from the good perceptibility of aspiration cues in this context. Given its poor acoustic saliency, pre-aspiration, survives best under stress, where its enhanced acoustic prominence increases its chances of survival (Steriade, 1997; Silverman, 2003).

The post-tonic preservation of pre-aspiration is common among West Scandinavian languages (Icelandic, Standard Faroese, Northern Faroese) but it is also found in other language groups (e.g., Celtic and Uto-Aztecan). Most cases discussed by González (2003) involve pre-aspiration after a short stressed vowel.

The Toreva dialect of Hopi (Whorf 1945; Steriade, 1997) presents this pattern of pre-aspirate distribution: the contrast is found intervocally in post-tonic position, (20)a, and a shift in stress causes a loss of preaspiration, (20)b.

(20) Pre-aspiration in Toreva Hopi (Whorf, 1946:182; Steriade, 1997:73; Silverman, 2003:15)
   a. [pa:sat(a)] "field-Abs.Obj.Sg."
      [ʔehpas]  'thy field-Const.Nom.Sg.'
   b. [tal,-wi³pi] approx. 'a lightning flash'
      [tal-wi₃-pi-ki] approx. 'a lightning flash design'

As in Toreva Hopi, Chamicuro (Maipuran (Arawakan), Peru) has a contrast between plain stops and pre-aspirates in post-tonic position (Payne, 1991; Parker, 1994; Silverman, 2003). While pre-
Aspirates are still preserved in the vicinity of stress in Chamicuro, other Maipuran languages have almost all lost this laryngeal gesture, usually replacing it with vowel length.

(21) Chamicuro pre-aspirates (Silverman, 2003:15)

\[
\begin{array}{l}
\text{[a.'pehta]} \quad \text{‘sardine’} \\
\text{[uit.'fehkil]} \quad \text{‘it burns’}
\end{array}
\]

In Northern Faroese the stress causes a shift in the timing of aspiration with respect to the closure of stop consonants. The language has contrastive aspirated and non-aspirated singleton and geminate oral stops /t, tt, tʰ, ttʰ/ (Gonzalez, 2003). After a non-high stressed vowel, post-aspirated singleton and geminates are realized as pre-aspirated stops, when they don’t occur in word-initial position (Kehrein, 2001; Petersen et al., 1998; Ladefoged and Maddieson, 1996; cf. Gonzalez, 2003).

(22) Pre-aspiration in Northern Faroese (Gonzalez, 2003; from Petersen et alia, 1998:126)

\[
\begin{align*}
\text{a. /papi/} & \quad \text{[pʰa.pi]} \quad \text{‘dad’} \\
\text{/lappi/} & \quad \text{[a.ppi]} \quad \text{‘rag’} \\
\text{b. /takka/} & \quad \text{[tʰa.ʰkka]} \quad \text{‘thank’}
\end{align*}
\]

A more complete list of languages in which the distribution of pre-aspiration is conditioned by stress is reported in table (23) below.

(23) Pre-aspiration in post-tonic position (adapted from González, 2003:102)

<table>
<thead>
<tr>
<th>Language</th>
<th>Language family</th>
<th>Reference</th>
</tr>
</thead>
</table>
| Icelandic           | West Scandinavian, 
Iceland                  | Silverman (1997) |
|                     |                  | Ringen (1999)                    |
| Standard Faroese    | West Scandinavian, 
Faroe Islands          | Kehrein (2001)                  |
| Northern Faroese    | West Scandinavian, 
Faroe Islands          | Kehrein (2001)                  |
| Scots Gaelic        | Celtic, Scotland        | Chasáide and Dochartaigh (1984) |
| Irish Gaelic        | Celtic, Ireland        | Chasáide and Dochartaigh (1984) |
| Toreva Hopi         | Uto-Aztecan, Arizona  | Whorf (1945), Steriade (1997)   |
| Ojibwa              | Algonquian, Canada    | Bloomfield (1956), Kehrein (2001) |
| Tarascan            | Tarascan, Mexico      | Foster (1969), Silverman (2002) |

The relation between aerodynamic mechanisms to increase the duration of the stressed vowel and the presence of post-aspiration is more complex than the consonantal effects described in the previous section. If it is the case that the presence of an increased aspiration in stress-adjacent obstruents could arise from the tensing of the vocal folds (Halle and Stevens, 1971), the appearance of a stress-conditioned glottal opening gesture can less straightforwardly be attributed only to a side-effect of a prominence requirement. Similarly, the stress-conditioned distribution of pre-aspiration is likely to result from the preservation of aspiration in this position, due to the greater availability of cues to the laryngeal contrast (Steriade, 1997; Silverman, 2003). Issues regarding aspiration are discussed in Chapter 4.
3.2.2.3 Glottalization

Like the distribution of aspiration, the timing of glottalization in underlying glottalized consonants is sensitive to the position of stress in some languages. Post-glottalization is the occurrence of a glottal constriction at or after the release of a consonant; in pre-glottalization on the other hand, a glottal constriction is timed before the oral constriction of a consonant. In most languages, pre-glottalized consonants occur in post-tonic position, and post-glottalized consonants in pre-tonic position, as in the case of aspiration, (24)a. There are however languages, (24)b, in which glottalization is avoided in the vicinity of stressed vowels.

(24) Glottalization in stress-adjacent consonants (adapted from González, 2003:108)

<table>
<thead>
<tr>
<th>Language</th>
<th>Language family</th>
<th>Process</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>/S?/ → [S?]/_V</td>
<td>Howe and Pulleyblank (2001)</td>
</tr>
<tr>
<td>Gitksan</td>
<td>Penutian, British Columbia</td>
<td>/S?/ → [?S]/V_</td>
<td>Rigsby and Ingram (1990)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>/S?/ → [S?]/_V</td>
<td>Kehrein (2001)</td>
</tr>
<tr>
<td>Sánčáłłën</td>
<td>Salishan, British Columbia</td>
<td>/R?/ → [?R]/_V-</td>
<td>Kehrein (2001)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>/R?/ → [R?]/_V-</td>
<td>Howe and Pulleyblank (2001)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>/R?/ → [R]/_V-</td>
<td>Howe and Pulleyblank (2001)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>/R?/ → [R?] elsewhere</td>
<td></td>
</tr>
</tbody>
</table>

Steriade (1997) has argued that glottalization is most frequently realized in immediately stress-adjacent position because the long vowel maximizes the perceptual cues to the laryngeal contrast. In a study of glottalization in languages of North America, Howe and Pulleyblank (2001) claim that the distribution of glottalization cannot immediately be reduced to a Licensing by Cue analysis, but rather based on syllable structure. It is not the aim of this chapter to provide an analysis of the distribution of glottalization. We’d like to observe however that the only language in González’ (2003) survey, Stʔátʔimcets (Salishan; Eijk, 1997; Caldecott, 1999, 2009), which has the opposite pattern of distribution in pre-tonic position (R? → ?R.V), also presents a process of neutralization of the laryngeal contrast in post-tonic position (R? → R/V_). In §3.5 pre-and post-tonic glottalization in Stʔátʔimcets are presented in more detail.

3.2.2.4 Summary

This section has presented the set of stress-sensitive phonological enhancement, which cannot be reduced to the durational enhancement of consonants in the vicinity of stress. These processes target a very restricted set of consonantal features: affrication, louder and more aspirated consonant releases, and occlusivization are found in pre-tonic position, §3.2.2.1. We claim that these processes arise in stress-adjacent consonants as side-effects of the aerodynamic mechanisms set in place to increase the loudness of the stressed vowel. They are triggered by an effort constraint which regulates modulations of the subglottal pressure levels (see Chapter 4).

A prediction of this claim is that these effects arise independently from prosodic constituency. The phonetic realization of consonants within the domain within which subglottal pressure is raised and vocal folds are tensed is affected. In Maori for instance, the affected consonants are in pre-tonic position, in the onset of the stressed syllable (C'V(C)). In Italian and in Finnish on the other hand, these effects are observable in post-tonic position, in the onset of the post-tonic syllable ((C)V'C').
Alternations of aspiration and glottalization are also found in stress-adjacent consonants. The distribution of these laryngeal contrasts around a stressed vowel is likely to be determined by the availability of cues to the contrasts adjacent to a long vowel (Steriade, 1997, 1998, 1999). The distribution of glottalization in St?átiucets on the other hand is claimed to arise from a general dispreference for glottal closing gestures adjacent to stressed vowels, since it creakiness would reduce the loudness of the vowel, §3.5. The pattern found in St?átiucets is therefore triggered by the same grammatical pressure which enforces the lowering of stressed vowels and the lengthening of pre-tonic obstruents (§3.2.1.2), namely the pressure to maximize the total perceptual energy of the stressed vowel ($V_{Energy}$ ≥ X).

3.3 Non-neutralizing processes restricted to stressless positions

The previous section reviewed stress-conditioned processes which are restricted to stressed positions within the prosodic word. This section looks at the set of processes which are conditioned by the position of stress, but which are found in stressless positions. Contrary to the homogeneous nature of close-to-stress phenomena, these processes are very diverse and they are attested in almost every position within the word, apart from the stressed position. Honeybone (2003) claims that unlike processes restricted to stressed positions, which are specifically enforced in these positions, cross-linguistically consonant lenition is never favored in specific environments; it may be blocked in certain positions, such as stressed positions. Okobi (2006) provides experimental evidence concerning the acoustic and aerodynamic characteristics of stressed and stressless vowels, which supports a different view of phonological processes in stressless positions. Stressless vowels are not simply lacking acoustic characteristics of stressed vowels, they appear to have very distinct acoustic properties; they are reviewed in Chapter 4. It is therefore plausible that contrary to Honeybone’s claim, phonological processes which are restricted to stressless positions are favored by the specific phonetic realization of segments in these positions.

The phonological process which is most frequently described as occurring exclusively in unstressed positions is the reduction of stressless vowels. Consonant lenition is a further process which is frequently documented in non stress-adjacent consonants. Lenition refers to an increase in consonant sonority which makes a consonant more vocalic and thus weaker (Vennemann, 1988). Phenomena which fall under this label include spirantization, by which a stop is pronounced as a fricative or approximant; approximantization of fricatives, and debuccalization, by which supralaryngeal features are lost. This processes are reviewed in §3.3.1. Flapping is illustrated in §3.3.2.

3.3.1 Fricativization and approximation

In addition to the post-aspiration of pre-tonic consonants, (18), Silacayoapan Mixteco (North and Shields, 1977) also presents a process of fricativization of consonants which are not adjacent to stressed vowels. The language is described as having a stressed two-syllable couplet as the root of the word. When /t/ occurs outside this domain it is said to be softened to /θ/, (25)a. González (2003) also describes the change from /θ/ to /j/ in rapid speech when it occurs outside the stressed syllable as a case of lenition, (25)b. Lenition of /θ/ is found in post-tonic position and outside of the couplet.

(25) Fricativization in Silacayoapan Mixteco (North and Shields, 1977:22-3)
A second, well studied case of lenition in unstressed syllables is Colombian Spanish (Kim, 2002; González, 2003). Unlike in other dialects of Spanish, where they are always approximants, /b/, /d/ and /g/ are pronounced as voiced stops in pre-tonic position, (26)a, and they are lenited elsewhere in the word, (26)b. Unlike Spanish, lenition also occurs after nasals, (26)c.

(26) Fricativization in Colombian Spanish (Kim, 2002)

| a. /'ha.bla/ | [a.βlə] | 'he talks' |
| /'fie.bre/ | [fie.βre] | 'fever' |
| b. /ke.brar/ | [ke.βrəɾ] | 'to break-inf' |
| c. /'don.de/ | [don.ðe] | 'where' |

A more complete list of these processes is presented in table (27), from González’ (2003) survey.

(27) Fricativization and approximation in stressless position (adapted from González, 2003:75)

<table>
<thead>
<tr>
<th>Language</th>
<th>Language family</th>
<th>Process</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Somali</td>
<td>Cushitic, Somalia</td>
<td>/b,d,g,ng/ → [β,ð,ɣ,ŋ]/V.V</td>
<td>Armstrong (1964)</td>
</tr>
<tr>
<td>Colombian Spanish</td>
<td>Romance, Colombia</td>
<td>/b,d,g/ → [β,ð,ɣ] when not V.</td>
<td>Kim (2002)</td>
</tr>
<tr>
<td>Silacayoapan Mixteco</td>
<td>Otomanguean, Mexico</td>
<td>/t/ → [ð] outside the couplet /s/ → [ʃ]/V., V.V</td>
<td>North and Shields (1977)</td>
</tr>
</tbody>
</table>

3.3.2 Flapping

Flapping is a lenition process which involves the shortening of the stop closure of a segment. In American English it is traditionally described as the process which turns /t/, /d/ and /n/ into /t/, /d/ within the word, before an unstressed vowel (among others, Kiparsky, 1979; Hammond, 1999). Flapping between two unstressed vowels is sometimes reported to be less frequent than flapping in post-tonic position (Zue and Laferrière, 1979: 33% vs. 99% after a stressed vowel). Kahn (1980) on the other hand points out that the requirement that the following vowel be unstressed is crucial for flapping to apply, on the contrary, the presence or absence of stress on the preceding vowel, which is sometimes said to play a role, is irrelevant. Flapping can occur following a stressed vowel, as in utter or an unstressed vowel (see also Hayes, 1995; Riehl, 2003), (28)a, b. Flapping never occurs in pre-tonic position, (28)c. It is also blocked word-initially and in a non-final coda (e.g. [at.kins]). Flapping is also found in Canadian English as a non-categorical process in unstressed syllables, but
it is more optional (de Wolf and Hasebe-Ludt, 1987; cf. Gonzalez, 2005).

(28) American English Flapping
a. obesity /o.'be.si.ty/ [o.'be.si.ry]
b. metal /me.tal/ [me.ral]
c. atomic /a.'to.mic/ [a.'to.mic]

Senoufo also exhibits stress-conditioned differences between consonants in stressed and unstressed syllables (Mills, 1984). This language has one stress per word, which always falls on the first syllable of the root. Consonants are long and mostly fortis in pre-tonic position; consonants in unstressed syllables are “lightly articulated” (Mills, 1984: 120). Word-medial /d/ is flapped, (29)a and b, and /b/ becomes a fricative in the same environment, (29)c, see also (27); flapping is blocked in pre-tonic position, (29)a.

(29) Lenition in Senoufo (Mills, 1984: 119)
   a. /kà-'dàdàgà/ [kà.'dà.rà.gà] 'spot on the skin'
   b. /pi:-'fàlìdà/ [pi:.'fàli.ra] 'seeds'
   c. /sjè:-'lìbèdè/ [sjè.'li.bè.re] 'worthy words'

More cases of flapping are listed in table (30) below.

(30) Flapping (adapted from González, 2003:59)

<table>
<thead>
<tr>
<th>Language</th>
<th>Language family</th>
<th>Process</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>American English</td>
<td>Germanic, USA</td>
<td>/t,d,n/ → /r/</td>
<td>V.V,V.V (opt.)</td>
</tr>
<tr>
<td>Canadian English</td>
<td>Germanic, Canada</td>
<td>/t,d,n/ → /r/</td>
<td>V.V,V.V (opt.)</td>
</tr>
<tr>
<td>Kupia</td>
<td>Indo-Iranian, India</td>
<td>/t/ → /t/</td>
<td>(opt.)</td>
</tr>
</tbody>
</table>

3.3.3 Summary

Lenition and flapping are processes which apply across the board, and are only blocked in stressed positions. The extent to which lenition processes are conditioned by stress seems to reduce to the fact that they are usually not found in pre-tonic position, or adjacent to stress. In this dissertation, processes of consonantal lenition are not analyzed as being favored in unstressed positions, rather, following Honeybone (2003), they are treated as the default phonological processes, and specially blocked in the vicinity of stress. The blocking of lenition in stress-adjacent consonants results from the side-effects of prominence enhancement on the phonetic realization of these segments. The analysis of consonantal lenition will therefore emerge in the formal analyses developed in the following chapters, Chapters 5-7, from comparison between those phonological processes which are restricted to stressed positions (§3.2), and those which are found elsewhere.

In this respect, the distribution of flapping in American English poses a possible problem: an analysis in which prominence requirements do not specifically target unstressed positions can account for blocking of flapping in non-pre-tonic position (e.g. in Senoufo). Similarly, it can account for the variable application of flapping in non-pre-tonic position, and for blocking in pre-tonic position (e.g. American English; Kahn, 1980). The problematic aspect of flapping arises if indeed the application of the process is specifically enforced in post-tonic position, namely if the data reported by Zue and Laferriere (1979) on the distribution of flapping (V.V vs. V.V) reflects
a difference in the grammatical requirements on the two positions. The grammatical preference for a lenition process in post-tonic position would be enforced while at the same time constraints on durational prominence enforce the durational enhancements of other consonants in the same position (i.e. post-tonic lengthening of consonants other than /t,d,n/).

3.4 Contrast preservation in stressed position

Steriade (1995, 1997) and Beckman (1998) observe that there are several asymmetries exhibited by segments which occur in prosodically strong positions (e.g. stressed syllables and syllable onsets). Featural contrasts which may be neutralized in non prominent positions are often maintained in the vicinity of stress. Although the opposite neutralization pattern is also attested (§3.5), languages with stress-based neutralization typically show this direction of neutralization. The result of this neutralization pattern is that the set of contrasting sounds in a stressed position is greater than the set of contrasts in an unstressed position.

Many cases of contrast preservation in strong positions have been discussed for vowels (e.g. Italian; Flemming, 1993; Miglio, 1997; Crosswhite, 1999 and Catalan; Recasens, 1986, 1991; Hualde, 1992; Prieto, 1992; Beckman, 1998). The blocking of consonant neutralization in these positions has mostly been neglected in previous literature (Beckman, 1998; Smith, 2002). In addition to the well known vowel cases there are however at least three documented cases of consonant contrast preservation in the vicinity of stress (Copala Trique, Italian and Finnish). They are presented here.

As already discussed in the previous chapter, a striking observation can be made about the nature of these processes: contrary to the predictions of previous accounts, Positional Faithfulness to featural content in stressed positions is restricted to a very small set of features. All of these processes share one property which makes them similar to the non-neutralizing alternations restricted to stressed position, §3.2. Phonological processes which are blocked in the vicinity of stress result in the neutralization to the more lenited and shorter consonant, or to the less prominent vowel of the contrast. The blocking of neutralization, I claim, does not arise from the grammatical pressure of positional faithfulness constraints, rather it results from the action of metrical constraints on prominence (\(D_{dur}\geq X\) and \(V_{Energy}\geq X\)) and from their side-effects (Effort C). The effects of these constraints on the phonetic realization of segments in the vicinity of stress block the application of otherwise occurring phonological processes. The formal mechanism which derives the stress-conditioned distribution of contrast neutralization processes from the action of markedness constraints is based on Flemming's (2006, 2008) model of neutralization. The analysis is cast in the Dispersion Theory of Contrast (Flemming 1995, 2004, 2006, 2008); it follows much previous work integrating the constraints on metrical prominence and the constraint regulating the implementation of prominence into phonological theory. The framework was introduced in Chapter 2. The analysis of the neutralizing processes in this section and in §3.5 is developed in the form of case studies in Chapter 6 and Chapter 7.

3.4.1 Blocking of vowel neutralization

Languages which show stress-based neutralization processes typically permit a segmental inventory in unstressed position which is a subset of the full inventory which appears in stressed syllables. Members of the unstressed segment inventory are usually less marked than members of those segments which do not appear in unstressed position. In languages exhibiting a stress-based positional
neutralization of vowels for example, the vowel inventory in unstressed position is limited to a set of peripheral vowels, or a set of schwa-like vowels, or else vowels which are not articulatorily marked (Liljencraft and Lindblom, 1972; Anderson, 1982; Lindblom, 1986; Flemming, 1995; Ni Chiosain and Padgett, 1997 and Beckman, 1998). Stressed syllables permit a much wider range of often more marked segments. This section reviews some of the cases discussed in previous literature, in which a process of vowel neutralization attested in non-prominent positions is blocked from occurring under stress.

Standard Italian shows a pattern of vowel neutralization in unstressed syllables: lax mid vowels are realized as tense in this position. Neutralization is not found in the nuclei of stressed syllables, which, as seen in §3.2.1, are substantially longer than unstressed ones. This process is shown in (31): (a) exhibits [o]/[o] and [e]/[e] contrasts in stressed syllables, (b) shows reduction of [a] to [o] and [ɛ] to [ɛ] in unstressed syllables.

(31) Vowel Neutralization in Standard Italian
   a. Contrast neutralization in unstressed syllables:
      /t'ertamente/ [t'er.ta.'men.te] 'surely'
      /m'dale/ [m.'da.le] 'modal'
   b. Lax/tense vowel contrast in stressed syllables:
      /t'erto/ ['tfr.to] 'sure'
      /pesca/ ['pes.ka] 'fishing'
      /m'do/ ['mo.do] 'manner, chance'
      /n'te/ ['no.te] walnut

A similar pattern is found in regional varieties of Italian as well; an example already encountered in §3.2.1 is the Italian dialect of Mistretta (Sicily; Mazzola, 1976; Flemming, 2004). Vowels in this language are long when stressed, and short when stressless. This language has a regular process of vowel reduction: the five vowel system, /i, e, a, o, u/, reduces to three vowels /i, a, u/ ([i, ɛ, ɔ]), in unstressed syllables. The prosodic contexts in which reduction is blocked coincide with the contexts of phonetic lengthening, i.e. the nucleus of a stressed syllable. The vowel reduction pattern in this language is presented in (32), adapted from (3).

(32) Vowel Neutralization in the Sicilian dialect of Mistretta (Mazzola, 1976: 38-41)
   a. Contrast neutralization in unstressed syllables:
      /morimu/ [mu.'ri:.mu] 'we die'
      /veniti/ [vi.ni:.ti] 'you-Pl. come'
   b. High/mid vowel contrast in stressed syllables:
      /munf'i/ ['mun.ʧi] 'he milks'
      /mori/ ['mo:.ri] 'he dies'
      /veni/ ['ve:.ni] 'you come'
      /rin'i/ ['ri:.ni] 'back'

A more complete list of similar patterns of vowel reduction based on Beckman (1998), Crosswhite (2001, 2004) and Flemming (2004, 2005) is reported in the table in (33).

(33) Stress-conditioned reduction of stressless vowels
The typology of vowel reduction which emerges from these works reveals a generalization about the specific nature of the vowel neutralization processes which are restricted to stressless vowels and blocked in stressed syllables. Vowel height contrasts tend to be neutralized before backness or rounding contrasts (Barnes, 2002; Flemming, 2005). Whereas stressless vowels tend to undergo reduction by a raising process, stressed vowels do not. The tendency for stressed vowels to resist raising is further supported by the existence of cases like Žabiče Slovene, §3.5, in which vowel neutralization is restricted to the stressed position. The neutralization in this position results in the lowering of stressed vowels. Backness and rounding contrasts can also be neutralized in stressless vowels, but generally where all vowel contrasts are neutralized to a single vowel (Flemming, 2005).

The preservation of vocalic contrasts under stress is analyzed in this thesis as arising from the grammatical pressure to maximize the duration and the perceptual energy of vowels in this position. The phonetic realization of stressed vowel which is enforced by metrical requirements yields a very distinct set of vowels in stressed position, therefore blocking the neutralization process.

3.4.2 Blocking of consonant neutralization

This section presents three cases in which the proximity to stress blocks the neutralization of a consonantal contrast. The inventory of contrasting segments in stressed position is larger than in unstressed position. As seen in the previous chapter, these processes have two characteristics which make them problematic for previous analyzes of prosodic conditioning.

First, only a very small set of phonological processes are blocked in this position. Unlike predicted by a Positional Faithfulness account, only a small set of features resists neutralization in the vicinity of stress. The small set of featural contrasts which are preserved in the vicinity of stress is a subset of laryngeal and manner features. Cross-linguistically, neutralizing processes in stressless positions target the features [+voice] (e.g. Copala Trique), [±continuant] (e.g. Copala Trique, Finnish) and [±strident] (e.g. Italian). Obstruents which are not adjacent to a stressed vowel may become fricatives and/or be voiced, these featural contrasts are not neutralized in stressed positions.

Second, the domain within which these neutralization processes are blocked does not correspond to the domain which has previously been considered to be the locus of positional privilege, namely the stressed syllable. These processes are blocked in stress-adjacent consonants, independently of prosodic constituency. We claim that the cross-linguistic distribution and the restricted nature of
these processes provides evidence for the origin of these patterns. The blocking of neutralization in the adjacencies of stress results from the effects of sub-glottal pressure increase on the phonetic realization of stress-adjacent consonants. The specific mechanisms through which the individual processes arise and their phonetic details are illustrated in the following chapters, this section provides a description of the phonological patterns. Chapter 7 provides experimental evidence for the claim that these processes arise as side-effects of prominence enhancement on the stressed vowel. The formal analysis of the three neutralization patterns presented in this section is the subject of three case studies in Chapter 6 and Chapter 7.

3.4.2.1 Lenition in San Juan Copala Trique

The Trique dialect of San Juan Copala is one of the few studied languages in which the neutralization of consonantal contrast is blocked in the vicinity of stress. Gonzalez (2003) classifies it as a stress-conditioned durational difference in her survey. In this language the contrast in stops (/p,t,k,b,d,g/) and fricatives (/s,f,§,z,3,E/) is described as a contrast between fortis and lenis. Fortis consonants are voiceless and lengthened, and fortis stops are unaspirated. Lenis consonants are usually voiced, but in unstressed position they can be either voiced or voiceless. Of the entire consonant inventory, fortis stops, fricatives, affricates and laryngeals are restricted to the stressed syllable (Hollenbach, 1977:36), the other consonants occur both in stressed and in unstressed positions. The contrast between fortis and lenis is thus preserved in pre-tonic position and neutralized elsewhere.

(34) Fortis/lenis contrast in San Juan Copala Trique
(Hollenbach, 1977: 36)

a. Contrast in stressed syllables
   [a.'ga?3] 'metal'
   [da.'ka3] 'crest' (of bird)

b. Neutralization in unstressed syllables
   [go.'pa32] * [ko.'pa] 'goblet'
   [ba.'sya32] * [pa.'sya] 'to take a walk'

Chapter 6 develops the formal analysis of the distribution of the fortis/lenis contrast in Copala Trique. It is argued that fortis consonants are generally dispreferred in the language and thus undergo a lenition process which makes them auditorily very similar to lenis consonants. The contrast between the two consonants is neutralized to a consonant whose auditory properties are close to the ones of a lenis consonant. By contrast, the increase in subglottal pressure preceding the stressed vowel yields a markedly long and tense realization of the fortis consonants in pre-tonic position. In this position, the indirect effects of prominence enhancement on the realization of fortis consonants block the neutralization process, since they yield very distinct phonetic realizations of lenis and fortis consonants.

This neutralization pattern is mentioned in Beckman (1998) as the only case of positional licensing of consonantal features in a prosodically prominent position. In the following paragraphs we present two very similar cases of stress-conditioned blocking of consonant neutralization, which question the assumption that these processes are rare.
3.4.2.2 Italian Palatalization

In contemporary Italian velar stops /k, g/ and palatoalveolar affricates /ʧ, ʤ/ are phonemically distinct. The language also has a process of velar palatalization before front vowels which is active across a morpheme boundary. In the nominal and adjectival inflection palatalization is triggered by the high front vowel /i/. The application context is further restricted, since the masculine morphemes /-i/ does not uniformly trigger palatalization. Aside from the idiosyncratic status of a small minority of words, the application of palatalization is conditioned by the location of main stress (Giavazzi, 2009): palatalization is generally blocked in immediately post-tonic position. It is important to notice here that what matters in the distribution of the process is the vicinity of stress, and not being in the stressed syllables. In all of the relevant cases, the velar stop is in the onset of the post-tonic syllable.

(35) Stress-conditioned palatalization in Italian (Giavazzi, 2010)
   a. Contrast in immediately post-tonic position
      /an.'ti.k-i/ ['an.'ti.ki] 'antique', Masc. Pl.
      /'va.g-i/ ['va.gi] 'vague', Masc. Pl.
   b. Neutralization far from stress
      /fi.'lo.lo.g-i/ [fi. lo.lo.ʧi] 'filologue', Masc. Pl.

Guion (1996) investigated the perceptual roots of velar palatalization. Based on acoustic and perceptual analyses, the author concludes that the change from /ki/ to /ʧi/ occurs because of the auditory similarity between velar stops and palatoalveolar affricates before a palatal vowel. This similarity has been analyzed by Ohala (1994) Guion (1996) as the cause of perceptual reanalysis by the speaker/hearer; similarly, Wilson (2006) has proposed that the speaker/hearer gives up on this weak contrast, neutralizing it. In Chapter 7 we provide experimental evidence for the modulation of the perceptual similarity of the /ki/-/ʧi/ by an adjacent stressed vowel. In post-tonic position, increasing the loudness of the stressed vowel (V_{Energy}≥X) results in a very sharp realization of the stop burst (Effort C), which makes it very different from an affricate. It is claimed that palatalization is always the preferred output across the morpheme boundary in nominal and adjectival inflection. It is only blocked by the strong auditory dissimilarity between velar stops and affricate in pre-tonic position.

Italian constitutes the second example of a consonant contrast neutralizing process which applies in non-prominent positions, but is blocked in the vicinity of stress.

3.4.2.3 Finnish assibilation

A third example of consonantal contrast neutralization blocked in a stressed position is assibilation in Standard Finnish verbs, Anttila (2003, 2006). Assibilation fricativizes a short nongeminate /t/ before /i/, thereby neutralizing the /si/-/ti/ contrast. Whereas assibilation in plural nominals is fully predictable based on the stem-final vowel (assibilation always applies in /e/-final nominals after /e/ raising, and is always blocked in /i/-final nominals), its application in the verbal domain is conditioned by the position of stress. The first generalization about assibilation in verbs (Laalo, 1988:10-11) is that the process is sensitive to the length of the stem. The descriptive generalization,
from Anttila (2006:9), is stated in (36):

(36) In Standard Finnish verbs, assibilation is
   a. blocked after a monomoraic first syllable (\(\mu\.ti\))
   b. variable and/or lexically conditioned after a bimoraic first syllable (\(\mu\mu\.ti\))
   c. obligatory after a trimoraic first syllable (\(\mu\mu\mu\.ti\))
   d. obligatory after two or more syllables (\(\sigma\sigma\.ti\))

The stress-conditioning is captured in Anttila's analysis, by appealing to the location of the /ti/ sequence with respect to the stressed foot. In his account, extra-metrical /ti/ sequences always undergo assibilation, and the process is always blocked within the main stressed foot. In the following examples I thus include the assumed underlying foot structure; where assibilation is variable, Anttila assumes variable foot structure. Both possibilities are given in these cases.

   a. /ti/-/si/ contrast after a monomoraic first syllable
      /vetä i/ ('ve.ti) ['ve.ti] 'pull-PAST'
      /.../
   b. Variable neutralization after a bimoraic first syllable
      /murta-i/ ('mur.ti) ['mur.ti] 'break-PAST'
      ('mur).ti ['mur.si]
   c. Contrast neutralization after a trimoraic first syllable
      /kaarta-i/ (kaar).si [kaar.si] 'veer-PAST'
   d. Invariant assibilation after two syllables
      /paranta-i/ ('pa.ran).ti ['pa.ran.si] 'improve-PAST'

In order to account for this pattern, Anttila extends the set of prominent positions (Beckman, 1998) to include the main stressed foot. The author analyzes this pattern as arising from the privileged status of strong positions which allows them to resist otherwise occurring phonological processes. The complications of this analysis were discussed in the previous chapter.

The analysis of Finnish assibilation developed in Chapter 7 is parallel to the analysis of Italian. We provide experimental evidence for the effects of stress on the realization of /-ti-/ sequences in assibilating and non-assibilating contexts. It is shown that assibilation is blocked in those post-tonic segments in which metrical requirements on the duration of the stressed domain (\(D_{dur} \geq X\)) affect the phonetic realization of the coronal stop. Within this region /-ti/ and /-si/ sequences are auditorily very dissimilar, and this not prone to the neutralizing assibilation process. The contrast is neutralized elsewhere.

3.4.3 Summary

The distribution of segmental contrasts can be conditioned by the position of stress. In this section we have reviewed the most frequent stress-conditioned neutralization pattern, namely one which yields a greater set of contrasting sounds in stressed position, and a smaller set of contrasts in unstressed position, (38).

(38) \(\#\text{contrasts}_{\text{stressed}} > \#\text{contrasts}_{\text{unstressed}}\)
The reduction of stressless vowels is generally a raising process which results in the neutralization of contrasts in the absence of stress. The neutralization of consonantal contrast in stressless position results in lenition and fricativization processes. These processes are blocked under stress, or in the vicinity of stress, because in these positions high ranked metrical prominence constraints ($D_{dur} \geq X$ and $V_{Energy} \geq X$) and high ranked effort constraints regulating the implementation of vowel prominence (Effort $C$), trigger the processes described in §3.2.

The account of contrast preservation in stressed positions presented here crucially does not rely on the action of Positional Faithfulness constraints. These processes are simply a special case of the processes illustrated in §3.2: the phonetic realization of segments under stress, or in the vicinity of stress result in a very distinct set of contrasts which are not prone to neutralization. Similarly, in the absence of stress, neutralization is not triggered by the inapplicability of Positional Faithfulness constraints, rather it results from generalized lenition and reduction processes like the one illustrated in §3.3. The outcome of these processes is a set of sounds which are auditorily very similar, and thus prone to neutralization. The domains within which these processes are found are therefore the domains within which non-neutralizing processes are found. These are the stressed domain, which is targeted by constraints on durational prominence, $D_{dur} \geq X$, and contains the stressed vowel ($V_{Energy} \geq X$), and the domain within which subglottal pressure is increased, targeted by effort constraints on changes in subglottal pressure (Effort $C$).

The formal mechanism in which the analysis is cast are presented in Chapter 4. These processes are the subject of case studies in Chapter 6 and Chapter 7.

### 3.5 Contrast neutralization in stressed position

Contrast neutralization is also documented in the opposite direction, namely as a neutralization pattern which is restricted to stressed vowels or stress-adjacent consonants. This pattern is less frequently attested than the previous one. We illustrate here one case of vowel neutralization, and one case of consonant neutralization in stressed positions. The analysis of these processes is the mirror image of the analysis of neutralization in stressless position. The phonetic realization enforced by metrical prominence constraints on segments under stress, or in the vicinity of stress, may yield to a set of contrasting sounds which is not distinct enough, and is therefore prone to neutralization. Unlike neutralization in unstressed positions, this pattern results in the neutralization to the most prominent segment.

#### 3.5.1 Vowel lowering in Zabiče Slovene

In the Zabiče dialect of Slovene, vowel qualities that are contrastive in unstressed syllables are neutralized in stressed syllables (Crosswhite, 2001; Smith, 2002). In this dialect etymological short stressed high vowels are realized as mid vowels: $/i/ \rightarrow [\ddot{e}], /\ddot{i}/ \rightarrow [\ddot{a}]$ and $/\ddot{u}/ \rightarrow [\ddot{a}]$. This language also has a two-way length contrast among stressed vowels. This contrast is neutralized in unstressed vowels. Citing Rigler (1963), Crosswhite lists the inventories of vowels in stressed and unstressed syllables in this language, (39). Unlike short vowels, long vowels do not neutralize under stress
(39) Vowels in Zabiče Slovene (adapted from Crosswhite, 1999: 43)

a. Short vowels in unstressed syllables
   - high i i u
   - mid e æ o
   - low a

b. Short vowels in stressed syllables b’. Long vowels in stressed syllables
   - high i: i: u:
   - mid e: æ: o:
   - low a

Unlike the neutralization of stressless vowels (§3.4.1), which results from the raising of stressless vowels, neutralization in Zabiče Slovene results from a process of vowel lowering. This language is the subject of a case study in Chapter 6. It is argued that sonority-sensitive constraints on the prominence of the stressed vowel (\(V_{\text{Energy}} \geq X\)) enforce the lowering of high short vowels under stress. The resulting phonetic realization of stressed high vowels is auditorily too similar to the realization of stressed mid vowels for the contrast to be preserved. Long vowels on the other hand are not lowered, since their length makes them prominent enough to satisfy the relevant \(V_{\text{Energy}} \geq X\) constraints without lowering.

3.5.2 Glottalization of resonants in Stʔátʔímcets

Like other Salish languages, Stʔátʔímcets has a very rich consonant inventory, including the following glottalized consonants: /mʔ, nʔ, lʔ, tʔ, sʔ, yʔʔ/ (Bird and Caldecott, 2004). These consonants pattern together phonologically, and are therefore considered to form the natural class resonants. The production of glottalized resonants is extremely varied. Glottalization is being lost in Stʔátʔímcets: the loss of glottalisation is described as being primarily a function of syllable position, position of stress, and age of speaker. When glottalisation is retained, its phonetic implementation varies considerably in terms of whether it involves creaky voicing or complete glottal closure and the timing of the glottal closing gesture in relation to the oral articulation (pre- vs. post-glottalisation).

In §3.2.2.3 we described the timing of glottalization in pre-tonic position. Glottalized consonants which are not stress-adjacent are realized as post-glottalized (González, 2003). Stʔátʔímcets is one of the few languages in which underlyingly glottalized resonants are realized as pre-glottalized in pre-tonic position (\(R^\}_{\rightarrow ?R/_{\text{ʔ}}}\)). In post-tonic position, glottalization is lost: a glottalized resonant surfaces as glottalized following an unstressed vowel, and plain following a stressed vowel (\(R^\}_{\rightarrow R/V_{\text{ʔ}}}\)), Caldecott (2009:64). The neutralization of the laryngeal contrast in post-tonic position is illustrated in (40).

(40) Laryngeal neutralization in Stʔátʔímcets: the suffix /-minʔ/
   (data from Caldecott, 2009:64, transcribed into IPA)

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2 Bird and Caldecott (2004) note that the place of articulation of /ʔʔ/ and /ʔʔʔ/ is unclear. They list them with the uvulars based on van Eijk (1997), but they may be better characterized as uvulo-pharyngeals or pharyngeals, as in other neighbouring Salish languages (Carlson et al. 2004; Kinkade, 1967).
The two patterns of glottal timing in stress adjacent resonants suggest that this language avoids glottal closing gestures immediately adjacent to stressed vowels. Lyon (2007) shows that glottalization in Stíst'amcets is produced with a very high degree of creakiness. It is known that creaky vowels and vowels adjacent to creaky phonation have a significantly decreased loudness (Gordon and Ladefoged, 2001; Lyon, 2007). We suggest that the distribution of glottalization in Stíst'amcets serves to maximize the prominence of the stressed vowel, and is therefore governed by the action of $V_{Energy} \geq X$ constraints.

3.5.3 Summary

This section has reviewed the second pattern of stress-conditioned contrast neutralization, namely one in which the set of contrasts which are realized in a stressed position is smaller than the set of consonants in a stressless position, (41).

(41) $\# \text{ contrasts}_{\text{stressed}} > \# \text{ contrasts}_{\text{unstressed}}$

We have claimed that these processes are enforced by the action of prominence constraints, namely those markedness constraints which require the prominence of the stressed vowel. Although this pattern yields contrast neutralization under stress, and not in the absence of stress, it can be analyzed in the same way. The effects of prominence requirements and their side-effects on the phonetic realization of segments under stress or in the vicinity of stress, i.e. those illustrated in §3.3, may yield the neutralization of segmental contrast in non-prominent positions, §3.4.2, or in prominent positions, like the processes presented in this section.

3.6 Summary

This chapter presented the typology of phonological processes which can be conditioned by the presence or by the absence of stress, and it provides cross-linguistic evidence to the claim that stress-conditioned processes are of a very restricted nature. Non-neutralizing phonological alternations are presented first; they are of two kinds. The first class of processes is triggered by the grammatical pressure to enhance the perceptual prominence of metrically strong positions through the increase of the length of segments within these positions ($D_{dur} \geq X$), and the increase of the perceptual energy of the stressed vowel ($V_{Energy} \geq X$). The second class of processes arises from the side-effects of implementing the prominence of the stressed vowel: they result from the side-effects of increasing the subglottal pressure level during the articulation of stress-adjacent segments. The formal analysis of these processes is developed in Chapter 5.

The second part of this chapter describes the languages in which the position of stress conditions the distribution of segmental contrasts. These patterns are argued to emerge as the direct consequences of prominence enhancement, or as the indirect consequences of implementing the perceptual prominence on the stressed vowel. The formal analysis of these processes is developed in Chapter 6 and Chapter 7. Chapter 7 provides experimental evidence for the link between the phonetic realization of segments in the vicinity of a stress, and the perceptual distinctiveness of segmental contrasts.
Chapter 4

The elements of the model

4.1 Introduction

The central argument of this dissertation is that there are only three phonological processes which can be conditioned by the presence, or by the absence of stress. The first two sets of processes are triggered by markedness constraints enforcing the prominence of metrically strong positions: the durational prominence of the stressed domain ($\hat{D}_{dur} \geq X$) and the perceptual energy of the stressed vowel ($\hat{V}_{Energy} \geq X$). The third set of processes arises from the restricted acoustic side-effects of increasing the prominence of a stressed vowel: these processes result from the modulations of the subglottal pressure level, and the tensing of the vocal folds which are necessary in order to increase the loudness of the stressed vowel. No other process is predicted to be sensitive to stress. Prosodic-conditioning thus does not arise from the positional privilege of stressed domains, nor from the effect of Positional Faithfulness to stressed positions. The chapter introduces these three grammatical pressures. It defines the two prominence requirements which hold of stressed positions, the grammatical constraints which are projected from these metrical pressures, and the domain within which they operate. It lays out the aerodynamic mechanisms which give rise to the side-effects of stress, the extents of the domain in which they are found, and the grammatical effort constraints which regulate subglottal pressure modulations.

The definition of stress which is crucial to this chapter and to the thesis more generally, is that stress is the linguistic manifestation of rhythmic structure (Liberman; 1975; Liberman and Prince, 1977; Hayes, 1995). Stress is the structural property of a word in a “stress-accent” language (Beckman, 1986) where one syllable in the word is more prominent than its neighbors. The characterization of the phonetic correlates of stress refers to those properties which distinguish the stressed realization of a syllable from its unstressed counterpart, and those properties which distinguish the stressed syllable from the unstressed syllables surrounding it. Those properties which are characteristic of stressed vowels which are also pitch accented prosodic heads are treated as correlates of accent and not of lexical stress, so we will treat them as distinct.

The study of the phonetic underpinnings of stress-conditioning starts from the analysis of the different strategies languages use to mark the rhythmic prominence of a metrically strong position. Hayes (1995) draws a distinction between two requirements which hold of the head of a prosodic word, which he identifies as the stressed syllable: syllable weight, and syllable prominence. Hayes notes that there is no single acoustic correlate of stress, since the linguistic manifestation of rhythm
is not tied to any particular physical realization; similarly, the detection of rhythm, be it in music or in language, is independent from the way it is realized (Hayes, 1995). Nevertheless, some phonetic phenomena more easily manifest rhythm in speech; these phonetic correlates are thus more readily used as cues for stress than others. In fact, the impression of rhythmic prominence can be achieved in only two ways.

Effective signals of rhythm in speech are alternating sequences of long and short domains, and the modulations of loudness which results from the modulation of airflow. A syllable is more prominent if it is longer; in Hayes' system, the durational weight of a stressed syllable is enforced by a grammatical mechanism requiring the main stressed syllable of a prosodic word to be bimoraic (i.e. either contain a long vowel, or a coda consonant). The second kind of prominence cannot be captured under moraic theory: it is the requirement that a stressed vowel be perceptually prominent along a dimension other than duration. Perceptual prominence is characteristic of syllables with low vowels, high tones, or higher intensity, since these will be perceived as louder and thus as heavier. In Hayes' system, stress rules are therefore of two kinds: either they refer to syllable weight as quantity, in a moraic theory, or they refer to a “less constrained criterion” (Hayes, 1995: 272-3) of syllable weight, namely vowel prominence, (1).

(1) Quantity and Prominence
   a. Duration of the stressed syllable (Quantity)
   b. Prominence of the stressed vowel

This chapter builds on these requirements, (1), and develops an account of stress-conditioning which results solely from their effect on the realization of segments in the stressed domain or in the proximity of stress.

The second section of the chapter describes durational prominence, §4.2. It sets the extent of the domain within which the durational prominence is enforced, §4.2.1, and defines the constraints which are projected from the prominence requirement, §4.2.2.

The third section describes the second metrical requirement, namely the need for the perceptual prominence of the stressed vowel, §4.3. It presents a detailed discussion of the acoustic properties of stressed vowels, §4.3.1, and of the aerodynamic mechanisms through which they are realized, §4.3.2. The acoustic side-effects of increasing the prominence of the stressed vowel are described as the phonetic trigger behind a subset of stress-sensitive phonological processes, §4.3.3. The metrical constraint enforcing the loudness of the stressed vowel (\(V_{\text{Energy}} \geq X\)), and the effort constraint regulating the modulations of subglottal pressure are defined in §4.3.4. Section 4.3.5 presents the outline of an account of pre-tonic lengthening as the enhancement of the perceptual energy of the stressed vowel.

# 4.2 Durational prominence

A metrically strong position may be signaled by its duration. Stress-conditioned durational enhancement is extremely frequent across the world’s languages, either as the sole correlate of stress (e.g. Finnish; Suomi and Ylitalo, 2004), or coupled with differences in the loudness of the stressed vowel (e.g. Dutch; Sluiter and van Heuven, 1996). Chapter 3 (§3.2.1) has illustrated many languages in which stress-conditioned differences in segmental duration are observed. A well studied case of phonetic lengthening of stressed vowels is found in Italian, Marotta (1985) and D’Imperio
and Rosenthall (1999). Both in Standard Italian and in regional dialects vowel duration is not contrastive. It is however the case that stressed vowels are longer than unstressed vowels. Phonetic lengthening is also found in languages that have contrastive vowel length. An example of such a language is Chickasaw (Muskogean, Oklahoma; Gordon, 2004). Stress in Chickasaw falls on a CVV syllable if there is one in the word, otherwise primary stress falls on the final syllable, even if the final syllable is CV and there is a non-final CVC. The author reports results from an acoustic analysis, showing that stressed short vowels are significantly longer than unstressed vowels; the categorical length contrast is not neutralized, since long vowels are always longer.

Consonants have also been frequently reported to lengthen or to geminate in the vicinity of stress. Chapter 3 presented a variety of durational alternations in pre-tonic and post-tonic position. As anticipated in the previous chapters, the analysis of consonantal lengthening calls for a definition of the stress domain within which durational prominence is enforced.

4.2.1 The stressed domain

We have been referring to the metrically strong position targeted by durational prominence constraints as the stressed domain in a pre-theoretical sense. The debate on which unit is the stress bearing domain has been ongoing for a long time. Following Williams' (1976) and Goldsmith's (1976) autosegmental theory of tonal tiers, Halle and Vergnaud (1987:46) argue that although not every phoneme in a word is capable of bearing stress, the placement of stress, and the extent of the stress bearing unit are not concerned with the phonological or phonetic substance of these elements. Depending on the language under analysis, this unit may consist of the stressed vowel only, the phonemes in the rhyme, or lexically specified segments. Hayes (1995) argues instead for a more constrained theory of the stress bearing unit, and defines it as the syllable. This proposal gets rid of the language-specific specification of the stressed unit and assumes the syllable as the universal domain which can be targeted by stress. Most research on stress-related phonological processes has followed Hayes and adopted the syllable as the stressed domain (among others, Beckman, 1998; Smith, 2002; Bye and deLacy, 2008). A further phonological domain which has been proposed as the stress bearing unit is the main stressed foot. For instance Anttila (2006) appeals to this unit his analysis of the stress-conditioning of assimilation in Finnish verbs. Finally, Fant and Kruckenberg (1994), McCrary (2004), Steriade (2010) suggest that the unit which is targeted by requirements of durational prominence is neither the syllable nor the foot. Instead, they claim that it is the interval which occurs between the onset of the stressed vowel, and the onset of the post-tonic vowel.

The following sections present evidence for a syllable-based approach, §4.2.1.1, and for an interval-based analysis, §4.2.1.2. The processes analyzed in this dissertation do not allow us to take a clear stand on which one of these two units constitutes the smallest rhythmical unit. It is nonetheless suggested, based on literature on rhythm perception (Mehler et al., 1996; Ramus et al., 1999) and consonantal lengthening (Farnetani and Kori, 1986; Fant and Kruckenberg, 1994; McCrary, 2004), that the interval is likely to be a better candidate than the syllable.

4.2.1.1 The stressed syllable

The view that in stress languages the syllable is the stress bearing unit goes back to Jakobson (1931), and it has been widely adopted in the literature on stress. By adopting it as the domain

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1Evidence in favor of the interval as the smallest rhythmic unit also comes from the study of formal metrical systems, as shown by Steriade (2010) for a wide variety of metrical traditions.
to which grammatical requirements on stress refer to, the stress phenomenon can be related to the well studied theory of syllable structure and moraic theories of syllable weight (Hayes, 1995). Bye and deLacy (2008) follow this line of research in their study on the interaction between metrical structure and fortition processes. They note that there are two durational enhancement processes which are found in stressed syllables, which are distinct. Both can be analyzed as being triggered by constraints on syllable weight. In iambic languages, lengthening invariably only affects the vowel in the stressed syllable (see also Hayes, 1995); the constraint driving iambic lengthening is a requirement on syllable nuclei. The other prototypical process of metrically conditioned durational enhancement on the contrary may be realized as consonant gemination, lengthening of the vowel and/or epenthesis. These processes are driven by a requirement on syllable rhymes. Although they argue against a unique metrical motivation behind stress-driven durational enhancement, all of these processes are triggered by constraints which refer to sub-components of the syllable as the stress bearing unit in the word. Implicit in this discussion of weight is the notion that the syllable constitutes a real phonological constituent. In order to appreciate the problems which this approach encounters, let us briefly review the relation between segment duration and syllable weight.

A fundamental distinction can be drawn between heavy and light syllables: it is the membership of a syllable in one of two classes that determines the behavior of that syllable with respect to word stress. Heavy syllables attract stress in many languages (e.g. Latin), in other languages, light syllables are turned into heavy syllables if they bear stress. Syllable weight can therefore broadly be defined as the property which differentiates syllables with respect to their prosodic behavior (Gordon, 2006). Syllable weight is represented in different ways, depending on the formal theory of weight. The two most widely accepted classes of theories are the skeletal slot models (McCarthy, 1979a,b; Steriade, 1982; Clements and Keyser, 1983) and the moraic models (Hyman, 1985; Hayes, 1989, 1995). In both models units of weight, either skeletal slots or morae are assigned to segments. Syllables with a greater number of segments receive thus a larger number of weight units, and length contrasts are associated with the units of weight within the syllable. A crucial assumption made by both models, is the division of the syllable between an onset and a rhyme and the weightless nature of the onset. Onsets are not contributing to the weight of syllable.

Cases of vowel lengthening in stressed syllables have been analyzed as weight enhancing processes which are triggered by a grammatical requirement on the weight of metrically strong positions. Similarly, most consonant lengthening processes in post-tonic position have been analyzed as cases of post-tonic gemination. They can therefore be analyzed very elegantly by syllable-based approaches. By contrast, lengthening in pre-tonic position (e.g. in Tukang Besi, (2), and Urubu-Kaapor) are problematic for a syllabic theory of stressed domains. If the segmental content of the onset does not contribute to syllable weight, and if the stressed domain is indeed the stressed syllable, the trigger of these processes is not immediately evident. Bye and deLacy (2008) acknowledge that pre-stress gemination, albeit rare, is problematic in that it does not add to the rhythmical prominence of the stressed syllable, and nevertheless is metrically conditioned.

(2) Pre-tonic lengthening in Tukang Besi (Bye and deLacy, 2008:10)
/to-paŋa/ [topːaŋa] ‘cut-branch’
/məlai/ [məlːai] ‘far’

This lengthening process is not triggered by a metrical requirement on the weight of the stress domain, since creating a long onset does not increase the weight of the syllable. Bye and deLacy propose to solve the problem by assuming that the Onset of the stressed syllable becomes moraic,
and therefore the lengthening is metrically motivated, (3).

(3) Moraic onsets in Tukang Besi (Bye and deLacy, 2008: 11)
/to-paña/ → [to.p̂aɲa] 'cut-branch'

This analysis is clearly problematic: the formal appeal of resorting to the theory of syllable weight to account for segmental lengthening within the stressed syllable is to incorporate rhythmically conditioned durational enhancements within a both empirically and theoretically supported framework. In spite of the fact that moraic onsets have been proposed in a variety of languages (e.g. Pattani Malay, Davis, 1999; Hajek and Goedemans, 2003; Topintzi, 2006), introducing the onset within the set of weight bearing components of the syllable undermines the empirical evidence collected in a vast literature against moraic onsets. It also has possible repercussions on stress-assignment rules in weight sensitive stress languages. A crucial assumption in moraic theories of syllable weight (Hyman, 1985; Hayes, 1989, 1995) is that whereas languages differ as to the weight distinctions which they encode, both the syllable as a phonological unit and the the rhyme as the weight bearing domain of the syllable, are universal properties of language. Bye and deLacy's proposal thus states as part of language-particular grammars what arguably should be part of universal grammar.

The definition of the interval as the alternative rhythmical unit does not present a solution to the problem of pre-tonic lengthening. It is therefore not presented for its advantages in this respect, rather it is proposed as a valuable alternative which emerges from experimental literature on the perception of linguistic rhythm.

4.2.1.2 The interval

Although syllable based accounts have been predominant in the literature on stress, an alternative proposal has been made in the literature, namely that the smallest rhythmical unit is independent from syllabic constituency. It is the domain which extends from the left edge of the nucleus to the left edge of the next nucleus, which we will refer to as the *interval* (Steriade, 2010). Farnetani and Kori (1986:11) named it the “rhythmical syllable”.

Two very different lines of evidence support the intuition that the units of rhythm do not align with syllable boundaries.

First, evidence for the existence of the interval is also found in experimental studies on durational cues to stress. Farnetani and Kori (1986) show that invariant aspects of duration emerge from the analysis of units corresponding to the interval, rather than the syllable (also, Fant and Kruckenber, 1994). In a careful study of the correlates of stress in Swedish, Fant and Kruckenber (1994) show that duration is the most consistent physical correlate of stress. The alternation between stressed and unstressed syllables produces quasi-rhythmical patterns that are language specific. A stressed syllable is about 100 ms longer than an unstressed syllable of the same number of phonemes and the duration increases with the number of phonemes. Importantly, the systematic covariation of vowel and consonant durations within a syllable makes it possible to base durational studies on VC units as an alternative to complete syllables (p.19). In a study on segmental duration in spoken Italian, Farnetani and Kori (1986) show that in Italian, like in Swedish, there is a tendency towards isochrony at a level which seems to be independent from syllable structure. For instance, significant changes in stressed vowel durations in closed syllables occurred as a function of the following voice/voiceless onset of the following syllable. Similarly, stressed vowels were shortened in open syllables, as the duration of the following syllable onset increased. The authors propose
that these facts can be accounted for by recognizing the rhythmic unit in the language to be the “rhythmical syllable”, i.e. the temporal interval extending from the left edge of a vowel to the onset of the following vowel. McCrary (2004) conducts a similar but larger acoustic analysis of segment duration in Italian and confirms the phonological reality of the interval. Her results show that the duration of the stressed vowel decreases significantly as the duration of the entire following consonantal interlude increases, regardless of the location of syllable boundaries, Figure 4-1. These results converge in showing that across languages there are trading relations between the duration of the stressed vowel and the duration of the following consonants up to the onset of the post-tonic vowel. The existence of such relations is only explained if these segments are contained within the same duration sensitive domain, independently of the syllabic constituency of the consonants.

Second, Steriade (2010) shows that an interval-based account is needed for an adequate analysis of rhyming domains in different metrical traditions.

In the rest of this dissertation, we will adopt the interval as the smallest rhythmic unit, and the stressed interval as the domain of stress, (4).

(4) The stressed domain:
The domain of stress is the stressed interval, $\hat{I}$, which extends from the onset of the stressed vowel to the onset of the post-tonic vowel.

Grammatical requirements enforcing the durational prominence of the stressed domain ($\hat{D}_{dur\geq X}$) therefore target the stressed interval, (5).

(5) Metrically enforced durational enhancements:
Grammatical constraints on the durational prominence of metrically strong positions target the stress interval ($\hat{I}_{dur\geq X}$)

The processes of durational enhancement illustrated in Chapter 3, which target the stressed vowel (e.g. Italian, Kashaya, Central Alaskan Yupic, Guelavia Zapotec), and post-tonic consonants (e.g. Gualavia Zapotec, Kuuku-Ya?u, South Greenlandic Inuktitut), are triggered by the grammatical pressure to increase the duration of the stressed interval, enforced by the markedness constraint $\hat{I}_{dur\geq X}$. The formal analysis of stress-conditioned durational enhancement is developed in Chapter 5 through the case studies of Gualavia Zapotec and Kuuku-Ya?u. The constraint family which
derives these analyses is projected from the metrical requirement presented above; it is defined in §4.2.2.

Like the syllable-based account, onset lengthening eludes an interval based explanation: pre-tonic consonants are never contained in the stressed interval, and thus never targeted by the metrical constraint. Section 4.3.5, presents a very different account of pre-tonic lengthening, which does not presuppose the inclusion of pre-tonic consonants in the same domain which is targeted by durational enhancement. It is shown that the durational enhancement in pre-tonic position is not triggered by constraints on durational prominence, rather, it is triggered by the constraints enforcing the prominence of the stressed vowel.

4.2.2 Constraints

The analysis of durational enhancement is based on markedness constraints which penalize the occurrence of short stressed intervals. The metrical requirement that the duration of a stressed interval should be maximized can be decomposed into a set of constraints requiring a specified minimal length of a stressed interval. The total length of a stressed interval is defined as the sum of the lengths of the segments which compose it. The hierarchy of durational prominence from which durational prominence constraints are projected is given schematically in (6).

\[
\hat{I}_{dur}=n > \hat{I}_{dur}=n-1 > \hat{I}_{dur}=n-2 > \hat{I}_{dur}=n-3 > \ldots > \hat{I}_{dur}=n-m
\]

The required length is indicated in the format \( Stressed \ interval \geq X \), where \( X \) is the minimal required duration of the interval. The constraint is defined in (7).

\[
Durational \ Prominence \ constraint (\hat{I}_{dur} \geq X)
\]

The total duration of a stressed interval, \( \hat{I}_{dur} \), should not be smaller than \( X \).

For instance, \( \hat{I}_{dur} \geq 3 \) is satisfied by a stressed interval whose total duration be at least 3. The choice of the units of duration is essentially arbitrary. It is sufficient for present purposes to refer to duration units and energy units (see also Flemming, 2004; Gordon, 2006). The evaluation of this specific \( \hat{I}_{dur} \geq X \) constraint is shown in (8)b with a sample of interval durations measured from the sum of the individual segment durations specified in the toy Inventory in (8)a.

\[
\begin{align*}
\text{a. Inventory:} & & \text{Segment} & \text{Duration} \\
& V & 1 \\
& V: & 2 \\
& C & 1 \\
& C: & 2 \\
\text{b. Stressed interval} & \text{Duration} & \hat{I}_{dur} \geq 3 \\
& VC & 2 & \checkmark \\
& VCC & 3 & \checkmark \\
& V:C & 3 & \checkmark \\
& VC: & 3 & \checkmark 
\end{align*}
\]
This constraint interacts with standard IDENT[$F$] constraints penalizing the unfaithful mapping between segmental duration in the Inventory and segmental duration in the output of the Realization, (18). This constraint can be evaluated differently for consonants and vowels, yielding two distinct constraints, IDENTC [dur] and IDENTV [dur].

(9) Durational faithfulness (IDENT[dur])
    Corresponding input and output segments have the same value for [dur].

The language-specific balance between metrical constraints in (7) and faithfulness constraints is modeled by specifying the language-specific ranking of the faithfulness constraints and the $\hat{l}_{dur} \geq X$ constraints. The first faithfulness constraint to outrank a $\hat{l}_{dur} \geq X$ constraint sets the threshold duration of a stressed interval. The optimal interval is the one which has the maximal total duration without violating any high ranked faithfulness constraint. The conflict between the metrical constraints as faithfulness constraints is illustrated in the tableau in (10). The basic consequence of these durational prominence constraints is to trigger the durational enhancements of stressed intervals which do not reach the required duration threshold.

(10)

<table>
<thead>
<tr>
<th>/pákata/</th>
<th>$\hat{l}_{dur} \geq 3$</th>
<th>IDENT V[dur]</th>
<th>$\hat{l}_{dur} \geq 4$</th>
<th>IDENT C[dur]</th>
<th>$\hat{l}_{dur} \geq 5$</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>*!</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>b.</td>
<td>*!</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c.</td>
<td>p-á:k- at-a</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d.</td>
<td>*!</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The analysis of stress-conditioned durational enhancement developed in Chapter 5 arises from the interaction of these two sets of constraints. Like the other set of prominence constraints ($\hat{V}_{Energy} \geq X$) introduced in the following section, durational prominence constraints are active in the Realization component of the grammar, in which stress assignment and metrical requirements are enforced.

4.3 Prominence of the stressed vowel

This section is about the second property of metrically strong positions, namely the auditory prominence of stressed vowels. The acoustic properties of stressed vowels are described, as well as the aerodynamic mechanisms which are used in order to implement the metrical requirements enforced on stressed vowels ($\hat{V}_{Energy} \geq X$). The importance of these mechanisms within the context of this dissertation is that they are the underlying trigger of those consonantal alternations which have been argued to be only indirectly triggered by metrical requirements. The analysis of how vocal intensity is modulated is necessary to understand the side-effects of prominence enhancement on stress-adjacent consonants. The consonantal alternations resulting from these side-effects are strictly determined by how the modulation of loudness on the stressed vowel indirectly affects the acoustic properties of stress-adjacent consonants.

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4.3.1 Acoustic prominence

Stressed vowels are characterized by longer duration, higher intensity and more extreme vowel formant values than their stressless counterparts. Increased vowel duration is a correlate of stress in many languages, it has been controversial on the other hand, whether an overall increase of intensity on stressed vowels is actually a property of word stress, or whether it is only an acoustic property of stress if the target syllable is pronounced with a pitch-movement characteristic of accent.

Sluijter and van Heuven (1996) show that although stress is associated with loudness, it is not overall intensity which is reliably correlated with stress. Stressed and stressless full vowels can be differentiated based on the relative level of energy at high frequencies, i.e. they can be distinguished by the degree of spectral tilt: stressed vowels have more energy in the high frequency range. Intensity differences are mostly concentrated in the three highest filter bands above 500Hz. The authors conducted a production study on Dutch, a language in which stressed syllables have been reported to be both longer and louder than unstressed syllables (Nooteboom, 1972; Eefting, 1991; Sluijter and van Heuven, 1995), as in English. The recording material consisted of disyllabic lexical items which formed minimal pairs stressed either on the first, or on the second syllable (e.g. /ˈka:nən/ “cannon”–/kaˈnən/ “canon”); the target words were either focused [+F] or non-focused [-F]. Figure 4-2 shows the effect of stress on spectral levels for syllables containing the vowel /æ/. The negative spectral tilt is steeper in unstressed vowels than stressed vowels. In stressed vowels the higher frequency bands (B2-B4, 500-4000Hz) intensity was increased by 5-10 dB, whereas in the lowest band (B1, 0-500Hz) it was hardly affected. Although most differences in spectral level are due to the presence of pitch movements (they are mostly found in the focused condition [+F]), left), there are significant effects of stress on spectral tilt even in the [-F] condition.

Okobi (2006) conducted a similar study, aimed at determining the acoustic parameters that consistently distinguish the primary stressed vowels from stressless full vowels in different pitch accented conditions, in American English. The results from this study show differences in duration, spectral tilt, and noise at high frequencies. Stressed vowels are longer, they have a reduced spectral tilt and lower noise than the stressless vowels. Okobi shows however that the simple measure of spectral tilt used by Sluijter and van Heuven (H1-A3*, the amplitude of the first harmonic, H1, relative to that of the third formant, A3, corrected for vocal tract shape, A*3) is not the most accurate description of the spectral differences between stressed and stressless vowels. In stressed position, the increase in spectral tilt is due to lowering of the amplitude of A3*, not an increase in H1. In stressed position on the other hand, A3* is raised, leading to a flatter harmonic spectrum.

Okobi relates these changes in spectral properties solely to changes in glottal configurations. In unstressed position, the lowering of A3* results from changes in the glottal region of the larynx. The presence of a posterior glottal chink (Hanson, 1995; Stevens, 1998) causes a less abrupt closing of the vocal folds, which leads to a less abrupt discontinuity in the waveform at the closure. The amplitude of the harmonics at high frequencies is therefore decreased, and the presence of noise at high frequencies increased. In stressed position on the other hand the vocal folds are more tense and the glottal source signal has a more pulse like shape. This glottal configuration significantly

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2 In stress-accent languages, pitch accents on prosodic heads mark the information structure of an utterance. Given that word’s prosodic head alway coincides with the main stress syllable, prominence lending pitch movements have been proposed as the most important phonetic correlates of stress. Both theoretical and empirical work has shown that this is not a correct analysis of the phenomenon, since pitch movement is an acoustic correlate of accent and not of word stress (among others Pierrehumbert, 1980; Beckman and Edwards, 1994; Sluijter and van Heuven, 1996).
increases the speed of the glottal closure and raises A3*. Figure 4-3 illustrates the origin of spectral tilt differences of full vowels in the two prosodic positions. Like Sluijter and van Heuven, Okobi's results show no consistent differences in H1 for unaccented stressed and stressless vowels. Okobi observes that the inaccurate predictions of previous spectral tilt measurements emerge from the comparison between stress and pitch accent. The first harmonic is increased on pitch accented vowels, resulting in an increase of the negative spectral tilt. A steep spectral slope appears therefore to be contradictorily the correlate of both unstressed vowels and pitch accented vowels, if the measure of the harmonic spectrum is calculated simply as the difference between H1 and A3*.

The mechanisms of vocal fold tensing in stressed position are not fully clarified by Sluijter and van Heuven, nor by Okobi. Whereas Okobi remains agnostic with respect to the source of the glottal configuration, Sluijter and van Heuven claim that vocal fold tensing is due to increased effort, without defining it further.

From the beginnings of the studies of word stress, effort was suggested as a physiological correlate of linguistic stress (Sweet, 1906: 47-9; Bloomeld, 1933:110-1), and it has been shown that the perceived loudness of a speech sound depends on the amount of effort that a speaker spends in producing it (Brandt et al., 1969; Glave and Rietveld, 1975). Ladefoged (1967, 1971) has claimed that stress is produced by expending more effort in the production of a syllable, whether at the pulmonic, glottal, or articulatory stage. The glottal configurations during the production of stressed and stressless syllables have been studied by Glave and Rietveld (1975) and Gauffin and Sundberg (1989), who have shown the effect of an increased vocal effort generates differential effects on the intensity over the full spectrum. The results are comparable to the ones of the later experiments: increased effort creates an asymmetrical glottal pulse whose closing phase is shortened. The shape of the glottal source affects the intensity, it does however so in a way that generates higher intensities in the higher harmonics, and barely affects low frequency components. Intensity below 500 Hz was not affected by effort: all increases in intensity were located in the frequency region between 500 and 4000 Hz. This result is also in line with the more recent studies reviewed above.
In summary, extended work on the acoustic properties of stressed vowel has shown that they are more prominent than stressless vowels since they are longer, louder, and have more extreme formant values, (11). Spectral balance has been found to be an acoustic correlate of word stress, which can quite reliably differentiate stressed from unstressed vowels, independently of pitch accent, although the most important correlate is the intensity of the second harmonic. Stress in languages like English and Dutch has thus been correctly referred to as dynamic (Sweet, 1906; Bloomeld, 1993), but the loudness percept does not arise from an overall intensity increase, it is circumscribed to those frequency bands which actually contribute to the percept.

(11) Manifestations of prominence on the stressed vowel:
   a. Increased duration;
   b. Extreme vowel formant values;
   c. Decrease of negative spectral tilt (higher A3);

The overall auditory prominence of the stressed vowel arises from the auditory properties in (11). In this dissertation we will refer to a measure of vowel prominence which has been proposed by Gordon (2006), the total perceptual energy (henceforth $V_{Energy}$). The “total perceptual energy” (Gordon, 2006:147) of a vowel is a measure which depends on its perceived loudness and its duration. The perceived loudness of the vowel is calculated approximately from the average intensity of the vowel (Warren, 1970), and it is then multiplied by the duration of the vowel to yield the total energy of the vowel. Section 4.3.4 defines the family of constraints, $V_{Energy} \geq X$, which is projected from the metrical requirement that metrically prominent positions have a high level of perceptual energy. It is shown that languages might vary on the degree of prominence differences which they encode. Whereas in some languages $V_{Energy} \geq X$ constraints are sensitive to the small differences in $V_{Energy}$ arising from different sonority levels (e.g. Javanese and Zabiče Slovene), in other languages $V_{Energy} \geq X$ constraints enforce greater enhancement of $V_{Energy}$ under stress (e.g. Maori)
4.3.2 Implementation of acoustic prominence

This section presents the aerodynamic mechanism through which the requirements on the rhythmic prominence of the stressed position are implemented. It lays out the ground for the discussion of how this implementation indirectly affects the acoustic realization of neighboring segments, in §4.3.3. A comprehensive model of the aerodynamic mechanisms behind the production of stress is beyond the scope of this section; its smaller aim is to show that an account of prosodic conditioning cannot abstract away from the physical realization of stress. The side-effects of loudness enhancement on the stressed vowel give rise to a subset of the stress-conditioned segmental alternations introduced in Chapter 3. The restricted nature of these processes is strictly determined by the very few effects that arise from the modulation of subglottal pressure under stress, and from the tensing of the vocal folds.

The presentation of these mechanisms is given in two steps. The aerodynamic mechanisms behind increasing the loudness of the stressed vowel are presented in §4.3.2.1; the time which is required for these mechanisms to take place is described in §4.3.2.2.

4.3.2.1 Increasing $\Dot{V}_{\text{Energy}}$

There are two primary physiological mechanisms underlying the production of stressed vowels. First, the increased loudness of stressed vowels has been claimed to reflect increased physical effort. Effort was suggested as a physiological correlate of linguistic stress a hundred years ago by Sweet (1906:47-49); the same view was expressed later by Bloomfield (1933:110-11). More recently, grounding studies on the aerodynamics of stress (Ladefoged and McKinney, 1963; Ladefoged 1967, 2005; Ladefoged and Loeb 2002; Lehiste, 1970; Allen, 1971) converge on the claim that stressed positions are characterized by the presence of greater respiratory effort than stressless positions. This effort leads to an increase in subglottal pressure, which in turns makes it possible to achieve the greater loudness of the stressed vowel. Early experimental results from electromyographic recordings relate peaks in subglottal pressure in stressed syllables to bursts of muscle activity of the internal and external intercostal muscles, which reduces the lung volume increasing the pressure below the vocal folds. Titze and Sundberg (1992) conduct a study which looks at the relation between respiratory effort and intensity during singing. They investigate the relation between modulations of vocal intensity and modulations of subglottal pressure. They show that increased respiratory effort and increased subglottal pressure cause a systematic increase of both intensity and $f_0$. Professional singers use fine-grained modulations of subglottal pressure as a control mechanism for vocal intensity and $f_0$.

Second, as reviewed in §4.3.1, the result of increased subglottal pressure is not just greater overall amplitude of the glottal waveform: low frequency components are hardly affected, the intensity increase is concentrated in the higher harmonics only, Sluijter and van Heuven (1996), Okobi (2006), (see Figure 4-2 and Figure 4-3).

The observed shift of intensity over the spectrum may result directly from the increased subglottal pressure, as implied by Titze and Sundberg (1992). In this case, the change in glottal configuration (a shorter closing phase and a steep trailing ank of the glottal pulse) could occur in order to enhance the effect of subglottal pressure on perceived loudness. Alternatively, the decreased negative spectral tilt could result from an independent mechanism of vocal fold tensing which which generates a more asymmetrical glottal pulse. In the following presentation, we follow Titze and Sundberg (1992) in assuming that the change in spectral tilt which characterizes stressed
vowels arises from a change in subglottal pressure. The tensing of the vocal folds is treated here as an additional mechanisms of loudness enhancement, possibly indirectly triggered by the greater respiratory effort (Sluijter and van Heuven, 1996), or else triggered independently in order to enhance the loudness increase.

The direct and indirect mechanisms through which vowel intensity is increased under stress are summarized in (12) below.

(12) Loudness enhancing mechanisms targeted at the stressed vowel:

a. Direct mechanism: increased subglottal pressure
   Leads to a greater amplitude of the glottal waveform;
   Leads a decreased negative spectral tilt;

b. Indirect mechanism: tensing of the vocal folds
   Leads to an asymmetrical glottal pulse, and enhances the decrease of the negative spectral tilt;

Subglottal dynamics are therefore the primary mechanism to enhance the prominence of the stressed vowel. Although the timing of subglottal pressure modulations is such as to produce the required acoustic effects on the stressed vowel, the displacement of the pressure level cannot be realized during the transitions into and out of the stressed vowel, it spans over the duration of its adjacent segments. The following section examines the time course of the displacement, and attempts at defining the domain within which effects of subglottal pressure increase are predicted to be found.

4.3.2.2 The domain of subglottal pressure modulation

The impossibility of raising subglottal pressure during the vowel transitions results from the relatively slowness of subglottal pressure adjustments. Since there is to my knowledge no published study on the rate of change of stress-conditioned subglottal pressure modulations, I base this description on Rothenberg (1968) which represents the most detailed description of active mechanisms of subglottal pressure control. The time constant of subglottal pressure modulation is presented first, it is then shown that the mechanisms can be extended to the present purposes.

Rothenberg's study analyses the modulations of subglottal pressure during the production of a voiceless plosive. The advantages of studying of subglottal pressure regulation during the production of a plosive is that if the glottis is open during a period of articulatory and velopharyngeal closure, the pressure in the supraglottal cavity can be considered equal to the subglottal pressure. The subglottal pressure could therefore be measured accurately during most or all of the period of articulatory closure with a pressure transducer coupled to the supraglottal cavity. To estimate of the constraints on the rate of change of subglottal pressure increase, the author measured the raising time during the production of initial voiceless plosives in Hindi and Korean. The increase is described as having a sigmoid shape with a long period during which the increase is near the maximum rate. The time constant is characterized by its maximum rate of increase and by its asymptotic total increase. The constant is reported by measuring the time between 1/10 and 9/10 of the total increase. For most simple subglottal pressure increases this procedure to measure the constant yields a number very close to the one which refers to the total change and the maximum rate. An illustration of the subglottal pressure increase during the closure of a plosive is provided in Figure 4-4. The results show that subglottal pressure variations of about 10cm H2O are produced within about 120ms. The minimum time constant which could be produced for an increase
in subglottal pressure during the closure of a plosive was ca. 100ms, though in normal speech a minimum time constant of 150ms was most common.

Rothenberg suggests that the time constant is independent of the magnitude of the total pressure increase, since the raising times are constant between different degrees of total displacement. The reason of the independence of time constant and total displacement is claimed to arise from the nature of what limit the slow raising times. Only ca. 20ms of the time constant which can physical properties of the respiratory system, namely from the variations in respiratory muscle tension which can be produced by the respiratory muscles. The remaining time is independent from the respiratory system: it depends from dynamic constraints in the central nervous system (Rothenberg, 1968: Section 3.9). It can therefore not be decreased, and it may be not dependent on the net displacement of the pressure level.

If the time constant of subglottal pressure increase measured by Rothenberg also applies to the pressure modulations required to produce the loudness increase on the stressed vowel, the increase can clearly not be contained within the transitions into the stressed vowel. If the domain within which subglottal pressure is increased covers ca. 150ms of the region before the stressed vowel, it is expected to affect the production of pre-tonic segments. There is to my knowledge no experimental study which specifically addresses whether the average loudness increment documented between stressless and stressed would require a displacement in subglottal pressure comparable to what found during the production of a stop closure. It is however possible to derive the extension of Rothenberg’s results to stress-conditioned pressure displacements from related available literature.

The procedure for checking the compatibility of Rothenberg’s with the known results of stress-
conditioned loudness increases was as follows. First, Sluijter and van Heuven’s (1996) measured a spectral differences between unaccented stressed and stressless vowels of about 5-10 dB in the frequency range of 500-4000Hz (see Figure 4-2). The difference in spectral slope in terms of dB/octaves was computed from the graph in Figure 4-2 (Sluijter and van Heuven, 1996:2481). This conversion yielded a difference of 1.6 dB/octave. Second, the subglottal increase required in order to produce a change in spectral slope of 1.6 dB/octave was computed from Titze and Sundberg (1992:2942, Figure 5 and Eq.s (37) and (38)). The measurements were made assuming an increase of 1.6dB/octave from a starting spectral slope of 12 dB/octave. This value that is often mentioned for the harmonic source spectrum of a healthy voice in the modal register (Fant and Lin, 1988; Flanagan, 1957; Hammarberg et al., 1980; Klatt and Klatt, 1990; de Krom, 1995). Finally, subglottal pressure levels given in kPa were converted to cm H2O, the unit used by Rotheberg (1968). Given a spectral slope of 12 dB/octave, a change in spectral slope of 1.6 dB/octave represents the range of subglottal pressure increments in (13). Since the variation of spectral slope as a function of subglottal pressure is dependent on the fundamental frequency, the subglottal pressure increments are given for three f0 ranges (average values from Titze and Sundberg (1992:2942, Figure 5).

(13) Subglottal pressure increment producing a decrease of negative spectral slope of 1.6dB/octave

<table>
<thead>
<tr>
<th>Speaker f0</th>
<th>Δ P_{SG}</th>
</tr>
</thead>
<tbody>
<tr>
<td>383 Hz</td>
<td>4.01 cm H2O</td>
</tr>
<tr>
<td>234 Hz</td>
<td>2.14 cm H2O</td>
</tr>
<tr>
<td>117 Hz</td>
<td>1.5 cm H2O</td>
</tr>
</tbody>
</table>

Titze and Sundberg (1992) estimated subglottal pressure from oral pressure during the closure of a preceding consonant following Rothenberg (1968; 1973) and Smitheran and Hixon (1981). The increases in subglottal pressure required to produce the average loudness increase on a stressed vowel in (13) are therefore comparable to those discussed in Rothenberg (1968).

The estimate of the constraints on the time constant of subglottal pressure increase, reveal that the modulations of the pressure level are significantly slower than the duration of the transition between a pre-tonic segment and the stressed vowel. In order to attain the increase in subglottal pressure needed to produce the required loudness increment during the entire duration of the stressed vowel, raising has to begin ca. 150ms before the stressed vowel, i.e. during the production of the pre-tonic, or pre-pre-tonic segment. Similarly, although the detailed mechanisms are not illustrated by Rothenberg, “the motor command for the decrease [of subglottal pressure, MG] must be initiated considerably before the full increase is attained.” (Rothenberg, 1968: Section 3.7). Immediately post-tonic segments are therefore also produced while the subglottal pressure level is decreasing, but hasn’t reached its baseline.

Figure 4-5 shows a schematized representation of stress-conditioned raising of subglottal pressure from its steady value, targeting the stressed vowel. The region within the square, i.e. the vowel, is the region with the highest pressure increase under stress, since it is the target of the metrical requirement on perceptual prominence. Importantly though, subglottal pressure is overall greater even during the articulation of the surrounding consonants, for the reasons discussed in the previous section. In the absence of precise data on the time constants of subglottal pressure decreases, we assume that rise and fall of the subglottal pressure are symmetrical with respect to the target vowel. This assumption is not supported by direct experimental evidence, it is never-
Figure 4-5: Schematic representation of the raising of subglottal pressure ($P_{SG}$) in a CVC sequence.

theless reasonable as an approximation, since almost the entire time constant associated with the variation of subglottal pressure can be attributed to dynamic constraints inherent to higher control levels such as the mechanism of muscle contraction and dynamic constraints in the central nervous system (Rothenberg, 1968). The same assumption is implicitly made by Stevens (2000):

“[...] Rothenberg concluded that a unidirectional change in subglottal pressure of 5 to 10 cm $H_2O$ (with an occluded vocal tract, i.e., with no airflow) can be achieved in 100ms, although times in excess of this minimum value are more likely to occur under conditions of normal speech. [...] These data suggest that a cyclic change, consisting of an increase in subglottal pressure from a steady value to some other value, followed immediately by a decrease to the original pressure, requires 300ms or more.” (Stevens, 2000:40)

This claim may be revised by future evidence without undermining the validity of the present claim. The crucial parts of the representation are the raising time in pre-tonic position, and a gradual pressure decrease in post-tonic position. Supra-glottal dynamics minimally affect subglottal pressure. The release of a pre-tonic stop closure causes small decreases in subglottal pressure which are added on the greater stress-conditioned increase, a similar modulation is present at the post-tonic release. Lehiste (1975) notes a decrease in subglottal pressure between the end of closure (peak oral pressure) and the release point (ca. 1cm of water).

The following section illustrates the claim that the modulation of subglottal pressure during the production of stress-adjacent segments affects the realization of these segments, especially when they are plosives. These effects are the side-effects of increasing the level of perceptual energy of the stressed vowel, on the phonetic realization of segments within the domain of pressure modulation.

4.3.3 Side-effects

This section argues that the increases in subglottal pressure during the production of stress-adjacent consonants have indirect effect on the acoustic properties of these segments, which trigger stress-conditioned alternations. in this position.
A subglottal pressure increase produces an increase of both the volume and the velocity of the airstream that passes through the glottis during the production of segments surrounding a stressed vowel. Since subglottal dynamics interact with supra-glottal mechanisms, the acoustic properties of stress adjacent consonants are indirectly affected by the increase in subglottal pressure on the stressed vowel. Not only is the level of intra-oral pressure largely dependent on the pressure below the glottis, as we saw in the previous section in the case of voiceless stops subglottal and oral pressure are comparable. Intraoral pressure during the production of voiceless stops can therefore be used as an estimate of subglottal pressure: the peak oral pressure during the last part of the closure is nearly equal to the subglottal pressure of a following vowel (Rothenberg, 1968, 1973; Smitheran and Hixon, 1981; Titze and Sundberg, 1992). In the description of how aerodynamic mechanisms in the production of stress-adjacent segments are modulated by the increase in subglottal pressure, we therefore use voiceless stops as the particular case. This choice allows for the simplest model of indirect effects of stress on acoustic properties on stress adjacent consonants. It also allows us to build on previous work on these effects, which exclusively looks at plosives.

Löfqvist’s (1975) study of subglottal pressure during the production of stops in Swedish is one of the first attempts to investigate the role of the respiratory system in the production of individual segments in a chain of speech. Whereas Ladefoged (1967) and Lehiste (1970) mainly looked at overall differences between stressed and unstressed syllables, Löfqvist’s analysis looks at how variation in subglottal pressure (measured by needle inserted through the cricothyroid membrane) influences fine grained phonetic properties of sounds, such as voicing, aspiration, and the different short temporal windows in the production of a stop. The author claims that peak subglottal pressure is sensitive to the prosodic position of the consonant: results show a significantly greater subglottal pressure at the offset of the stressed vowel, compared to the unstressed vowel. Löfqvist also reports sharp decrease in oral pressure at the stop release both in pre-tonic and in post-tonic stops position. These sharp decreases result from the increase in airflow that characterizes stressed syllables. Similarly, in a study on the aerodynamics of stops, Miller and Daniloff (1977) show a strong positive correlation between intraoral air pressure, sound pressure at the burst transient and the duration of consonantal closure. Chapter 7 provides experimental evidence of a similar effect of the burst transient in pre-and post-tonic plosives in Italian.

This experimental evidence converges on showing that the effects of stress, though predominantly affecting the target vowel, are not strictly local, but also modulate the acoustic realization of the neighboring consonants. Figure 4-6 is a schematic representation of how modulations in subglottal pressure (P_{SC}), below, correspond to modulations in oral pressure (P_{O}), above. In pre-tonic position higher subglottal pressure during stop closure leads to higher oral pressure behind the release. The raised oral pressure in pre-tonic position results in a louder release and a sharper pressure drop after the transient, than in pre-atomic consonants, in which the subglottal pressure level is steady. In post-tonic position, the effect of raised subglottal pressure is smaller, since the closure is not immediately adjacent to the stressed vowel. The pressure level is nevertheless somewhat higher than in post-atomic consonants: Chapter 7 show that effects of pressure on the stop burst are observed even in this position.

We argue that the indirect effect of subglottal pressure increases on the acoustic properties of stress-adjacent consonants triggers stress-conditioned alternations in the acoustic realization on segments in this position. Although Figure 4-6 shows stronger effects in pre-tonic position, changes in the realization of post-tonic plosives are also expected.

In pre-tonic position, the oral pressure behind the release is significantly higher than in other
Figure 4-6: Effects of stress-conditioned subglottal displacement on the realization of stress-adjacent plosives, schematic representation. Oral pressure dynamics ($\Delta P_o$), top schema; subglottal pressure dynamics ($\Delta P_{SG}$), lower schema. Dotted lines indicate the dynamics in unstressed position; solid line the dynamics under stress. Arrows indicate the burst transient. [Time scale from Rothenberg, 1968 and Stevens, 2000]

contexts. The increase in pressure a results in a sharp and loud release: stops in this position have an increased loudness of the burst, and increased frication noise, which may lead to the production of an affricated stop. Stop consonants with these acoustic properties are documented in pre-tonic positions. These cases are illustrated in Chapter 3 (§3.2.2.1) as segmental alternations which are not triggered by grammatical requirements on durational prominence, or on the perceptual energy of the stressed vowel, but are nevertheless conditioned by the position of stress. Farsi is described as having loud and enhanced stop bursts in this position (Samareh, 1977:17; González, 2003) and in Maori pretonic consonants have loud and affricated releases (Bauer, 1993: 555). Chapter 6 develops an analysis of Maori which shows how affrication emerges as a side-effect of enhancing the energy of the stressed vowel.

Stops with these acoustic properties differ significantly from non-stress-adjacent stops which are may undergo lenition processes (Chapter 3, §3.3). The properties of the acoustic realization of stops in pre-tonic position make them less prone to lenition. In Copala Trique for instance, fortis consonants are generally lenited to lenis, lenition is only blocked in pre-tonic position (Chapter 3, §3.4.2.1). Similar, though less extreme effects of subglottal pressure increases are attested in the phonetic realization of plosives in post-tonic position. For instance, sharper bursts in this position

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are responsible for the blocking of the weakening palatalization process of post-tonic velars in Italian. The analysis of stress-conditioned Italian palatalization is developed in Chapter 7. The stress-conditioned realization of plosives is demonstrated by an acoustic analysis, as well as by a study on the perceptual saliency of these side-effects.

A further effect of the mechanisms which enhance the loudness of the stressed vowel cannot be directly linked to the raising of subglottal pressure, rather to the the tensing of the vocal folds which is responsible for the decrease in the negative spectral tilt of stressed vowel. Halle and Stevens (1971) provide evidence for the increased stiffness of the vocal folds as the glottal flow increases, which is possibly caused by a contraction of the cricothyroid and vocalis muscles (Stevens, 2000:452). Since the vocal folds are tensed throughout the duration of the stressed vowel, the tensing mechanism is likely to begin close to transition into the vowel. In the case of a pre-tonic plosive, vocal fold tensing reduces the abducting movement of the vocal folds immediately after the release and inhibits vocal fold vibration.

It is unlikely that the presence of a long post-aspiration can arise as the side-effect of vocal fold tensing, as it requires a significantly longer period of glottal opening. By contrast, the slight increase of the aspiration in pre-tonic position is likely to arise from the very mechanism used to increase the loudness of the stressed vowel. In Chapter 3 (§3.2.2.2) we presented several languages in which post-aspiration is conditional on the presence of a following stressed vowel. In Maori (Bauer, 1993) for instance, pre-tonic obstruents are slightly aspirated in pre-tonic position, in addition to having a louder or/and affricated release. The same process is documented for Farsi (Samareh (1977) and Pattani (Sarma, 1982). Similarly, in American English aspiration is conditioned by stress, in addition of occurring word-initially. It is likely that in English an active spreading gesture causes the long aspiration noise.

4.3.4 Constraints

This section introduces the two sets of constraints: first, those metrical constraints which ensure that stressed vowels be realized with the acoustic properties illustrated above, §4.3.4.1. Second, the aerodynamic constraints which restrict the dynamic implementation of vowel prominence, §4.3.4.2.

4.3.4.1 Vowel prominence

The prominence of the vowel is defined following Gordon (2006) in terms of its total perceptual energy. This is a measure in which the average amplitude of the segment is converted to its perceived loudness (Warren, 1970:Fig.1), and multiplied by its duration. The perceived loudness of a vowel is a relative measure, representing the loudness relative to a reference vowel which is set to be the loudest in the comparison set. The loudness of the reference stimulus (also called Standard, Garner, 1954) set at 100. The perceived loudness of any vowel other than the reference vowel is calculated from the difference between the intensity of the reference vowel, and the intensity of the given vowel, based on an experimentally constructed response function for pure tones (Warren, 1970:1399).

Note that in this dissertation Gordon’s usage of the perceptual energy measure has been restricted. Gordon uses energy level in order to compare the auditory prominence of possible weight distinctions within a language. The author works from a syllable-based model of metrical weight; energy levels therefore refer to the entire rhyme. Energy values in this dissertation are calculated for vowels only, since it is claimed that constraints referring to this measure only target the stressed
vowel. Because of this difference between our model and Gordon’s, energy values have very different magnitudes. The method with which perceptual energy is derived from segmental duration and perceived loudness is the same; we have adopted Gordon’s metrics exactly. The difference arises from the number of segments over which the energy is calculated.

The energy level of a vowel can therefore be derived from its duration and its intensity, whose auditory targets are specified in the inventory. Both durational and loudness components contribute to the energy measure. We discuss the contribution of the individual components.

Distinction of different total energies can be based on duration: long vowels have a higher energy level than short vowels, short vowels have a higher energy level than reduced vowels. The table in (14) is an example of the effect of duration on the energy measure based on two phonetic studies of Chickasaw (Muskogean, Oklahoma) conducted by Gordon et al (2000) and Gordon (2004). Vowel length is contrastive in Chickasaw, short and long vowels are not reported to have different intensity values. Given that the comparison set contains values of equal intensity, their perceived loudness is set to 100. The distinct energy levels only arise from the durational difference. Total energy values are reported in arbitrary units.

(14) Perceptual Energy: short vs. long V

<table>
<thead>
<tr>
<th>Vowel</th>
<th>Intensity (dB)</th>
<th>Loudness</th>
<th>Duration (s)</th>
<th>V\textsubscript{Energy}</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>78</td>
<td>100</td>
<td>0.09</td>
<td>9</td>
</tr>
<tr>
<td>V:</td>
<td>78</td>
<td>100</td>
<td>0.150</td>
<td>15</td>
</tr>
</tbody>
</table>

Distinctions between different perceptual energies can also arise from differences in the intensity of the different vowels. These differences can result from the different subglottal pressure used to produce the vowels: vowels produced with a higher subglottal pressure have a higher energy level than vowels produced with a lower subglottal pressure. Intensity differences can also result from differences in the intrinsic intensity of vowels. Vowels with higher F1 values have a higher intensity than vowels with lower F1 values; this difference in amplitude is not restricted to the F1 itself, it affects the entire spectrum (Fant, 1960; Howitt, 2006:54). Since F1 is a primary acoustic correlate of segmental sonority (Donegan, 1978; Keating, 1983, 1988; Kingston, 1998), sonority differences among vowels also yield different energy levels. Parker (2002) investigates the link between sonority and overall intensity: he found that when vowels are produced at the same fundamental frequency, height is inversely correlated with intensity\(^3\). Gordon also distinguishes between the energy levels of vowels of different sonority. The energy levels of high vowels are lower than energy levels of lower vowels, for most analyzed languages, and in general energy values for low vowels are at least as great as energy values for high vowels.

The table in (15) presents an example of the correlation between sonority and perceptual energy, based on durational and intensity data from American English stressed vowels. Intensity data are taken from an acoustic analysis of vowel intensities by Fairbanks et al. (1950), with male speakers of American English. Vowel duration data are taken from Parker (2002). Intensity and durational data were based on the phonetic symbol used by the authors to describe the recorded vowels. Fairbanks et al. provide intensity data in the form of “relative intensity in dB above an arbitrary

\(^3\)The author notes that this correlation is frequently reversed by the effect of pitch on intensity. High vowels inherently tend to have higher pitch than lower vowels (Kingston, 1991), and the higher a vowel is in intrinsic F\(_0\), the louder it tends to be. In order not to observe a reversal of the expected relation between intensity and sonority, pitch has to be controlled for. Some studies previous to Parker controlled for this effect by manipulating subglottal pressure (e.g. Ladefoged and McKinney, 1963).
reference" (Fairbanks et al., 1950:458), this explains the low values in (7). Since the measure of perceived loudness is a relative measure, these intensity values could be used. The short central vowels [i, a, θ, u] are not reported here; they were reported to have surprisingly low intensities, possibly as an effect of the surrounding consonants. In the absence of durational data, and detailed information on the nature of the consonantal effect, they are not included. The low vowel [æ] was reported to have the highest intensity, it is therefore used as the reference. Vowels differing less than 2dB from the reference vowel are treated as equally loud (100), since Warren reports only loudness judgments for differences greater than 2dB. Differences in energy values in (15) arise both differences in perceived loudness, and differences in duration, since duration is also a correlate of sonority. The table shows that more sonorous vowels have higher energy values than less sonorous vowels. The differences in energy are overall comparable in magnitude to the differences in (14), but more fine-grained differences arise from differences in vowel height.

(15) Perceptual Energy: sonority differences
(Duration data from Parker, 2002:187; intensity data from Fairbanks et al., 1950:458)

<table>
<thead>
<tr>
<th>Vowel</th>
<th>Intensity (dB)</th>
<th>Loudness</th>
<th>Duration (ms)</th>
<th>$V_{\text{Energy}}$</th>
<th>$V_{\text{Energy}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>i</td>
<td>14.8</td>
<td>61</td>
<td>0.0866</td>
<td>5.283</td>
<td>5.283</td>
</tr>
<tr>
<td>u</td>
<td>15.7</td>
<td>68</td>
<td>0.0866</td>
<td>5.889</td>
<td>5.889</td>
</tr>
<tr>
<td>e</td>
<td>16.7</td>
<td>75</td>
<td>0.136</td>
<td>10.208</td>
<td>10.208</td>
</tr>
<tr>
<td>o</td>
<td>16.8</td>
<td>75</td>
<td>0.136</td>
<td>10.208</td>
<td>10.208</td>
</tr>
<tr>
<td>e</td>
<td>16.0</td>
<td>72</td>
<td>0.136</td>
<td>9.799</td>
<td>11.7</td>
</tr>
<tr>
<td>o</td>
<td>17.6</td>
<td>100</td>
<td>0.136</td>
<td>13.61</td>
<td></td>
</tr>
<tr>
<td>æ</td>
<td>18.3</td>
<td>100</td>
<td>0.154</td>
<td>15.41</td>
<td>15.41</td>
</tr>
<tr>
<td>a</td>
<td>17.5</td>
<td>100</td>
<td>0.154</td>
<td></td>
<td>15.41</td>
</tr>
</tbody>
</table>

The total perceptual energy is a complex auditory dimension, since it is derived from the combination of two dimensions, loudness and duration; it can nonetheless be treated in the same way as its components. In the present model, it is the dimension which reflects the prominence of a vowel; metrical constraints enforcing the prominence of the stressed vowel refer to it. Like other auditory dimensions, perceptual energy is a scalar feature (see Chapter 2): vowels are located at different points along this dimension, based on their duration and loudness.

The requirement that a stressed vowel should have a high perceptual energy, $V_{\text{Energy}}$, is decomposed into a set of constraints requiring a specified minimal energy level for the stressed vowel. The required distance is indicated in the format Energy level of $V \geq X$, where $X$ is the minimal required energy of the stressed vowel. The constraint is defined in (1-b).

(16) Vowel prominence constraint ($V_{\text{Energy}} \geq X$)

The total perceptual energy level of a stressed stressed vowel, $V_{\text{Energy}}$, should not be smaller than $X$.

For instance, $V_{\text{Energy}} \geq 8$ is satisfied by a stressed vowel whose perceptual energy is at least 8 energy units. The evaluation of this constraint is shown in (17), for a small subset of the American English vowels.
We don’t know to this point what grammatically relevant steps on this dimension. In the absence of the necessary perceptual evidence, we will distinguish between three step sizes, which emerge from the empirical observation of the kind of energy enhancements which can be enforced on stressed vowels. Some languages, require high thresholds of perceptual energy for the stressed vowels. These are languages (e.g. Italian and Central Alaskan Yupik) in which stressed short vowels become long in order to satisfy the metrical requirement. Other languages require somewhat lower thresholds of perceptual energy for the stressed vowels. These are languages with quality-sensitive stress (Kenstowicz, 1997), or sonority-sensitive stress (Crosswhite, 1998). In some of these languages (e.g. Kobon and Zabiče Slovene), high vowels are may be lowered in order to satisfy the metrical requirement, or low vowels attract stress. We will develop the analysis of Zabiče Slovene in Chapter 6, as a case study of this pattern. Some languages enforce small energy enhancements through the lengthening of pre-tonic obstruents, or even smaller ones through the lengthening of pre-tonic fricatives (e.g. Urubu-Kaapor and Tukang Besi). This strategy of prominence enhancement is illustrated in §4.3.5 below. The formal analysis of these processes is developed in Chapter 5. Finally, in some languages the effect of these constraints results in the enhancement of vowel intensity predominantly through the increased perceived loudness of the stressed vowel.

This set of constraints interacts with standard IDENT[F] constraints penalizing the unfaithful mapping between segmental duration, IDENT [dur], (18), and height, (19), in the Inventory, and the phonetic realization of these auditory features in the output of the Realization. It also interacts with aerodynamic constraints regulating the subglottal pressure modulations required in order to produce changes in vowel intensity. These constraints are introduced in the next section (§4.3.4.2).

(18) Durational faithfulness (IDENT Vdur)
Corresponding input and output vowels have the same value for [duration].

(19) Durational faithfulness (IDENT Vheight)
Corresponding input and output vowels have the same value for [height].

The language specific effects of the metrical constraints $\hat{V}_{Energy} \geq X$ emerge from the interaction of these constraints with faithfulness constraints. Like for the durational prominence constraints introduced earlier ($I_{dur} \geq X$), the nature of the faithfulness constraints outranking $\hat{V}_{Energy} \geq X$ constraints sets the threshold energy level required of stressed vowel, and restricts the processes which can be implemented in order to produce it. For instance, in a language with the ranking in (20)a, the energy of the vowel can be increased significantly by lowering, lengthening (the vowel or/and the pre-tonic consonants) or increasing its intensity. In a language with the ranking in (20)b on the other hand, increasing the sonority of the vowel in order to promote its energy level is penalized by a high-ranked faithfulness constraints. Similarly, vowels cannot be lengthened in a language with the ranking in (20)c in order to reach the required energy level.

(20) a. $\hat{V}_{Energy}:X \gg IDENT [dur], IDENT V_{height}, IDENT V_{int}$
b. IDENT $V_{height} \gg \hat{V}_{Energy}:X, IDENT [dur], IDENT V_{int}$
4.3.4.2 Effort constraints

The analysis of the side-effects of prominence enhancement presented in §4.3.3 relies on a new constraint in addition to the two metrical constraints introduced so far. This constraint is the grammatical instantiation of the constraints on the time constant of subglottal pressure displacement presented in §4.3.2.2. It is argued that these restrictions on the rate of change, are reflected in the grammar. A class of markedness constraint penalizes displacements of the subglottal pressure level which are either too effortful, or impossible to implement, given dynamic constraints inherent in the mechanism of muscle contraction and in the central nervous system. The constraint is defined in (21).

\[(21) \quad \text{Control of subglottal pressure displacement: } *\text{FAST } vP_{SG}\]

No change in subglottal pressure may be faster than allowed by the control mechanism of muscle contraction and by the dynamic constraints of the central nervous system.

Assign one violation mark for every increase in vowel prominence requiring a fast displacement of the subglottal pressure level.

This constraint interacts with the metrical set of \( \dot{V}_{\text{Energy}} X \) constraints, since the former favors subglottal pressure raising as a strategy to enhance the prominence of the stressed vowel. For example, in a language in which prominence constraints require stressed vowels to be produced with greater intensity than unstressed vowels, subglottal pressure has to be increased to the level which results in the required energy level. Changes in subglottal pressure are slow, therefore the pressure level cannot be instantaneously raised in the transition into the stressed vowels, nor can it be lowered to its baseline right at the transition out of the stressed vowel.

Assume that in order to satisfy a requirement of metrical prominence, \( \dot{V}_{\text{Energy}} X \), the perceptual energy of the stressed vowel needs to be increased. There are three ways in which the energy of the vowel can be enhanced: by lengthening the vowel, by lowering it and by increasing its loudness. The choice of strategy is determined by the relative ranking of metrical constraints and faithfulness constraints. If vowel lengthening, is blocked by a high-ranked faithfulness constraint, IDENT\([\text{dur}]\), the energy level of the stressed vowel is enhanced by increasing its loudness, and possibly by lowering it. Increasing the loudness of the stressed vowel requires an increase in subglottal pressure, and the tensing of the vocal folds.

Figure 4-7 is an illustration of how subglottal pressure could in principle be raised in order to produce the required increase in the total energy level. Subglottal pressure can start rising ca. 150ms before the onset of the stressed vowel, during the articulation of the pre-tonic segment, and return to the baseline pressure level ca. 150ms into the articulation of the post-tonic segment, Fig. 4-7a. As seen in §4.3.3, this slow pressure change affects the realization of the surrounding segments. Specifically, if these are plosives, their burst properties will be affected; it will affect the loudness of their burst, and it may give rise to aspiration. Alternatively, subglottal pressure could start raising later, ca. 110ms into the articulation of the pre-tonic segment, and return to its baseline ca. 110ms into the post-tonic segment, Fig. 4-7b. This displacement is more effortful, and therefore dispreferred by the markedness constraint in (21). It also affects the realization of
Figure 4-7: Displacement velocities of the subglottal pressure level \(P_{SC}\) targeting a stressed vowel.

contrasting segments, but to a lesser extent. Finally, subglottal pressure could stay at its baseline level until the onset of the stressed vowel, increase during the transition into the stressed vowel to reach the target and return to its baseline during the transitions into the post-tonic segment, Fig. 4-7c. Although it would have the advantage of producing the required level of vowel prominence without affecting the phonetic realization of the surrounding segments, this type of displacement is impossible given the control mechanisms of the nervous system. This displacement is penalized by the a constraint whose basis are physiological. This constraint is inviolable, since it is enforced by unalterable properties of high level control systems of sound production.

Like the metrical constraints introduced in the previous sections, this markedness constraint is active in the Realization component of the grammar. Its role in this subcomponent of the grammar particularly emerges particularly in its interaction with constraints which enforce modulations of subglottal pressure away from its baseline. Metrical constraints requiring the enhancement of the energy level of a stressed vowel, \(\hat{V}_{Energy} \geq X\), are a prototypical example of this interaction.

This constraint triggers those phonological alternations which we have labeled side-effects of prominence enhancement. Note that these effects are exclusively restricted to those which result from an increase of subglottal pressure during the production of pre-tonic and post-tonic segments.
They are the increase sharpness and amplitude of stop bursts, the presence of affrication at release and longer aspiration noise in pre-tonic position. Furthermore, these side-effects only occur in those languages in which $V_{\text{Energy}} \geq X$ actively enforce subglottal pressure increases to enhance metrical prominence. Languages in which the intensity of the stressed vowel is not an acoustic correlate of stress (e.g. Finnish), $V_{\text{Energy}} \geq X$ are not active, and thus their side-effects are not found.

The effects of these markedness constraints of the realization of stress-adjacent plosives are illustrated in the formal analyses of the side-effects of stress in Chapters 5-7. Evidence for these effects does not only come from the empirical observations about the nature of non-prominence enhancing consonantal alternations; Chapter 7 provides experimental support to the specific effects of these effort constraints on the realization of pre-tonic stop releases.

### 4.3.5 Onset lengthening

This section presents a strategy to increase the perceptual energy of the stressed vowel, which does not require increasing its intensity nor its duration. The energy of the vowel can be enhanced by lengthening the period of silence preceding it, which increases its perceived loudness.

Several languages present processes of consonantal lengthening in the onset of a stressed syllable. Section 4.2.1.1 reviewed the problems that stress-conditioned durational enhancement poses for moraic-based accounts of segmental lengthening. It was also mentioned, that these processes are problematic for the interval-based account proposed in this dissertation as well: the lengthening of pre-tonic segments increases the durational prominence of the pre-tonic interval. The duration of the stressed interval is never affected by pre-tonic lengthening. This process can therefore not be enforced from the grammatical pressure to increase the duration of the stressed interval.

The claim made here is that although onset and coda lengthening superficially look like mirror images of post-tonic lengthening, the two processes are fundamentally distinct. Whereas lengthening in post-tonic position is the response to metrical constraints on the duration of the stressed interval, pre-tonic lengthening is the response to constraints enforcing the high perceptual energy of the stressed vowel. Lengthening in this position enhances the percept of prominence of the stressed vowel by increasing the period of silence preceding it. This claim builds on acoustic literature on the perception of vocalic sounds in different contexts, more precisely, on the effect of context on the auditory response to an acoustic stimulus. A similar claim, on the link between the availability of perceptual cues to phonological contrast and properties of the auditory system is made by Wright (2004):

"[...] to understand the role of perception in the shaping of cross-linguistic patterns of segmental organization, the ways in which the auditory periphery shapes the acoustic signal must be taken into consideration. That is, not only should the distribution of perceptual cues in the signal be considered, but also how the auditory system can change a particular portion of the speech signal." (Wright, 2004:42).

Not all acoustic features that one observes in a waveform have an equal impact on the listener. As an example of how the robustness of cues is influenced by general properties of our auditory system, Wright discusses work by Delgutte and Kiang (1984) on the speech coding of consonantal sounds in the auditory nerve. The response of the auditory nerve fiber to speechlike, and non-speechlike sounds depends on the environmental context of the signal itself. A large literature on the physiology of the auditory pathway has shown an asymmetry between onset- and offset
responses to sound (e.g. Kiang, Watanabe and Clark, 1966). At the onset of a stimulus signal there is a sharp burst in the activity of the auditory nerve, but rapid adaptation causes a decay of the response level after 5ms.; a period of short-term adaptation follows in the next 50ms, bringing the response level on a steady pattern. Changes in stimulus intensity after this period do not cause a large change on the firing rate, since at levels typical of speech, saturation occurred in the auditory fiber.

Delgutte and Kiang show that the magnitude of the peak response at the onset of a stimulus signal depends on the levels of activity immediately preceding the stimulus onset: the smaller the activity, i.e. the longer the period of inactivity of the fibers in the same frequency regions, preceding the onset (up to 50ms), the greater the initial response. Specifically, Delgutte and Kiang (1984, IV), show that the greatest auditory response increase is seen following the period of silence which results from a voiceless stop closure, or an onset following a pause. These results are in line with perceptual experiments which have shown that the phonetic value of an acoustic event often depends on the neighboring speech segments (Liberman and Pisoni, 1977; Summerfield and Haggard, 1977; Dorman et al., 1979; Repp, 1981), and suggest that by increasing the duration of the silent interval, “auditory-nerve fibers would recover more from adaptation by the preceding vowel, so that the peaks in discharge rate at the onset of the noise would be more prominent” (Delgutte and Kiang, 1984 (IV): 905).

These findings suggest that the lengthening of a pre-tonic stop consonant, and the related increase in closure duration, increases the perceived prominence of the stressed vowel, and thus is triggered by the metrical requirement to increase the perceptual energy of the stressed vowel. Delgutte and Kiang point out that auditory effects triggered by sudden changes of the signal (e.g. from a long period of silence to the release and the transition to the following vowel) can be used to encode important phonetic information (e.g. the presence of stress). They write that “the peaks in discharge rate that occur in response to certain rapid changes could be used by the central processor as pointers to regions of the spatio-temporal pattern of auditory-nerve activity that are rich in information about phonetic distinctions.” (Delgutte and Kiang, 1984 (IV): 906)

If it is the case that the greatest increase in auditory response at the onset of a vowel follows a long closure of a voiceless stop, the increase in activity after a low amplitude noise such as the closure of a voiced stop is less marked. Even less increase is observed following the high amplitude noise of a nasal consonant. In the case of fricatives, the intensity and frequency of the frication noise determines the degree of activation at the onset of voicing of the vowel (Delgutte and Kiang, 1984, III). This makes the prediction that if a language has onset lengthening, it will prefer to lengthen voiceless stops more than voiced stops, more than nasals and fricatives. The prediction seems to hold for some of the languages which are described as having onset lengthening by González (2003).

Urubu-Kaapor (Tupi Guarani, Kakumasu, 1986), which is described as having onset gemination, shows the expected pattern. The consonants of the language are /p, t, k, kw, ?, m, n, η, s, j, h, r, w, j/, but only the voiceless stops lengthen in the onset of a primary stressed syllable (/p, t, k, kw, ?/). Most consonants in English are longer in onsets of stressed syllables than in unstressed syllables (Umeda, 1977; Turk, 1992; Lavoie, 2001). Particularly, voiceless stops have longer VOT in stressed syllables (Lisker and Abramson, 1967; Turk, 1992; Crystal and House, 1988; Lavoie, 2001). Some languages on the other hand lengthen more segments. In Copala Trique for example, fortis consonants, voiceless stops and fricative, are reported to lengthen before a short, stressed vowel (Hollenbach, 1977:37). In Tukang-Besi (Donohue, 1999; Bye and deLacy, 2008), nasals and liquids lengthen, as well as voiced and voiceless stops. These languages are less expected under the
present theory of lengthening in pre-tonic position.

4.4 Summary

This chapter has laid out the grammatical building blocks of the present account of stress-conditioning, which are directly derived from the phonetic implementation of metrical prominence. Stress-sensitive alternations result from the effects of prominence requirements on the realization of segments in the stressed domain or in the proximity of stress. The three grammatical pressures which trigger stress-sensitive phonological processes are introduced. The chapter defines the two prominence requirements which hold of stressed positions, the grammatical constraints which are projected from these metrical pressures ($\hat{I}_{dur} \geq X$ and $\hat{V}_{Energy} \geq X$), and the domain within which they operate. It lays out the aerodynamic mechanisms which give rise to the side-effects of stress, the extent of the domain in which they are found, and the grammatical effort constraints which regulate subglottal pressure modulations (*FAST vP$_{SG}$).

An account of pre-tonic lengthening is proposed, which analyzes this process as a strategy to satisfy the grammatical requirement of vowel prominence in stressed position.

The formal analysis of stress-sensitive processes is developed in the following three chapters of this dissertation, through the analysis of case studies. The crucial role of the building blocks presented in this chapter will emerge from these analyses.
Chapter 5
Non-neutralizing stress-conditioned processes

5.1 Introduction

This chapter and the two that follow develop the formal analysis of prosodically conditioned segmental alternations from the building blocks introduced in Chapter 4. These chapters demonstrate that the full range of prosodically conditioned processes presented in Chapter 3 is accounted for with the two families of markedness constraints which enforce the prominence of a metrically strong position (\(I_{dur} \geq X\) and \(V_{Energy} \geq X\)), and the markedness constraint which regulates the implementation of loudness enhancement on the stressed vowel (*FAST vPSG). The insight behind the third set of constraints is that the analysis of stress-conditioning cannot abstract away from the phonetic side-effects which arise as a consequence of implementing increasing the prominence of the stressed vowel. These side-effects affect the phonetic realization of stress-adjacent consonants and trigger stress-conditioned consonantal alternations.

The analysis of these processes is cast within Flemming’s (2006) model of phonology, in which the system is divided into three components, Inventory, Realization and Evaluation of Surface contrasts (henceforth Evaluation component). The relative ranking of distinctiveness constraints and *MAXIMIZE CONTRASTS in the Inventory derives the set of underlying contrasts in the language. The Realization component plays a crucial role in the analysis of prosodic-conditioning: stress is assigned in this component, and markedness constraints on metrical prominence are active in this component. The aerodynamic effort constraint on subglottal pressure displacement interacts with constraints enforcing the loudness of the stressed vowel in the Realization. The acoustic properties of the phonetically realized output of the Realization are evaluated in the Evaluation component. This component requires that contrasts be adequately distinct in the contexts created in the Realization, to be easily recoverable. The same distinctiveness which are active in the Inventory evaluate the contrasts in the Evaluation. The interaction of these constraints with *MERGE determines whether the surface contrasts can be preserved, or whether they are insufficiently distinct and therefore have to be neutralized.

This chapter develops the analysis of non-neutralizing processes which are triggered by metrical requirements and their side-effects. The non-neutralizing nature of these process restricts the focus of the analysis on the Inventory and on the Realization components of the grammar. The role of the Evaluation component will be marginal, since these process do not trigger a reorganization of
the system of contrasts. The effects of markedness constraints affects the phonetic realization of segments in the Realization; it does not however cause neutralization processes in the Evaluation. The patterns of stress-conditioned contrast neutralization and contrast preservation are analyzed through case studies in Chapter 6 and Chapter 7.

The chapter is divided into three parts, which correspond to the three constraint families that trigger the processes described in the chapter. The markedness constraints which enforce the prominence of a metrically strong positions are stated in (1-a) and (1-b).

(1)  
   a. Durational Prominence constraint (İ\text{dur} \geq X) 
   The total duration of a stressed interval, İ\text{dur}, should not be smaller than X.  
   b. Vowel prominence constraint (V\text{Energy} \geq X) 
   The total perceptual energy level of a stressed stressed vowel, V\text{Energy}, should not be smaller than X.

The constraint which regulates the displacement velocity of subglottal pressure is stated in (2). This constraint triggers those segmental alternations which we have called side-effects of prominence enhancement. These processes do not enhance the auditory prominence of a metrically prominent position per se, they arise as the inescapable consequences of loudness enhancement.

(2) Control of subglottal pressure displacement: *FAST vPSG

No displacement in subglottal pressure may be faster than allowed by the control mechanism of muscle contraction and by the dynamic constraints of the central nervous system.

This chapter begins in §sec:InterludeDur with the analysis of those stress-conditioned processes which are triggered by markedness constraints which enforce the durational prominence of the stressed interval, İ\text{dur} \geq X. The analysis of this processes is developed through one case studies. Section 5.2.1 presents the pattern of stressed conditionional duration enhancement in Guelavia Zapotec (Otomanguean, Mexico). The analysis of Guelavia Zapotec shows a pattern of lengthening which is sensitive to the fine-grained differences in duration specification of the elements of the Inventory.

The second section of this chapter, §5.3.1 develops the analysis of the phonological alternations which are triggered by constraints enforcing a required level of perceptual energy of the stressed vowel, V\text{Energy} \geq X. This section is divided into two parts. The first part presents the analysis of prominence-driven stress assignment through the case study of Javanese (Austronesian, Indonesia, Java and Bali). The second part, §5.3.2 develops the analysis of pre-tonic consonantal lengthening as a strategy of increasing the energy of the stressed vowel. Pre-tonic lengthening in Urubu-Kaapor (Tupi-Guaraní, Brazil) is analyzes as a case-study of this pattern.

Finally, the third section of this chapter, §5.4.1, illustrates the mechanisms through which side-effects of stress are triggered by the aerodynamic markedness constraint *FAST vPSG. The analysis of phonetic enhancement of pre-tonic stops in Maori (Austronesian, New Zeland) is presented as a case study of side-effects of prominence enhancement on the realization of stress-adjacent consonants.
5.2 Interval duration

This section develops the analysis of a case study of a language, Guelavia Zapotec in which metrical constraints enforce a complex pattern of segmental lengthening processes within the stressed interval. This study has the following three aims. First it demonstrates that a complex pattern of durational enhancement can be accounted for very straightforwardly by incorporating the family of constraints on durational prominence proposed in Chapter 4 into the grammar, specifically among those markedness and faithfulness constraints which determine the phonetic realization of strings segments, in the Realization component. Second, this case study highlights the need to incorporate phonetic detail into the analysis of phonetic conditioning. The analysis of the complex pattern of lengthening in this language cannot abstract away from the underlying auditory properties of the sounds in the Inventory, and from how they are phonetically realized. Third, this analysis provides evidence to the claim outlined in Chapter 4, that both markedness constraints which enforce the prominence of stressed positions are scalar. The threshold of prominence which is required by these constraints is never fixed. It emerges from the relative ranking of metrical constraints and other constraints active in the Realization. This point is demonstrated here for the metrical constraint on durational prominence.

5.2.1 Stress-conditioned lengthening in Gualavia Zapotec

Gualavia Zapotec (Otomanguean; Jones and Knudson, 1977) presents two distinct processes of durational enhancement within the stressed interval: vowel lengthening and post-tonic consonant lengthening. This case study shows first that durational prominence constraints may enforce segmental alternations in the stressed interval. Second, that the extent to which segments are lengthened in the stressed interval is not uniform: it depends on the duration specification of that segment, and on the duration of the other segments in the stressed interval.

This language has a contrast between lenis and fortis consonants, (3)). The fortis/lenis distinction is characterized by greater duration and increased energy of fortis compared to lenis consonants. A fortis consonant is described as being voiceless, more tense and generally longer than a lenis consonant. Lenis consonants on the other hand are voiced, short and more lax; the stops tend to be produced with a fricative articulation. I follow Esposito (2006) in representing the fortis/lenis obstruents with the symbols for voiceless and voiced consonants, respectively, since this is their typical orthographic representation in Zapotec languages. Likewise, the fortis sonorants are represented by a double consonant, and the lenis ones by a single consonant. Consonants in parenthesis only appear in loan words, which are generally from Spanish (Esposito, 2004). Lenis consonants are indicated in italics.

(3) Consonant inventory of Gualavia Zapotec (Esposito, 2004:73)\(^1\)

\(^1\)Jones and Knudson (1977) do not discuss the exact nature of fortis /m l n/ vs. lenis /m l n/. In the absence of acoustic data on consonants in this language, we rely on Jones and Knudson (1977) in assuming that the distinction between lenis and fortis /m l n/ is one of duration and voicing. Voiceless nasals are attested in a small number of languages, also within Otomanguan languages (e.g. Jalapa Mazatec; Silverman et al., 1995).
The language has six vowels, which occur plain, laryngealized, or "checked by glottal closure" (Jones and Knudson, 1977: 170). Each vowel carries one of three phonemic tones, /low/, /mid/, /high/. Phonetically long vowels may carry two identical level tones or a mid followed by a high tone. Given that stress-conditioned alternations in the language are determined by constraints on durational prominence, and not by constraints on vowel prominence, the following discussion will refer to vowel duration only, without taking into account tones.

(4) Vowel inventory of Gualavia Zapotec (Jones and Knudson, 1977: 170-6)

<table>
<thead>
<tr>
<th>Oral</th>
<th>Laryngeal</th>
<th>Glottalized</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>i i u</td>
<td>i? i? u?</td>
</tr>
<tr>
<td>Mid</td>
<td>e o</td>
<td>e? o?</td>
</tr>
<tr>
<td>Low</td>
<td>a a?</td>
<td>a?</td>
</tr>
</tbody>
</table>

Cross-linguistically, non-modal vowels have a quite different distribution from modal vowels (Gordon, 1998). First, they are rare as phonemic segments contrasting with modal vowels, and as non-contrastive allophones of modal vowels (Maddieson, 1984). Second, they have a limited distribution: creaky vowels for instance tend to occur adjacent to glottalized consonants. Creaky vowels have greater overall duration than their modally voiced counterparts.

The phonetic study of non-modal voicing in a language which is closely related to Gualavia Zapotec, Jalapa Mazatec (Otomanguean) has shown that creaky vowels are phonetically much longer (up to 50% longer) than their modally voiced counterparts (Kirk et al., 1993; Gordon and Ladefoged, 2001). This additional length associated with non-modal vowels in Jalapa Mazatec is shared with other languages (e.g. breathy voiced vowels in Kedang; Samely, 1991). Non-modal phonation is usually realized primarily in the first portion of the vowel, actually beginning toward the end of any prevocalic sonorant. The second portion of the vowel usually possesses severely weakened creakiness or breathiness, almost modal phonation (Kirk, 1966; Silverman et al., 1995). Vowel contrasts are therefore distinguished both by the quality of the phonation, and by the length of the segment, so these properties are specified in the inventory. In the absence of precise acoustic data on this particular language, the inventory specifications are schematic approximations of actual durations, which are given in arbitrary duration units. Following Gordon and Ladefoged (2001) will assume a large duration difference between creaky vowels on the one side, and modally voiced vowels and vowels with a glottal closure on the other; We assume that creaky vowels are twice as long. The feature specifications for vowel duration are reported in (5) below.

(5) Inventory: Target specifications for vowels
Oral modal 1
Laryngeal creaky 2
Glottalized modal with final glottal closure

Similarly, fortis and lenis consonants are distinguished by voicing and by the duration of the segment. Duration and voicing specifications of consonants in the Inventory are reported in (6), durations are arbitrary units.

<table>
<thead>
<tr>
<th>Inventory: Target specifications (arbitrary units)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consonants</td>
</tr>
<tr>
<td>duration</td>
</tr>
<tr>
<td>voice</td>
</tr>
<tr>
<td>Vowels</td>
</tr>
<tr>
<td>duration</td>
</tr>
</tbody>
</table>

The language has one stress per word, usually in the penultimate syllable. The following two processes are described as being conditioned by stress: first, oral open vowels are lengthened when they are stressed if they precede a lenis consonant, (7)a, and short glottalized vowels are re-articulated if stressed, (7)b. Second, fortis consonants are lengthened intervocically when they follow a stressed vowel, (7)c; they also lengthen after a stressed vowel before the semivowels /j,w/ and before a voiced consonant, (7)d.

(7) Stress-conditioned lengthening in Guelavía Zapotec (Jones and Knudson, 1977:166-172)
   a. /bídý/ [biːdɨ] 'plant shoot'
      /bred/ [bréːd] 'board'
   b. /bɛʔld/ [bɛʔld] 'meat'
      /tiʔfi/ [tiʔfi] 'body'
   c. /rapaʔ/ [rapaʔ] 'i have'
      /jpaːka/ [jpaːka] 'my tadpole'
   d. /fitja/ [fit ja] 'my onion'

A schematic illustration of these processes is given in (8)

(8) Stress-conditioned lengthening: schema

<table>
<thead>
<tr>
<th></th>
<th>Stressless</th>
<th>Stressed</th>
</tr>
</thead>
<tbody>
<tr>
<td>V + fortis</td>
<td>VC</td>
<td>V:</td>
</tr>
<tr>
<td>V + lenis</td>
<td>VC</td>
<td>V:C</td>
</tr>
<tr>
<td>Vʔ + lenis</td>
<td>VʔC</td>
<td>VʔVC</td>
</tr>
<tr>
<td>V + lenis</td>
<td>VC</td>
<td>V:C</td>
</tr>
<tr>
<td>V + fortis</td>
<td>VC</td>
<td>VʔVC</td>
</tr>
</tbody>
</table>

Vowel lengthening and post-tonic lengthening are analyzed as arising in the Realization component from metrical requirements enforcing the prominence of a metrically strong position. Prominence requirements on duration refer to the total duration of the stressed interval, and they require that it have a minimum duration, $\hat{t}_{dur}\geq X$. The required duration threshold emerges from the interaction of these constraints with faithfulness constraints penalizing unfaithful mappings along the duration dimension, (9) (10). Voicing alternations are penalized by a faithfulness constraint to the underlying
voicing specification,

(9) Scalar faithfulness to vowel duration (IDENT $X V_{dur}$)
The difference in [duration] between corresponding input and output vowels is at least $X$.
Penalizes a difference of more that $X\%$ between the target duration and the duration of the output vowel, i.e.

\[ \text{IDENT 0}\% V_{dur} \gg \text{IDENT 50}\% V_{dur} \gg \text{IDENT 100}\% V_{dur} \]

(10) Scalar faithfulness to consonant duration (IDENT $X C_{dur}$)
The difference in [duration] between corresponding input and output consonants is at least $X$.
Penalizes a difference of more that $X\%$ between the target duration and the duration of the output consonant, i.e.

\[ \text{IDENT 0}\% C_{dur} \gg \text{IDENT 50}\% C_{dur} \gg \text{IDENT 100}\% C_{dur} \]

(11) IDENT [voice]:
Corresponding input and output segments have the same value for [voice].

The enhancement of durational prominence in a stressed interval may be implemented by either increasing the duration of the vowel, or the duration of the consonant in post-tonic position: with the exception of one case, only one of the two possible strategies is used at a time.

Table (12) illustrates that the duration of the interval corresponds to the sum of the target durations of the segments that it contains. It also shows that the lengthening of a fortis consonant following a modally voiced stressed vowel increases the duration of the stressed interval.

<table>
<thead>
<tr>
<th>Interval (stressed)</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>/Oral V + Fortis C/</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>[Oral V + Fortis C:]</td>
</tr>
</tbody>
</table>

The tableaux in (13) show the derivation of fortis consonant lengthening before a modally voiced stressed vowel. The duration of an interval in the input of the Realization is calculated from the sum of the individual durations of the segments which it contains. In the specific case, the duration of the stressed interval is $2.5 \times \text{[(Oral V [dur]:1) + (Fortic C[dur]:1.5)]}$. The relative ranking of prominence constraints and faithfulness sets the threshold duration of a stressed interval to 3.

Intervals are indicates by dashes (I–I). The duration of the individual segments in the stressed interval is indicated in each candidate by subscripts to vowels and consonants (e.g. $k_{1,5} = k\{dur\}:1.5$). it should be noted that the palatal glide /j/ forms a diphthong with the following vowel, it is not part of the stressed interval.

(13) Realization: Fortis consonant lengthening

<table>
<thead>
<tr>
<th>/pa\textsubscript{1}k\textsubscript{1,5}a\textsuperscript{2}/</th>
<th>$I_{dur} \geq 3$</th>
<th>IDENT 100% $V_{dur}$</th>
<th>$I_{dur} \geq 4$</th>
<th>IDENT 1 $C_{dur}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. $\bar{p}^{-} \hat{a}\textsubscript{1}{k_{1,5}}a\textsuperscript{2}$</td>
<td>$*$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. $\bar{p}^{-} \hat{a}\textsubscript{2}{k_{1,5}}a\textsuperscript{2}$</td>
<td></td>
<td>$*$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. $\bar{p}^{-} \hat{a}\textsubscript{2}{k_{2,5}}a\textsuperscript{2}$</td>
<td></td>
<td>$*$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>d. $\bar{p}^{-} \hat{a}\textsubscript{1}{k_{2,5}}a\textsuperscript{2}$</td>
<td></td>
<td></td>
<td></td>
<td>$*$</td>
</tr>
</tbody>
</table>
Since the length of the stressed interval is smaller than the required threshold, markedness constraints enforce its lengthening. The relative ranking of the two faithfulness constraints chooses the candidates in (d) over the ones in (b); this ranking is possibly a reflection of the need to preserve durational cues to vowel quality, i.e. creaky vs. modal. As seen above, creaky vowels frequently possess modal phonation in their second portion, diminishing the cues to the phonation type: phonation differences between the two sets of vowels therefore strongly relies of durational information, see (5). The relative ranking of $\text{Idur}_2 \geq 3$ and IDENT $C_{dur}$ will be set at a later stage of the analysis (see (21)).

The table in (14) illustrates the durational properties of a different interval, and how these are modified under stress.

<table>
<thead>
<tr>
<th>/\text{Oral V + Lenis C}/</th>
<th>\text{Interval (stressed)}</th>
<th>\text{Duration}</th>
</tr>
</thead>
<tbody>
<tr>
<td>/Oral V + Lenis C/</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

The preference of vowel lengthening over consonant lengthening in the case a lenis stop following a stressed modal vowel arises from a ban against long voiced consonants, (15).

(15) *\text{Voiced Long}  
A segment specified as [+voice] may not be long.

The tableau in (16) shows the derivation of vowel lengthening within an interval consisting of a stressed oral vowel and a lenis consonant. In this case like in the previous one, the duration of the stressed interval is smaller than the required one, $\text{Idur}_2 = ([\text{Oral V [dur]}:1] + (\text{Lenis C[dur]}:1)]$. The fully faithfully candidate (a) is therefore penalized by the high ranked markedness constraint which requires the duration of a stressed interval to be at least 3. The relative ranking of the effort constraint and faithfulness to vowel duration and consonant voicing determines the winning candidate, (d) over candidate (b) and (c).

(16) Realization: Oral vowel lengthening
upon the middle of the stressed vowel. We don’t have an acoustic analyses of the duration of these vowels in Gualávia Zapotec, interrupted vowels have been described as long in other languages. In a study of Trique vowels, Longacre (1952) hypothesizes that each vocalic part of an interrupted vowels is a single mora in length. Jany (2007) conducted an analysis of the phonetic correlates of the Mixe-Zoque language Chuxmabán Mixe: the author shows that although interrupted vowels are not exactly as long as long modal vowels, they are almost as long. Importantly these vowels have been reported to be are always significantly longer than both short modal vowels, and short glottalized vowels, in languages closely related to Gualávia Zapotec.

The table (17) in illustrates the behavior of glottalized vowels in a stressed intervals, assuming that interrupted vowels have the same length of a long modal vowel, i.e. 2. Tableau (18) derives the occurrence of interrupted vowels in stressed interval as a strategy to increase the duration of the stressed interval. This process is thus enforced by the same constraint ranking which enforces vowel and consonant lengthening in the interval analyzed above. Candidate (a) is ruled out because it violates the metrical markedness constraint: a stressed interval composed of a glottalized vowel and a lenis consonant is does not reach the required duration threshold, see also (17). Candidate (b) is penalized by the effort constraints against long voiced consonants.

Jones and Knudson (1977) do not report words in which a glottalized vowel is followed by a fortis consonant.

\[
\begin{array}{|c|c|c|}
\hline
\text{Interval} & \text{Duration} & \text{Interval (stressed)} & \text{Duration} \\
\hline
\text{Glottalized V} + \text{Lenis C} & 2 & \text{Interrupted V} + \text{Lenis C} & 3 \\
\hline
\end{array}
\]

Realization: Glottalized vowel lengthening

\[
\begin{array}{|c|c|c|}
\hline
\text{Interval} & \text{Duration} & \text{Interval (stressed)} & \text{Duration} \\
\hline
\text{Glottalized V} + \text{Lenis C} & 2 & \text{Interrupted V} + \text{Lenis C} & 3 \\
\hline
\end{array}
\]

The last interval considered in the analyzed in this language is one whose stressed vowel is a creaky vowel. As seen in (5), creaky vowels are substantially longer than the modally voiced vowels, they are specified for a duration specification equal to the one of long oral vowels, 2. When these vowels occur in the stressed interval and they are followed by a lenis consonant, they contribute enough length to the duration of the stressed interval to satisfy the metrical requirement on durational prominence. On the other hand, when a stressed creaky vowel is followed by a fortis consonant, we observe the only case in this language in which both the vowels and the consonants are affected within the stressed interval (e.g. /gi\text{I}t_{1,2}y/ \rightarrow [gi?_2t_2]). The two stress-conditioned pattern involving creaky voiced vowels are illustrated in .

\[
\begin{array}{|c|c|c|}
\hline
\text{Interval} & \text{Duration} & \text{Interval (stressed)} & \text{Duration} \\
\hline
\text{Creaky V} + \text{Lenis C} & 3 & \text{Creaky V} + \text{Lenis C} & 3 \\
\text{Creaky V} + \text{Fortis C} & 3.5 & \text{Interrupted V} + \text{Fortis C} & 3.5 \\
\hline
\end{array}
\]

The second process in (19) is problematic for the present analysis: it is a case of stress conditioned alternation which is apparently not enforced by the constraint on durational prominence. We propose that the alternation of creaky vowels to interrupted vowels in this context is triggered by
a co-occurrence restriction against a glottal closure gesture immediately followed by the glottal
opening gesture of a fortis, voiceless consonant, (20). In order to resolve the co-occurrence violation,
the glottal closure gesture is moved to the middle of the vowel. Evidence for this proposal comes
from the absence of glottalized vowel-fortis consonant sequences (V^ C_{fortis}) in the language, which
would present the same articulatory configuration.

(20) *?-voice
No glottal closing gesture is immediately adjacent to a glottal opening gesture.

Lengthening of fortis consonants in this context arises from the interaction of a more stringent
constraint of durational prominence, and the faithfulness constraint to the duration specification
of the consonant (\( I_{dur} \geq 4 \geq IDENT C_{dur} \)).

The tableaux in (21) derive the phonological behavior of creaky vowels under stress, when they
are followed by either a lenis (top) or a fortis consonant (bottom).

(21) Realization: Creaky voiced vowels under stress

\[
\begin{array}{|c|c|c|c|}
\hline
/k-\hat{\varepsilon}_2z_1-a^?/ & I_{dur} \geq 3 & \text{*Voiced Long} & \text{IDENT 50\% C_{dur}} & I_{dur} \geq 4 \\
\hline
a. k-\hat{\varepsilon}_2z_2-a^? & & ! & * & \\
\hline
b. ?k-\hat{\varepsilon}_2z_1-a^? & & & & *
\hline
\end{array}
\]

\[
\begin{array}{|c|c|c|c|c|}
\hline
/g-i_2t_{1.5}-\gamma/ & \text{*-}\text{voice} & \text{IDENT 100\% V_{dur}} & \text{IDENT 50\% C_{dur}} & I_{dur} \geq 4 & \text{IDENT 100\% C_{dur}} \\
\hline
a. g-i_2t_{1.5}-1 & & ! & & & \\
\hline
b. g-i?_2t_{3}-1 & & & ! & & \\
\hline
c. g-i?_2t_{1.5}-1 & & & ! & & \\
\hline
d. ?g-i?_2t_{2}-1 & & & * & & \\
\hline
\end{array}
\]

The first tableau shows that stressed intervals composed of a creaky vowel and a lenis stop satisfy
the minimal duration required of a stressed interval, they therefore surface faithfully in the Real-
ization. The winning candidate is the fully faithful output, namely candidate (b).

The second tableau on the other hand shows that the minimal duration required in the language
is not absolute: the threshold shifts in the interaction of durational prominence constraints with
other constraints active in this component.

A new threshold becomes relevant in the evaluation of the candidates in the second tableau,
because of the tie between the two candidates which are not rules out by the co-occurrence re-
striction on glottal gestures, namely (b) and (c). The new minimal distance (\( I_{dur} \geq 4 \)) is reached
by the candidate which lengthens the fortis stop (d). Unlimited lengthening of fortis consonants
is penalized by a scalar faithfulness constraint which requires input and output vowels to be in a
ratio of 1:2.

The relative location of the threshold is a characteristic property of the present proposal. Unlike
constraints on syllable weight, which are not scalar in their common formulation, both markedness
constraints on metrical prominence proposed in this dissertation refer to auditory features, and their
scalar nature is a fundamental part of their definition. The analysis of the phonological behavior of
the last interval highlights the crucial role of the interaction between metrical constraints and gen-
eral faithfulness and markedness constraints in determining the distribution of stress-conditioned alternations.

5.2.2 Summary

This section has shown how stress-conditioned lengthening of stressed vowels and post-tonic consonants can be accounted for by the markedness constraints on the durational prominence of stressed intervals defined in Chapter 4. Lengthening in this position emerges from the interaction of metrical constraints and faithfulness and markedness constraints which are active in the Realization. The crucial role of the auditory specifications of segments in the Inventory has emerged from this analysis. The analysis of the complete pattern of stress-conditioning in Guelavia Zapotec relies on acknowledging the different specifications of contrasting vowels and consonants in the Inventory.

All processes analyzed in these language are derived by a constraint ranking which is illustrated in Figure 5-1. None of the processes analyzed in this language yields the neutralization of segmental contrasts; for this reason the evaluation of surface contrasts is not developed here.

![Figure 5-1: Stress-conditioned lengthening in Guelavia Zapotec: Full ranking of constraints in the Realization component.](image)

5.3 Vowel prominence

The aim of this section is to illustrate the role of the second family of markedness constraints on metrical prominence, namely those constraints which determine the minimal level of perceptual
energy required of a stressed vowel, $\hat{V}_{\text{Energy}} \geq X$. The section is divided into two parts which illustrate two different phonological processes triggered by these constraints. The first part of this section, §5.3.1 develops the analysis of prominence-driven stress assignment through the case study of Javanese. This analysis shows how this phonological pattern arises in the Realization from the interaction of stress-alignment constraints and metrical constraints enforcing the prominence of the stressed vowel. The second part of this section, 5.3.2, presents a different strategy used to increase the energy of the stressed vowels, namely by increasing the duration of the pre-tonic consonant. Pre-tonic lengthening is analyzed through the case study of Urubu Kaapor.

5.3.1 Prominence driven stress assignment

Gordon (2006) describes different ways in which weight-sensitive stress systems distinguish among different levels of weight: the most common weight distinctions refer to the length of the segments in the Rhyme, (i); some languages treat full and light central vowels as different for the purposes of stress assignment, (ii); yet another group of languages makes prominence distinctions based on vowel height, (iii). The former two groups of languages are good examples of how constraints on the auditory prominence of the stressed vowel interact in the grammar with stress-alignment constraints. This section develops the analysis of this interaction through the analysis of one exemplar case study. Javanese (Herrfurth, 1964; Prentice, 1990) presents a stress pattern of the kind in (ii): it shows a weight distinction between full and central vowels for the purposes of stress assignment.

Although interpretations of the Javanese vowel system differ, descriptions of the language (Dudas, 1976; Hayward, 1999) agree on the fact that it has six phonemic vowels; we follow here Hayward (1999: 203-5) and assume that the language has the six phonemic vowels /i/, /e/, /o/, /a/, /o/ and /u/.

Stress in this language falls on the penultimate vowel, if it is a full vowel, and it falls on the final syllable if the penultimate is a reduced vowel (/a/). Examples from Javanese are given in (22) below.

\begin{align*}
\text{(22) & Javanese stress (Gordon, 2006: 168)} \\
& a. /badan/ \quad [\text{badan}] \quad \text{‘body’} \\
& /balur/ \quad [\text{balur}] \quad \text{‘type of fish’} \\
& /marmar/ \quad [\text{marmar}] \quad \text{‘marble’} \\
& /padat/ \quad [\text{padat}] \quad \text{‘compact’} \\
& b. /kompal/ \quad [\text{kompal}] \quad \text{‘gather’} \\
& /tøka/ \quad [\text{tøka}] \quad \text{‘come’} \\
\end{align*}

Gordon (2006) shows that the avoidance of stress on central vowels results from the low energy of these vowels compared to the energy of a full vowel, $V_{\text{Energy}}$. Given total energy levels for all the possible rhymes of Javanese, rhymes containing a reduced vowel have a lower energy level than those rhymes which are treated as heavy for stress purposes in the language (compare: 74.2 vs. 126.2 energy units; Gordon, 2006: 317)\(^2\). Stress assignment in Javanese is an example of a system in which the prominence of the stressed vowel determines the position of stress. The analysis of

\(^2\)Note that Gordon’s energy measures are calculated over the entire rhyme, whereas we will refer to the energy of the stressed vowel only. For this difference between our model and Gordon’s, energy values have very different magnitudes, see Chapter 4.
Javanese presented in this section relies on Gordon’s energy measurements.

Although Gordon distinguishes between the energy level of high and low vowels, he does not provide individual energy levels for the single measured vowels (a, i, u, e). Energy level also depends on the sonority of the vowel and in fact among the many languages studied by Gordon, energy values for low vowels are at least as great as as energy values for high vowels. In Javanese high and low vowels don’t have significantly different energy values (t=.563, p=.5747). Based on these findings we distinguish here between full vowels and reduced vowels, without going into any further detail.

Two caveats have to be mentioned regarding the usage of Gordon’s data in this analysis. First, the perceptual energy of a segment is a measure which is derived from the segment’s duration and intensity. Since Gordon does not provide durational data and intensity data of the analyzed vowels, we cannot provide the specific values of these two components in the Inventory. Since the present analysis only refers to the energy values, and never to its components, the absence of more precise data is not problematic. Second, Gordon does not provide data of the energy levels of individual segments within the rhyme. Energy levels for individual vowels are therefore calculated through an arbitrary method, by taking one tenth of the total energy value. This method reduces the magnitude of the energy levels to a range closer to the energy levels of vowels calculated in Chapter 4. Although arbitrary, this transformation does not distort the relative differences in energy between the different vowels.

In the Inventory component, vowels are specified for their target duration and height. The energy level which is derived from these two specifications corresponds to the perceptual prominence of the vowel. The specifications of full and light vowels are reported in (23). The table reports the average energy level of the rhymes containing each vowel, and the transformed energy value, $V_{Energy}$, used in this analysis.

<table>
<thead>
<tr>
<th>(23) Prominence specifications of Javanese vowels$^3$</th>
<th>Av. Energy Level</th>
<th>$V_{Energy}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Vowels (a, i, u)</td>
<td>126.2</td>
<td>13</td>
</tr>
<tr>
<td>Central Vowel (a)</td>
<td>74.2</td>
<td>7</td>
</tr>
</tbody>
</table>

We have analyzed the Javanese stress pattern described by Ras (1982): stress in falls on the penultimate vowel unless it is a reduced vowel$^4$.

We derive the default stress pattern of Javanese through the ranking of standard Optimality Theoretic constraints. Repulsion of stress from the right edge is captured in Optimality Theory by NON FINALITY (e.g. Prince and Smolensky; 1993; Walker, 1996; Gordon, 2002). We adopt a version of NON FINALITY which penalizes stress on the final interval, (24).

| (24) NON FINALITY: Stress does not fall on the final interval. |

NON FINALITY plays a role in capturing default stress assignment on the penult, when it is ranked above the gradient constraint ALIGN I-R.

---

$^3$Gordon only provides the difference between the energy levels of full and light reduced vowels (54.04), but not the actual numbers, we use here the average energy level of syllables containing full and reduced vowels as an approximation.

$^4$We are aware of the fact that Ras’ analysis is not uncontroversial. Poedjoesoedarmo (1982) claims that stress in Javanese falls on the the nal syllable. Norhoff (2009) writes that this variance is indicative of the elusive nature of stress.
ALIGN I-R: Every stressed interval is aligned with the right edge of a prosodic word.

Assigns one violation for interval which separates the stressed interval from the right edge of the prosodic word.

The tableaux in (26) show the derivation of the default penultimate in Javanese. As we saw in (22), stress falls on the penultimate vowel, unless it is reduced. The cases in which the penultimate vowel is a full vowel are considered first. The data for these and the following tableaux is taken from Gordon (2006) and Thurgood (2004).

(26) Realization: Default penultimate stress

<table>
<thead>
<tr>
<th>/badan/</th>
<th>NON FINALITY</th>
<th>ALIGN I-R</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. b-ad-'an</td>
<td>*!</td>
<td></td>
</tr>
<tr>
<td>b. b-ado'an</td>
<td>*</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>/godogan/</th>
<th>NON FINALITY</th>
<th>ALIGN I-R</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. g-od-og-'an</td>
<td>*!</td>
<td></td>
</tr>
<tr>
<td>b. g-od-og-'an</td>
<td>**!</td>
<td></td>
</tr>
<tr>
<td>c. g-od-og-'an</td>
<td>*</td>
<td></td>
</tr>
</tbody>
</table>

Constraints on the prominence of the stressed vowels play a role when the penultimate vowel is a reduced vowel. We analyze the avoidance of assigning stress on a reduced vowel as arising from the action of markedness constraints which impose a minimal required perceptual energy for a stressed vowel. The pattern of final stress exemplified in (22) arises in the case of a reduced penultimate vowel from the relative ranking of prominence constraints and stress assignment constraints in the Realization. Whereas full vowels lie on the threshold ($V_{Energy}:13$), reduced vowels do not attain the required energy level ($V_{Energy}:7$); they therefore dispreferred positions for stress. Three constraints of the $V_{Energy}:X$ family of constraints are relevant to the analysis of Javanese, $V_{Energy}:8$, $V_{Energy}:8$ and $V_{Energy}:13$, requiring that stressed vowels have a minimal energy level of 7, 8, and 13 energy units, respectively.

The derivation of this stress pattern in illustrated in (27).

(27) Realization: Final stress (a)

<table>
<thead>
<tr>
<th>/tComo/</th>
<th>$V_{Energy}:7$</th>
<th>$V_{Energy}:13$</th>
<th>NON FINALITY</th>
<th>ALIGN I-R</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. t-øk-a</td>
<td>*!</td>
<td>*</td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>b. t-øk-æ</td>
<td>*</td>
<td>*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>/kompal/</th>
<th>$V_{Energy}:7$</th>
<th>$V_{Energy}:13$</th>
<th>IDENT V</th>
<th>NON FINALITY</th>
<th>ALIGN I-R</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. k-omp-æ</td>
<td>*!</td>
<td>*</td>
<td></td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>b. k-omp-'al</td>
<td>*</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. k-omp-'al</td>
<td>*</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
If both the penult and the final vowel are reduced, stress falls on the final syllable. Stress is final even when there is a full vowel earlier in the word: it never moves beyond the penult, (28).

(28) Stressed reduced vowels in Javanese (Gordon, 2006: 168)

/\badar\ / [ba'\n\ar\] 'correct'
/g\atalan/ / [ga'ta'lan\] 'itch'

This stress pattern is problematic for the present analysis, since the dispreference for final stress is ranked higher than the requirement that stress be aligned with the right edge. This ranking was necessary to derive the default stress assignment on the penultimate vowel, (26). We speculate that the preference of the final vowel over the penultimate vowel in this context arises from the different energy level of the two reduced vowels. If final vowels are slightly lengthened, their energy level is increased. Even in case of a small increases in duration, the final reduced vowel would become more prominent than the penultimate reduced vowel, and therefore a preferable candidate for stress. A confirmation of this proposal would rely on the confirmation of the existence of word-final lengthening in Javanese. In the absence of this evidence, we propose an analysis of the third stress pattern in the language, assuming that reduced final vowels have an energy level slightly larger than non-final reduced vowels, $V_{\text{Energy}}:8$.

The proposed derivation of final stress in this context is illustrated in (29). Final lengthening of the reduced vowel is indicated by a half lengthmark ($V'$).

(29) Realization: Final stress (b)

<table>
<thead>
<tr>
<th>/\badar\ /</th>
<th>$V_{\text{Energy}} \geq 8$</th>
<th>NON FINALITY</th>
<th>ALIGN I-R</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. \b-a\n-\a\r\</td>
<td>*!</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>b. \b-a\n-\a\r\</td>
<td>*!</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>c. \b-a\n-\a\r\</td>
<td>*!</td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>

The analysis implies a revision of the previously set threshold. It assumes that the minimal required energy level for a stressed vowel in Javanese is not 13, but a smaller level, 8. Full vowels would therefore not lie on the threshold, they would be largely above it. Reduced vowels on the other hand would be only slightly below it. The change in threshold also implies the re-ranking of $V_{\text{Energy}} \geq 13$ below NON FINALITY. This amendments to the grammar do not have consequences for the stress patterns discussed above.

The full ranking which derives prominence-sensitive stress assignment in Javanese is reported in Figure 5-2.

This section has developed the analysis of a stress system in which the position of stress is determined by constraints on stress-alignments, like in all variable stress languages, and by constraints which enforce the perceptual prominence of the stressed vowel. Javanese is only one of many cases discussed by Gordon (2006), in which differences in the energy level of vowels in the inventory condition the placement of stress.

The next section develops the analysis of a very different consequence of the grammatical pressure enforced by this family of constraints. Lengthening of pre-tonic obstruents is argued to arise a strategy to increase the perceptual energy of the stressed vowel.
5.3.2 Pre-tonic lengthening

This section presents the analysis of a second type of stress-conditioned process which is triggered by metrical requirements enforcing the prominence of the stressed vowel, pre-tonic lengthening. The acoustic bases of this claim are laid out in Chapter 4.

This analysis is built from the well established fact (Delgutte and Kiang, 1984; Wright, 2004; Gordon, 2005) that the auditory nerve response to a vowel-like sound which is preceded by either silence or of a sound with little intensity is greater, than the response to a stimulus preceded by a period of equal intensity.

The analysis developed here is built on the same grounds Gordon’s (2005, 2006) analysis of a similar phonological process, namely onset-sensitive stress. Gordon suggests that the presence of a consonant in the onset of a syllable provides a quiet phase during which the auditory system recovers between exposures to intense adjacent vowels. A vowel thus receives an auditory boost if it is preceded by an onset consonant. Onset consonants with lesser acoustic intensity provide more of an auditory boost to a following vowel and are thus more likely to make their syllable prominent. In a survey of onset-sentive stress languages Gordon shows that lower sonority (less intense) onsets such as voiceless consonants and obstruents are heavier than higher sonority ones (e.g. voiced consonants and glides) in some languages (e.g. Alyawarra, Arandic, Australia: CV \(\gg (W)V\); Yallop, 1977; Goedemans, 1998). In his proposal, onsets contribute to the auditory prominence of a stressed vowel: they influence the weight of a syllable through their effect on the following rhyme.

In the analysis of stress assignment in onset sensitive systems, Gordon posits a series of prominence constraints requiring that different syllable types be stressed or not, PRoM, following Prince and Smolensky (1993) and Kenstowicz (1997). The constraints which determine onset-sensitivity stand in a universally fixed ranking: the constraint requiring that syllables with a voiceless onset be stressed is universally ranked above the constraint requiring that syllables with a voiced onset be stressed (PRoM \([X[-\text{voice}]]_\text{R}\) \(\gg\) PRoM \([X[+\text{voice}]]_\text{R}\)). Similarly, the constraint requiring that syllables without an onset be unstressed is universally ranked above a constraint requiring that syllables with an onset be unstressed (\(*\text{PRoM} [X[\text{R}]]_\sigma \gg \ast\text{PRoM} [[\text{R}]]_\sigma\)).

The purpose of the present section is to propose that the cases of pre-tonic lengthening presented...
in Chapter 3 can receive a similar analysis. The lengthening of pre-tonic consonants is analyzed here as the attempt to enhance the perceptual realization of metrical prominence: by increasing the distance between a stressed vowel and a preceding vowel, the auditory prominence of the stressed vowel is increased. This increase is mediated by an increase in perceived loudness which yields an increase in total perceptual energy, $V_{Energy}$.

Not every consonant lengthening process has the same prominence enhancing effect on the stressed vowel. The effect of pre-tonic lengthening on the stressed vowel depends on the acoustic intensity of the lengthened consonant. The perceptual energy of the stressed vowel is enhanced by the lengthening of a lower sonority onset due to the recovery period it provides; lengthening of higher sonority onset on the other hand yields a smaller perceptual boost. The different effects of increasing the duration of different consonants of the perceived loudness of the stressed vowel is schematically represented in (30) below.

(30) Segment-specific effects of lengthening on the prominence of the stressed vowel:

Voiceless stops (K → K:) > Voiced stops (G → G:) >
Voiceless affricates (tʃ → tʃ:) > Voiced affricates (dʒ → dʒ:)
Voiceless fricatives (S → S:) > Voiced fricatives (Z → Z:)
Nasals (N → N:) > Liquids (L → L:) > Glides (W → W:)

Unlike Gordon’s analysis, in which the segment-specific effect arises from the fixed ranking of feature specific constraints, the effect of lengthening different consonants is measured in terms of auditory effect on the stressed vowel.

In the absence of experimental results showing the effect of the individual processes in (30) on the perceptual energy of a following stressed vowel, we build a schematic representation of the magnitude of these effects, based on the hierarchy in (30). Differences in the auditory nerve response are sensitive to differences within very small time windows (Delgutte, 1984; Wright, 2004). We assume therefore that the difference in perceptual energy which arises through the lengthening of a low-sonority pre-tonic consonant is significantly smaller than the differences between vowels of different sonority or length. We have estimated differences in perceptual energy level to be in the order of magnitude of ca. 6 energy units between short and long vowels, of up to 10 energy units between vowels of different sonority and duration (Chapter 4). Having established that the effect of pre-tonic lengthening is smaller, we set the maximal increase in perceptual energy arising from the lengthening of a low-sonority consonant to 1 energy unit. A schematic representation of these effects is illustrated in (31). The table indicates the increments in the perceptual energy of the vowel that arises from the lengthening process. The baseline of these increments are context with the same consonants, before lengthening has applied.

(31) Schematic representation of the effects of pre-tonic lengthening on the prominence of the stressed vowel:
The subset of the lengthening processes which is attested, in a given language results from the language-specific interaction between $\hat{V}_{Energy}>X$ constraints triggering the processes in (30) and durational faithfulness constraints. The hierarchy in (30) and the relative effects in (31) allow us to make the prediction that if a language increases the duration of a consonant which yields a small increase to the energy level of the following stressed vowel, it will also increase the duration of a consonant which yields a larger increase.

In the following section, we develop the analysis of pre-tonic lengthening in Urubu Kaapor as arising from the pressure of increasing the perceptual energy of the stressed vowel.

5.3.2.1 Pre-tonic lengthening in Urubu-Kaapor

The phonemic inventory of Urubu-Kaapor (Tupi-Guarani; Kakumasu, 1996) consists of the thirteen consonants in (32) and the six vowels [i, i, u, e, o, a] along with their nasalized counterparts [ɨ, ɨ, ʉ, ɵ, ɑ, ɒ].

(32) Consonant inventory of Urubu-Kaapor (Kakumasu, 1996: 399-401)

<table>
<thead>
<tr>
<th></th>
<th>labial</th>
<th>coronal</th>
<th>velar</th>
<th>glottal</th>
</tr>
</thead>
<tbody>
<tr>
<td>plosive</td>
<td>p</td>
<td>t</td>
<td>k</td>
<td>kw</td>
</tr>
<tr>
<td>fricative</td>
<td>s</td>
<td>f</td>
<td>h</td>
<td></td>
</tr>
<tr>
<td>nasal</td>
<td>m</td>
<td>n</td>
<td>ɨ</td>
<td></td>
</tr>
<tr>
<td>liquid</td>
<td>r</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>glide</td>
<td>w</td>
<td>j</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In this language only voiceless stops lengthen before a stressed vowel, i.e. those consonants which have the greatest effect on the energy level of the following vowel, (33).

(33) Effects of pre-tonic lengthening on $\hat{V}_{Energy}$ in Urubu-Kaapor:

<table>
<thead>
<tr>
<th>Pre-tonic C</th>
<th>Increment of $\hat{V}$ prominence ($\Delta \hat{V}_{Energy}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>K$\hat{V}$ → K:V</td>
<td>$\Delta \hat{V}_{Energy} = + 1$</td>
</tr>
</tbody>
</table>

Primary stress occurs on the final syllable of the word and secondary stress is described as usually falling on every second syllable counting back from the primary stressed syllable (Kakumasu, 1996:401). This stress-conditioned lengthening process is analyzed in virtually the same way as prominence-sensitive stress assignment in Javanese: it is enforced by metrical constraints on the prominence of the stressed vowel. The minimal required energy level which is required of a stressed vowel emerges from the relative ranking of these constraints with faithfulness constraints on consonantal duration in the Realization. In the absence of acoustic data on vowel intensity and duration in Urubu Kaapor, we assume that like in Javanese a full stressed oral vowel has a prominence of
The derivation of pre-tonic lengthening in this language is illustrated in (34); this process is only found in voiceless stops preceding a primary stressed vowel. The presence of pre-tonic lengthening is determined by the relative ranking of markedness over faithfulness. The candidates in (a) are penalized by the high ranked markedness constraint. By contrast, the candidates in (b) increase the energy level of the stressed vowel by 1, reaching the required energy threshold, by lengthening the pre-tonic consonant.

(34) Realization: Pre-tonic lengthening of voiceless stops

\[
\begin{array}{|c|c|c|c|}
\hline
\text{/ka'?a/} & V_{\text{Energy}} \geq 13 & V_{\text{Energy}} \geq 14 & \text{IDENT} \text{ C}_{\text{dur}} \\
\hline
\text{a. ka'?a} & \star & \star \\
\text{b. ka'?:a} & \star & \star \\
\hline
\end{array}
\]

\[
\begin{array}{|c|c|c|c|}
\hline
\text{/tata/} & V_{\text{Energy}} \geq 13 & V_{\text{Energy}} \geq 14 & \text{IDENT} \text{ C}_{\text{dur}} \\
\hline
\text{a. ta'ta} & \star & \star \\
\text{b. ta'ta} & \star & \star \\
\hline
\end{array}
\]

Some suffixes (e.g., modifiers, focus particles and verbal suffixes) cause the primary stress to shift: when the primary stress moves from the last syllable of the head word to the postponed element, the secondary stress shifts where the primary stress would otherwise occur. If the pre-tonic consonant of the postponed is a voiceless stop, it is lengthened. No lengthening occurs in the otherwise pre-tonic stop.

(35) Pre-tonic lengthening and stress shift

/nupâ/ [nu'ppâ] 'he hits' /nupâ ta/ [nu,pa't:a] 'he will hit'
/myra/ [mi'ra] 'tree' /myra ka/ [mi,ra'k:a] 'tree-FOCUS'
/myrara?yr/ [mi,rara'?yr] 'small tree'

5.3.3 Summary

This section has analyzed two stress-conditioned phonological processes which arise from the pressure to maximize the energy level of the stressed vowel. It has shown that processes which are apparently very distinct can be accounted for with the same family of constraints, once their common grammatical origin is recognized.

Like the durational processes analyzed in the previous section, §5.2 these effects of prominence constraints on the phonetic realization of segments in the Realization component do not affect the number of contrasts in these language. For instance, since Urubu Kapor does not have an underlying contrast between short and long vowels, pre-tonic lengthening does not threaten this contrast be decreasing the distinctiveness between long and short consonants. Chapter 6 presents the analysis of a case study, Zabiče Slovene, in which a phonological process which is triggered in the Realization component by the same family of constraints yields the neutralization of a segmental contrast in stressed position.

We have analyzed the mechanisms through which metrical constraints on the prominence affect stress assignment and enforce segmental alternations in pre-tonic consonants; the next section
presents the analysis of the side-effects of the action of $\hat{V}_{E_{nergy}} \geq X$ constraints on the phonetic realization of stress-adjacent consonants. These effects arise as the indirect effects of prominence enhancement; they are enforced by aerodynamic constraints regulating the modulation of intensity.

5.4 Side-effects of prominence enhancement on the stressed vowel

This section introduces the last class of phonological processes analyzed in this chapter, namely those segmental alternations which are indirectly conditioned by stress, since they don’t result in the increased perceptual energy of the stressed vowel, nor in the increased duration of the stressed interval. These processes are the side-effects of loudness enhancement which we argue arise in the Realization component from the interaction of $\hat{V}_{E_{nergy}} \geq X$ constraints. Their sensitivity to metrical structure is therefore only apparent: they really arise from general aerodynamic restrictions, whose action is only particularly evident in the presence of stress.

The grammatical mechanisms through which these effects are enforce are illustrated in this section through the case study of Maori. In this language the constraint interaction of prominence constraints and *FAST vPSC gives rise to a pattern of indirectly stress-conditioned alternation within the domain of the subglottal pressure modulation.

5.4.1 Maori

Maori presents stress-conditioned consonantal alternation which we argue should be analyzed as a side-effect of loudness enhancement.

The consonantal inventory of Maori is given in (36), adopted from Bauer (1993).

| Consonants in Maori (Bauer, 1993: 520) |
|-----------------|---------|--------|
| plosive         | labial  | coronal|
| t               |         | velar  | glottal|
| fricative       |         |        | h |
| nasal           | m       | n      |
| liquid          | r       |        |
| approximant     | w       |        |

The position of word stress in Maori is predictable from the syllable types of the word; Bauer (1995) describes three kids of syllables which are allowed in the language: syllables containing long vowels (\((C)V_i\)), syllables containing a diphthong (\((C)V_1V_2\)) and finally syllables whose nucleus is a single short vowel (\((C)V\)). The language does not allow any kind of consonant clusters; cluster in English loanwords are broken up through the insertion of an epenthetic vowel.

The rule for primary stress assignment in mono-morphemic words refers to a hierarchy of vowel prominence in (37) below. If a word contains a long vowel, that vowel will be stressed, else the diphthong, finally a short vowel. If there is more than one vowel of the the same prominence in the word, the leftmost is stressed. The distribution of stress is illustrated by the examples in (38), the division in intervals is provided. Unlike in previous work on Maori, Hohepa (1967), Bauer dismisses the possibility that there be other levels of stress in the language, we follow him in only indicating one stress per word.

<table>
<thead>
<tr>
<th>Hierarchy of vowel prominence in Maori (Bauer, 1995: 546)</th>
</tr>
</thead>
</table>
The distribution of Maori stress (Bauer, 1995: 546)

a. V: \( \Rightarrow V_1 V_2 \Rightarrow V \) /k-owh-ai/ [k-'owh-ai] 'kowhai'

b. \( V_1 V_2 \Rightarrow V \) /k-ur-i:/ [k-ur-'i:] 'dog'

c. Align stress L /k-auw-ae/ [k-'auw-ae] 'jaw'

The position of stress is insensitive to the presence or to the duration of post-tonic consonants, suggesting that indeed stress assignment in Maori is conditioned by the prominence of the vowel and not by the duration of the stressed interval.

The perceptual energy of the stressed vowel is derived from its duration and its perceived loudness. Vowel duration is contrastive in Maori, duration specifications are illustrated in (39). These specifications refer to the durations of short and long vowels as reported by MacLagan et al. (2004:6). Target specifications, [V dur], are a transformation of the average segment durations. Long vowels are 2 times longer than short vowels, diphthongs are in average 2.3 times longer than singleton vowels. The phonological behavior of long vowels and diphthongs with respect to stress assignment cannot be attributed to differences in duration: diphthongs are longer than long vowels, nevertheless they are lower than long vowels in Bauer's hierarchy. In the absence of intensity data, perceptual energy levels were calculated from the actual durations, assuming equal intensity for all three vowels. Equal intensity yields equal perceived loudness (Warren, 1970), which is set to 100 (Warren, 1970; see Chapter 4 for a similar example).

(39) Inventory: Auditory targets of Maori vowels

<table>
<thead>
<tr>
<th>Vowel</th>
<th>av. V duration (ms.)</th>
<th>V[dur]</th>
<th>V Prominence</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>70</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>( V_1 V_2 )</td>
<td>160</td>
<td>1.6</td>
<td>16</td>
</tr>
<tr>
<td>V:</td>
<td>140</td>
<td>2</td>
<td>14</td>
</tr>
</tbody>
</table>

The phonetic correlates of primary stress in Maori have been described in Chapter 3. They consist of the increased loudness of the stressed vowel, a slight durational enhancement, and falling pitch. In addition to these features, stressed syllables are described as having emphatic onsets (Bauer, 1993: 545). The author (1993:530) reports that obstruent immediately preceding a stressed vowel have stronger aspiration and can even be affricated, (40). Whereas aspiration is extremely frequent in pre-tonic position, independently of the specific segmental context, affrication seems to be conditioned by the nature of the stressed vowel. Affrication of /p/ and /t/ is more common before a high front vowel, and affrication of /k/ is more common before /a/.

(40) Maori stress-conditioned affrication (Bauer, 1993:521-22)

/\(piu/)\ ['pç(i)u] 'swing'
/\(iti/)\ ['itsi], [itçi] 'small'
/\(karanga/)\ ['kxereie] 'call'

The importance of vowel prominence in determining the position of stress reveals a stress system in which active requirements of metrical prominence enforce the prominence of the stressed vowel. We argue that these requirements affect the realization of pre-tonic consonants, due to stringent aerodynamic requirements in the language. The effect is found in all pre-tonic obstruents: the absence of an effect of stress on pre-tonic segments other than obstruents is due to the articulatory difference between the two classes of segments. Whereas a subglottal pressure increase greatly
affects the acoustic realization of a stop release in a language with strict aerodynamic constraints, its effect are smaller on the realization of fricatives, nasals and liquids. Stress-conditioned alternations of the sort reported in pre-tonic obstruents are not reported post-tonically. Chapter 4 has illustrated the aerodynamic mechanisms which give rise to these acoustic side-effects, and shown that the effects of high subglottal pressure on the release of post-tonic obstruents are expected to be smaller than those found in pre-tonic position. The absence of a reported effect of vowel loudness on the release of post-tonic obstruents does not exclude the possibility that smaller effects of stress are found also in this position.

The stress-conditioned alternation in the realization of obstruents in Maori is accounted for here in terms of the interaction of metrical requirements enforcing a high perceptual energy of stressed vowels ($\tilde{V}_{Energy} \geq X$) and a stringent constraint on subglottal pressure modulation ($^{*}\text{FAST vP}_{SG}$). The latter constraint penalizes displacements in subglottal pressure which occur within the transitions into and out of the stressed vowel, and enforces slow pressure modulations. Raising of subglottal pressure to the level required in order to increase the loudness of the stressed vowel takes ca. 150ms (Rothenberg, 1968; Stevens, 2000): the realization of a pre-tonic obstruent which is produced within this raising time is affected by the high pressure level in the ways described in Chapter 4.

Bauer describes the realization of consonants in pre-tonic position as extremely variable across speakers and dialects, between phonetic enhancement, aspiration and affrication. All possible realizations can be ascribed to the indirect effects of prominence requirements. The variability reflects the unsystematic phonetic realization of stop bursts under high subglottal pressure.

The co-occurrence of multiple effects is not problematic for our analysis, on the contrary, it supports the idea that they are not directly triggered by prominence constraints, and instead are their necessary side-effects.

The tableau in (42) shows how segmental alternations emerge in Maori as the indirect effect of prominence requirements when these interact with aerodynamic constraints on subglottal dynamics in the Realization component. The relative ranking of prominence constraints and faithfulness constraints determine the enhancement of the energy level of all vowels under stress. The ranking of two faithfulness constrains enforces that the energy level be increased through an increase intensity, and not through vowel lengthening, (41). Subscripts indicate the energy level of the vowel. The tableau presupposes word stress on the first interval. This simplification is due to the fact analysis focuses on the phonetic realization of the stressed positions, not on stress-assignment, although it also takes place in this component of the grammar.

\begin{align}
(41) & \quad a. \text{ Faithfulness to vowel duration (IDENT } V_{dur}) : \\
& \quad \text{ Corresponding input and output vowels have the same value for [duration].} \\
& b. \text{ Faithfulness to auditory specications of the burst (Ident } C_{Burst}) : \\
& \quad \text{ Corresponding input and output consonants have the same value for burst characteristics.} \\
(42) & \quad \text{ Realization: The indirect effects of vowel prominence on pre-tonic consonants.}
\end{align}
The derivation in (42) illustrates the enhancement of the energy level of a short vowel, which does not have the minimal energy level required of a stressed vowel. The side-effect of stress on the phonetic realization of example is the presence of affrication in pre-tonic position, (d). The candidate which reaches the required energy level by increasing the loudness, but without affecting the pre-tonic segment is ruled out by the high ranked *FAST vPSG constraint, (a).

### 5.4.2 Summary

The idea behind this analysis is, as discussed earlier, that phonetic enhancement is only apparently conditioned by stress: there is no metrical requirement which enforces this process, since per se it does not increase the prominence of either the stressed vowels, or the stressed interval. Instead, the process results from the restrictions that the grammar imposes on prominence enhancement, namely the action of faithfulness constraints, and the independently present aerodynamic limitations on subglottal pressure movements.

The analysis of Maori relies on the family of prominence constraints which also triggered the stress-conditioned processes analyzed in the previous section, and on the aerodynamic effort constraint introduced in Chapter 4. The former constraint is active in the grammar independently of stress and its requirements; nevertheless, metrical requirement on prominence of the stressed vowel make their action in the grammar particularly important.

Maori is not the only case of a language with simple phonetic enhancement. Farsi (Samareh, 1977) for instance, is also described as having emphatic bursts of obstruents in pre-tonic position, a description of this class of processes was given in Chapter 3.

The process triggered in the Realization does not have an effect on the evaluation of contrasts in the Evaluation. The next chapter develops the analysis of a case study, Copala Trique, in which the side-effects of stress on the realization of pre-tonic segments results to the preservation of a consonantal contrast in this position, which is neutralized elsewhere in the word. The analysis of Copala Trique is thus virtually identical to the analysis of Maori. A further instance of a process that is triggered by the same constraints.

The prediction on this account is that side-effects triggered by the aerodynamic effort constraint are only attested in languages in which \( \hat{V}_{\text{Energy}} \geq X \) constraints are active in the Realization. The account also restricts the predicted nature of the side-effects to those which arise in obstruents' bursts from a sustained increase of subglottal and oral pressure throughout the closure.

### 5.5 Summary

This chapter has developed the formal analysis of prosodically conditioned segmental alternations which do not affect the distribution of segmental contrasts; they are distinguished from the neutralizing processes which are analyzed in the following chapter. These chapter has shown that the range of non-neutralizing phonological processes presented in Chapter 3 is accounted for with the
two families of markedness constraints which enforce the prominence of a metrically strong position ($\tilde{I}_{dur} \geq X$ and $\tilde{V}_{Energy} \geq X$), and the markedness constraint which regulates the implementation of loudness enhancement on the stressed vowel (*FAST $vP_{SC}$).
Chapter 6

Indirect effects of stress-conditioning on segmental contrast

6.1 Introduction

This chapter develops a formal analysis of those stress-conditioned phonological processes which indirectly affect the contextual distribution of segmental contrasts. Chapter 3 has illustrated two patterns which belong to this class of processes: first, the neutralization of segmental contrasts which is restricted to stressed positions, e.g. (1), second, the preservation of segmental contrasts which is restricted to stressed positions, e.g. (2).

(1) Vowels in Zabiče Slovene (adapted from Crosswhite, 1999: 43)
   a. Short vowels in unstressed syllables
      high i i u
      mid e ø o
      low ø a
   b. Short vowels in stressed syllables
   b'. Long vowels in stressed syllables
      high i: i: u:
      mid e: ø: o:
      low ø a

(2) Fortis/lenis contrast in San Juan Copala Trique (Hollenbach, 1977: 36)
   a. Contrast in stressed syllables
      [a.'gaʔ3] ‘metal’
      [da.'kaŋ] ‘crest’ (of bird)
   b. Neutralization in unstressed syllables
      [go.'paŋ2] *[ko.'pa] ‘goblet’
      [ba.'syəŋ2] *[pa.'syə] ‘to take a walk’

The central aim of this chapter is to show that both patterns arise as indirect consequences of one of three grammatical pressures which affect the phonetic realization of segments in the Realization component. The first two pressures are constraints which enforce the prominence of a
metrically strong position, $\hat{\text{d}}_{\text{dur}} \geq X$ and $\hat{V}_{\text{Energy}} \geq X$. The third pressure is the markedness constraint which regulates the implementation of loudness enhancement on the stressed vowel ($^\ast$FAST $\nu P_{\Sigma C}$). In other words, it is claimed that cases of contrast neutralization in stressed position, and cases of contrast preservation in stressed position are special instances of the processes analyzed in Chapter 5.

In the processes analyzed in the previous chapter, the alternations enforced by these three constraints on the phonetic realization did not affect the evaluation of surface contrasts. For instance, the durational enhancement of oral vowels in Guelavia Zapotec does not yield the neutralization of the contrast between the lengthened oral vowels and underlyingly long creaky vowels in stressed position. The same number of contrasts is available in both stressed and stressless positions, only the phonetic realization of the oral vowels under stress is affected.

In the processes analyzed in this chapter, on the other hand, the effects of these constraints on the realization of stressed positions affect the contextual evaluation of the segmental contrast. The Evaluation component requires that contrasts in the contexts created in the Realization be adequately distinct. If the alternations triggered in the presence of stress decrease the distinctiveness between contrasting sounds, a pattern of contrast neutralization might arise, which is restricted to the stressed position. If on the other hand the alternations triggered in the Realization increase the distinctiveness between contrasting sounds, a pattern of contrast preservation might arise, which is restricted to the stressed position.

The claim that contrast preservation in stressed positions arises from the the specific phonetic properties of segments in these positions is new, and goes against previous accounts of these processes, which appeal to Positional Faithfulness. In the following chapter we provide experimental evidence in support of our claim that there is no effect of Positional Faithfulness to features in stressed positions. In two languages which have either been analyzed, or can be analyzed, as prototypical cases of contrast preservation under stress, Italian palatalization and Finnish assibilation (Anttila, 2003, 2006), the phonetic realization of consonants which fail to undergo neutralization is responsible for the lack of neutralization, not positional privilege. Markedness constraints acting on the stressed position in these language, respectively $\hat{V}_{\text{Energy}} \geq X$ and $\hat{\text{d}}_{\text{dur}} \geq X$, indirectly enhance the distinctiveness of the /ki/-/ʃ/ and /ti/-/si/ contrasts, and thus favor the preservation of these contrasts in these positions.

The formal analysis of the processes in this chapter and in the following chapter is identical to the analyses illustrated in Chapter 5, with addition of deriving the indirect effects of stress-conditioning on segmental contrast, which takes place in the Evaluation component. Stress-conditioned contrast neutralization, e.g. (1), is analyzed a type of positional neutralization of perceptually indistinct contrasts under stress. Stress-conditioned contrast preservation, e.g. (2), is analyzed as a type of positional neutralization of perceptually indistinct contrasts in a stressless position, with preservation of a distinct contrast under stress. The analysis is cast in the Dispersion Theory of Contrast (Flemming 2004, 2006).

The analysis of the two distinct patterns is developed in this chapter through two case studies. Section 6.2 presents the analysis of stress-conditioned neutralization of the contrast between high and mid vowels in the Zabiče dialect of Slovene. The analysis of stress-conditioned contrast preservation is analyzed in section 6.3 through the case study of the preservation of the lenis-fortis consonantal contrast in pre-tonic position in Copala Trique.
6.2 Stressed-conditioned contrast neutralization in Zabiče Slovene

In a study of stress-related vowel-neutralization effects, Crosswhite (1999) discusses a large number of languages in which vowel qualities that are contrastive in stressed syllables undergo neutralization in unstressed syllables. However, there is one language reported in the study, the Zabiče dialect of Slovene, in which vowel qualities that are contrastive in unstressed syllables are neutralized in stressed syllables. In this dialect underlying short accented high vowels are realized as mid vowels: 

\[ /i/ \rightarrow [\ddot{e}], \ /\ddot{i}/ \rightarrow [\ddot{a}] \text{ and } /\ddot{u}/ \rightarrow [\ddot{a}] \].

Slovenian has a two-way length contrast among stressed vowels. This contrast is neutralized in unstressed vowels (Petek et al., 1996). Citing Rigler (1963), Crosswhite lists the inventories of vowels in stressed and unstressed syllables in this language, (3). Long and short vowels do not contrast in unstressed position, (3)(a). Unlike in short vowels, the contrast between long mid and long high vowels is preserved under stress (compare (3)(b) and (b')).

(3) Vowels in Zabiče Slovene (adapted from Crosswhite, 1999: 43)

a. Short vowels in unstressed syllables
   high i i u
   mid e o o
   low a

b. Short vowels in stressed syllables
   mid e o o
   low a

b'. Long vowels in stressed syllables
   high i: i: u:
   mid e: o: o:
   low a:

In Crosswhite (1999) and Smith (2002) the set of short unstressed vowels is derived through the lowering of high vowels to mid vowels, in order to satisfy the grammatical requirement that stressed vowels be sonorous. The relationship between the sonority of the vowel, and its ability to bear or attract stress has been widely analyzed in the literature (e.g. Kenstowicz, 1997; Crosswhite, 1999); it has been suggested that more sonorous vowels are more prominent than less sonorous vowels. Parker (2002) has shown that there is a physical reality behind the sonority scale among both vowels and consonants, in terms of intensity, duration and F0. Sonority in vowels is therefore determined by their F1 values and their perceived loudness. Not surprisingly some languages with prominence-sensitive stress show an interaction between the sonority of a vowel and stress, it is a type of interaction between stress and requirements on \( \hat{V}_{\text{Energy}} \) of the sort analyzed in Chapter 5.

The present analysis similar to the previous accounts, but it differs from them in two important respects. First, the specific mechanism of vowel lowering is analyzed in two steps: as a strategy to increase \( \hat{V}_{\text{Energy}} \) which indirectly yields the neutralization of high and mid vowels. Second, the sonority based neutralization is analyzed by referring to the auditory properties of vowels of different length and intensity: the analysis of this process refers to the need to enhance the perceptual energy of the vowel. Incorporating duration among the properties which contribute to the prominence level of a stressed vowel makes it possible to analyze the behavior of long vowels and well as the behavior of short vowels under stress.

The analysis is developed as follows. First the set of contrasting vowels of Zabiče Slovene is derived in the Inventory; second, the total perceptual energy of each vowel is calculated; third the phonetic
realization of stressed and stressless vowels is derived in the Realization from the interaction of \( \hat{V}_{\text{Energy}} \leq X \) constraints and faithfulness to the target specifications of the vowels in the Inventory. Finally, vowels contrasts in both prosodic positions are evaluated in the Evaluation component, enforcing the neutralization of stressed short mid and high vowels.

The analysis of the length contrast neutralization in stressless position is presented briefly at the end of this section; this process is not the focus of the section.

The relevant auditory dimension to derive the height contrast in the vowel inventory is F1: high and low vowels primarily differ along this dimension. The table in (4) illustrates the space of possible vowels (adapted from Flemming, 2002: 30): it is a quantized representation on the range of physiologically possible F1-F2 values.

(4) Vowel space

\[
\begin{array}{cccc|c}
\text{F2} & 5 & 4 & 3 & 2 & 1 \\
\hline
\text{i} & \text{y} & \text{i} & \text{u} & \text{u} & 1 \quad \text{F1} \\
\text{i} & \text{y} & \text{i} & \text{u} & \text{u} & 2 \\
\text{e} & \text{ø} & \text{e} & \text{o} & 3 \\
\varepsilon & \text{ø} & \Lambda & \text{ø} & 4 \\
\text{a} & \text{a} & & & 5 \\
\end{array}
\]

In order to analyze contrasts on this dimension, distinctiveness constraints must specify what constitutes a sufficient distance on each dimension, e.g. \( \text{MINDIST}= F1:2 \) is satisfied by a distance of 2 on the F1 dimension. The tableau in (6) illustrates the derivation of the Zabže Slovene short vowel inventory along the F1 and F2 dimension. In order to analyze contrasts along these two dimensions we specify the \( \text{MINDIST} \) constraints which determine what is the sufficient distance on each dimension, (5).

(5)  
  a. \( \text{MINDIST F1:2} \)  
      Contrasting vowels differ by at least 2 on the F1 dimension  
  b. \( \text{MINDIST F2:2} \)  
      Contrasting vowels differ by at least 2 on the F2 dimension  
  c. \( \text{MINDIST F1:2 or MINDIST F2:2} \)  
      Contrasting vowels differ by at least 2 on the F1 dimension or by at least 2 on the F2 dimension.

Given the ranking in (6), we derive the contrast between short high, mid and low vowels in the inventory: this is the inventory which realizes the highest number of contrasts (\( \text{MAX CONSTRASTS} \)) which are at least two steps apart either along the the F1 or along the F2 dimension (\( \text{MINDIST F1:2 or MINDIST F2:2} \)). The additional set of long vowels can be derived by the same grammar. The number of contrasts among the long vowels is derived by the same constraint ranking. In order to derive the full vowel inventory, i.e. the complete contrasts between short and long vowels, it is crucial to know the exact inventory of contrasting long vowels. In the absence of any specific description of the long vowel inventory in this language, we hypothesize that every vowel can be either long or short. The complete inventory in (3)(b) is derived by adding one more disjunction to the high ranked constraint \( \text{MINDIST F1:2 or MINDIST F2:2} \), namely a \( \text{MINDIST} \) constraint penalizing contrasting sounds which are not separated along the duration dimension, see (17) below.
Zabič Slovene vowel inventory (short vowels)

<table>
<thead>
<tr>
<th></th>
<th>MinDist F1:2 or Max</th>
<th>MinDist F1:2</th>
<th>MinDist F2:2</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>i i u e o a</td>
<td>*!</td>
<td></td>
</tr>
<tr>
<td>b.</td>
<td>i u e o a</td>
<td>6!</td>
<td></td>
</tr>
<tr>
<td>c.</td>
<td>i u e o a</td>
<td>7</td>
<td></td>
</tr>
</tbody>
</table>

In the absence of acoustic data of Zabič Slovene, specifications of intensity and duration in the inventory are very schematic. We refer to intensity data of English vowels to present an acoustically plausible relation between vowel height and intensity (House and Fairbanks, 1950:458). We idealize an arbitrary target duration of 0.095 duration unit for all short vowels, and of 0.15 units for long vowels. Differences between front central and back vowels do not play a role in the analysis, we therefore only consider height differences here in order to focus on the relevant differences. The perceptual energy measure is derived following Gordon's method; see chapter Chapter 4 for a the description of this method.

Inventory: deriving perceptual energy (Intensity data from House and Fairbanks, 1950:458)

<table>
<thead>
<tr>
<th></th>
<th>Int.(dB)</th>
<th>Loudness</th>
<th>Dur.</th>
<th>VEnergy</th>
</tr>
</thead>
<tbody>
<tr>
<td>high</td>
<td>15.25</td>
<td>68</td>
<td>0.095</td>
<td>6.5</td>
</tr>
<tr>
<td>mid</td>
<td>16.8</td>
<td>75</td>
<td>0.095</td>
<td>7</td>
</tr>
<tr>
<td>low</td>
<td>17.5</td>
<td>100</td>
<td>0.095</td>
<td>9.5</td>
</tr>
<tr>
<td>high</td>
<td>15.25</td>
<td>68</td>
<td>0.13</td>
<td>9</td>
</tr>
<tr>
<td>mid</td>
<td>16.8</td>
<td>75</td>
<td>0.13</td>
<td>10</td>
</tr>
<tr>
<td>low</td>
<td>17.5</td>
<td>100</td>
<td>0.13</td>
<td>13</td>
</tr>
</tbody>
</table>

When strings of segments are mapped onto their phonetic realizations, stress is assigned to the penultimate vowel. The energy threshold which is required of a stressed vowel emerges from the interaction of prominence constraints enforcing the prominence of the stressed vowel, (8), and faithfulness constraints to the target specifications of auditory properties, (9).

Vowel prominence constraint (VEnergy ≥X)
The total perceptual energy level of a stressed stressed vowel, $\hat{V_{\text{Energy}}}$, should not be smaller than X.

a. Faithfulness to vowel duration (Ident Vdur):
Corresponding input and output vowels have the same value for [duration].

b. Faithfulness to vowel height (Ident VHeight):
Corresponding input and output vowels have the same value for [F1].

In the present analysis, the different behavior of short and long vowels with respect to the neutralization of the high-mid contrast derives from the different perceptual energies of the two sets.
of vowels. Long vowels are good stress bearers because of their high perceptual energy: they reach the required threshold independently of their sonority. The auditory specifications for long mid and low vowels result in a perceptual energy which is at least as large as the threshold. Long high vowels reach the required threshold by lengthening slightly ($V_{[dur]} = 0.15$). The preference for lengthening the vowel over lowering it is determined by the relative ranking of the two faithfulness constraints. The tableau in (10) derives the phonetic realization of long high vowels in stressed position. Subscripts indicate the perceptual energy of the vowel. The extra length (0.02 arb. duration units) in the winning candidate (c) is indicated by its higher perceptual energy.

(10) Realization: long high vowels

<table>
<thead>
<tr>
<th>/ki̯ 9 va/</th>
<th>$V_{Energy} \geq 10$</th>
<th>IDENT V Height</th>
<th>IDENT V dur</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. 'ki̯ 9 va</td>
<td>*!</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. 'ki̯ 10 va</td>
<td>*!</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. 'ki̯ 10 va</td>
<td></td>
<td></td>
<td>*</td>
</tr>
</tbody>
</table>

Short vowels on the other hand are worse stress bearers; high and mid vowels in particular are significantly less prominent than the required threshold. The acoustic analysis of Standard Slovenian vowels (Petek et al., 1996) reveals a significant increase in the duration of short vowels when stressed, although the length contrast is preserved. It is likely that a similar lengthening process is also found in Zabiče Slovene. The proposed analysis is that although high and mid vowels are significantly lengthened under stress, they do not reach the required energy threshold. These vowels also have to be lowered, and the lowering process results in the merging of the high-mid contrast.

We illustrate the proposal with our schematic analysis of the process. Let's assume that short high and mid stressed vowels are significantly lengthened, to the duration of stressless long vowels ($V_{[dur]} = 0.13$). The perceived loudness of a vowel whose perceptual energy has to be at least 10, and whose duration is 0.13 is 83. Since both high and mid vowels have a lower perceptual energy than 83, they are lowered to the point at which they reach the required threshold (i.e. to e). The lowering and lengthening of high and mid vowels under stress is illustrated in the tableaux in (11) and (12). Lengthened short vowels have a duration of 0.13 duration units; lengthening is indicated by a half lengthmark ($V_{-}$) to distinguish them from underlyingly long vowels ($V_{i}$).

(11) Realization: short high vowels

<table>
<thead>
<tr>
<th>/ki̯ 6.5 va/</th>
<th>$V_{Energy} \geq 10$</th>
<th>IDENT V Height</th>
<th>IDENT V dur</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. 'ki̯ 6.5 a</td>
<td>*!</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. 'ki̯ 8.5 va</td>
<td>*!</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. 'ke 7.8 va</td>
<td>*!</td>
<td></td>
<td></td>
</tr>
<tr>
<td>d. 'ke 10.8 va</td>
<td></td>
<td></td>
<td>*</td>
</tr>
</tbody>
</table>

(12) Realization: short mid vowels
Only candidates is which both prominence-enhancing strategies occur, (11) (d) and (12) (d), are not ruled out by the high ranked prominence constraint. Candidates (b) and (c) show that either lengthening or lowering by themselves are not sufficient. Crucially, the winning candidates in the two tableaux are equal: in order to reach the required energy threshold, both high and mid short vowels are realized with the same phonetic properties. It is because of this prominence-enforced alteration to the phonetic realization of these vowels, that the the distinctiveness between high and mid vowels is extinguished. This lowering process affects the distribution of contrasts between the two classes of vowels, since it yields its neutralization, ??.

The tableau in (13) shows that like long vowels, short low vowels attain the required threshold through an increase in their duration.

(13) Realization: short low vowels

<table>
<thead>
<tr>
<th>/ka_9.5va/</th>
<th>( V_{Energy} \geq 10 )</th>
<th>IDENT ( V_{Height} )</th>
<th>IDENT ( V_{dur} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. ( 'ka_9.5va )</td>
<td>*!</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. ( 'ka_{10.8}va )</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>

Surface contrasts are evaluated in the Evaluation component, where the ranking of \text{MINDIST} constraints is the same as it is in the Inventory. This results in the reduction of the number of contrasting short vowels under stress, (14)(b). The contrast between high and mid vowels on the other hand, is preserved among long stressed vowels, (15)(b).

(14) Evaluation: Neutralization of the high-mid contrast in stressed short vowels

<table>
<thead>
<tr>
<th>( k\text{'va}-'k\text{\textacute{e}}va-'k\text{\textacute{e}}va-'k\text{\textacute{e}}va-'k\text{\textacute{e}}va-'k\text{\textacute{e}}va-'k\text{\textacute{e}}va-'ka\text{\textacute{a}}va )</th>
<th>\text{MINDIST} F1:2 or \text{MINDIST} F2:2</th>
<th>*\text{MERGE}</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. ( [k\text{'va}-'k\text{\textacute{e}}va-'k\text{\textacute{e}}va-'k\text{\textacute{e}}va-'k\text{\textacute{e}}va-'k\text{\textacute{e}}va-'k\text{\textacute{e}}va-'ka\text{\textacute{a}}va] )</td>
<td><em>!</em>*</td>
<td></td>
</tr>
<tr>
<td>b. ( [k\text{'va}-'k\text{\textacute{e}}va-'k\text{\textacute{e}}va-'k\text{\textacute{e}}va-'k\text{\textacute{e}}va-'k\text{\textacute{e}}va-'k\text{\textacute{e}}va-'ka\text{\textacute{a}}va] )</td>
<td>***</td>
<td></td>
</tr>
</tbody>
</table>

(15) Evaluation: Preservation of the high-mid contrast in stressed long vowels

<table>
<thead>
<tr>
<th>( ki\text{\textacute{a}}va-'ki\text{\textacute{a}}va-'ko\text{\textacute{a}}va-'ke\text{\textacute{a}}va-'ko\text{\textacute{a}}va-'ko\text{\textacute{a}}va-'ko\text{\textacute{a}}va-'ka\text{\textacute{a}}va )</th>
<th>\text{MINDIST} F1:2 or \text{MINDIST} F2:2</th>
<th>*\text{MERGE}</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. ( [ke\text{\textacute{a}}va-'ko\text{\textacute{a}}va-'ko\text{\textacute{a}}va-'ke\text{\textacute{a}}va-'ko\text{\textacute{a}}va-'ko\text{\textacute{a}}va-'ko\text{\textacute{a}}va-'ka\text{\textacute{a}}va] )</td>
<td><em>!</em>*</td>
<td></td>
</tr>
<tr>
<td>b. ( [ki\text{\textacute{a}}va-'ki\text{\textacute{a}}va-'ko\text{\textacute{a}}va-'ke\text{\textacute{a}}va-'ko\text{\textacute{a}}va-'ko\text{\textacute{a}}va-'ko\text{\textacute{a}}va-'ka\text{\textacute{a}}va] )</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Neutralization only applies among the stressed vowels, unstressed vowels are spared, since their realization is not affected by prominence constraints, (16).
ESC: Preservation of the high-mid contrast in stressed long vowels

<table>
<thead>
<tr>
<th>[kavi-'kavi-'kavu-'kave-'kava-'kavo-'kava]</th>
<th>MINDist F1:2 OR MINDist F2:2</th>
<th>*MERGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. [kave-'kava-'kavo-'kava]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. [kavi-'kavi-'kavu-'kava-'kavo-'kava]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The analysis of neutralization argued for here views neutralization within a prominent position as arising in the Evaluation from the effects of metrical prominence requirements in the Realization. It is shown how a prominence-conditioned process such as the lowering of stressed vowel high and mid can affect the contextual distribution of contrasts which are evaluated in the Evaluation.

We show how the pattern of vowel neutralization in the Zabiče dialect of Slovene can be analyzed within the current proposal, and crucially by the exact same mechanisms which trigger the blocking of neutralization in the same contexts.

Zabiče dialect of Slovene has a further phonological process, which belongs to the class of processes analyzed in the following section, namely the preservation of the length contrast in stressed position, and the neutralization of that contrast in stressless vowels. The analysis of this process is only sketched here. Neutralization of the length contrast in stressless vowels is analyzed as the consequence of long vowel shortening in this position, which is enforced by a markedness constraint penalizing long stressless vowels. The shortening of long vowels decreases the distinctiveness between long and short vowels, yielding contrast neutralization.

The contrast between long and short vowels is derived in the Inventory, as shown in (17). Subscripts indicate vowel duration in arbitrary duration units. The MINDist constraint which penalizes non-distinct durational contrasts forms a disjoint constraints with MINDist F1:2 or MINDist F2:2, MINDist F1:2 or MINDist F2:2 or MINDist [dur]:0.02, in the derivation of the full vowel inventory of Zabiče Slovene.

(17) Zabiče Slovene vowel inventory (long vowels)

| a. |
|----------------------------------|-----------------|------------------|
| a. 0.005–a.0.13                  | MINDist [dur]:0.02 | Maximize Contrasts | MINDist [dur]:0.04 |
| b. a.0.13                        |                  |                  | *                |
| c. a.0.095                       |                  |                  | *                |

Long stressless vowels are shortened, (18). The shortening of long vowels in this position is enforced by the markedness constraint UNSTRESSED VOWELS ARE SHORT (Flemming, 2004), a place-holder for constraints which require unstressed vowels to be shorter than stressed vowels.

(18) Realization: long stressless vowels

<table>
<thead>
<tr>
<th>/kava:0.13ta/</th>
<th>UNSTRESSED VOWELS ARE SHORT</th>
<th>IDENT Vdur</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. 0.13</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>b. 0.11</td>
<td>*</td>
<td></td>
</tr>
</tbody>
</table>

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The neutralization of the length contrast in unstressed position is attributed to the decrease in distinctiveness between long and short vowels along this dimension, (19). A low-ranked constraint banning long vowels, *LONG V, determines the output of the neutralization process to be shorter vowel of the contrasting set, (c).

Evaluation: Neutralization of the length contrast in stressless position

<table>
<thead>
<tr>
<th></th>
<th>MinDist</th>
<th>*MERGE</th>
<th>*LONG V</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. [kavao.11ta-'kavao.095]</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
</tr>
<tr>
<td>b. [kavao.095ta]</td>
<td><img src="image4.png" alt="Image" /></td>
<td><img src="image5.png" alt="Image" /></td>
<td><img src="image6.png" alt="Image" /></td>
</tr>
<tr>
<td>c. [kavao.095ta]</td>
<td><img src="image7.png" alt="Image" /></td>
<td><img src="image8.png" alt="Image" /></td>
<td><img src="image9.png" alt="Image" /></td>
</tr>
</tbody>
</table>

6.2.1 Summary

This section had presented a pattern of stress-conditioned contrast neutralization through the case study Zabiče Slovene. The proposed analysis is that the contrast between high and mid vowels in this language indirectly arises from the need to enhance the perceptual energy of short vowels under stress. Whereas long and short low vowels can reach the required energy threshold by simply lengthening their duration, short high and vowels are enforced to lower in addition to lengthening.

This case study more generally presents the schema of the formal analysis of stress-conditioned neutralization adopted in this dissertation. The proposal is that this pattern arises when direct and indirect effects of prominence constraints (\( \hat{V}_{Energy} \geq X, \hat{I}_{dur} \geq X \) and *FAST \( \nu P_{SG} \)) affect the phonetic realization of segments in stressed position, i.e. through the processes analyzed in Chapter 5, and these effects decrease the contextual distinctiveness of contrasts among of surface forms. This account of stress-conditioned neutralization incorporates the formal elements of the analysis of direct and indirect effects of prominence on prominent positions, developed in Chapter 5, with Flemming's (2004, 2006) model of positional neutralization.

The constraint ranking which derives the full pattern of stress-conditioning in the vowel system of Zabiče Slovene is presented in Figure 6-1 (a) and (b).
Figure 6-1: Zabiće: Full ranking of constraints in the Inventory and Evaluation (a) and Realization component (b)
6.3 Stress-conditioned contrast preservation in Copala Trique

This section presents the analysis of the pattern of preservation of a contrast within a prominent position, which is otherwise neutralized in non-prominent positions.

The stress-conditioned preservation of segmental contrast consonants in Copala Trique (Hollenbach, 1977; Beckman, 1998; Smith, 2002; González, 2003) is analyzed here as indirectly arising from the effect of $\hat{\text{V}}_{\text{Energy}} \geq X$ and *FAST vP$_{SG}$ constraints on the realization of consonants in pre-tonic position. It is proposed that the phonetic properties of pre-tonic stops are affected by the need to increase the loudness of the following stressed vowel. The consonants are affected in a way which increases the auditory distance between fortis and lenis stops in pre-tonic position. In pre-atomic position, prominence constraints do not affect the realization of the stressed vowel, therefore also effects of *FAST vP$_{SG}$ are absent from this position.

The voicing contrast in stops and fricatives is described as a contrast between fortis and lenis. Fortis consonants are voiceless and lengthened; stop are unaspirated. Lenis consonants are usually voiced, but in unstressed position they can be either voiced or voiceless. The consonantal inventory of Copala Trique is given in (20), adopted from Hollenbach (1977). The language contrasts long and short vowels; the eight vowels of Copala Trique are given in (21). Vowel length contrast is specified in the inventory as a difference along the auditory dimension of length, [V dur]. The neutralization of the length contrast among high vowels is beyond the scope of this analysis.

(20) Consonants in Copala Trique (Hollenbach, 1977: 36)

<table>
<thead>
<tr>
<th>plosive</th>
<th>labial</th>
<th>alveolar</th>
<th>post-alveolar</th>
<th>retroflex</th>
<th>palatal</th>
<th>velar</th>
<th>glottal</th>
</tr>
</thead>
<tbody>
<tr>
<td>fricative</td>
<td>p b</td>
<td>t d</td>
<td></td>
<td></td>
<td>k g</td>
<td></td>
<td></td>
</tr>
<tr>
<td>flap</td>
<td>s z</td>
<td>f 3</td>
<td></td>
<td></td>
<td>$s$</td>
<td></td>
<td>h</td>
</tr>
<tr>
<td>nasal</td>
<td>m n</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>liquid</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>j</td>
</tr>
<tr>
<td>approximant</td>
<td>w</td>
<td>a</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(21) Vowels in Copala Trique (Hollenbach, 1977: 41)

- i: u:
- e a e: o:
- a

(22) Inventory: Length specifications of vowels

<table>
<thead>
<tr>
<th>Vowel</th>
<th>[V dur]</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>1</td>
</tr>
<tr>
<td>V:</td>
<td>2</td>
</tr>
</tbody>
</table>

Fortis stops and fricatives, affricates and laryngeals are restricted to the stressed syllable (Hollenbach, 1977: 36), the other consonants occur both in stressed and in unstressed position. The contrast between fortis and lenis is thus usually neutralized in unstressed syllables, and neutralization is only blocked in pre-tonic position. Examples showing the distribution of the contrast are given in (23). More data is provided in the typological description in Chapter 3.

(23) Fortis/lenis contrast in San Juan Copala Trique (Hollenbach, 1977: 36)
a. Contrast in stressed syllables

[a.ˈga?³]  'metal'
[da.ˈka³]  'crest’ (of bird)

b. Neutralization in unstressed syllables

[go.ˈpa³²] *[ko.ˈpa]  ‘goblet’
[ba.ˈsyə³²] *[pa.ˈsyə]  'to take a walk'

The result of neutralization Copala Trique is described as a segment whose auditory properties lie in between those of the two contrasting segments. Lenis consonants are described by Hollenbach as being not always fully voiced in non stress-adjacent position (p. 36), fortis consonants on the other hand are reported to lengthen before a short, stressed vowel (Hollenbach, 1977:37).

Fortis consonants are produced with greater muscular force than lenis (Ladefoged and Maddieson, 1996; Kirchner, 1998); in the feature system of Chomsky and Halle (1968) the contrast between this consonants is between [+tense] and [-tense]. A fortis gesture facilitates the maintenance of an occlusion (or partial constriction, in the case of fricatives), for this reason fortis consonants are frequently described as long (Kirchner, 1998: 56). The fortis constriction is produced with a greater overall tensing of the vocal tract walls, and with a greater effort cost than lenis. We show here that the neutralization of the lenis-fortis contrast results from the partial loss of the length and voicing contrast, and therefore from a decrease in distinctiveness between the two consonants classes. In pre-tonic position, indirect effects of prominence requirements on the consonant realization enhance the perceptual distinctiveness of the contrast between fortis and lenis, resulting in the preservation of the contrast in this position.

This analysis can be formalized as follows. We will assume three auditory dimensions along which the contrast between lenis and fortis consonants is established; these are the duration of the segment, [dur], and the duration of voicing [voice], and the degree of tenseness of the vocal tract, [tense]. We follow Flemming (2004) in defining the [voice] dimension as the intensity of the periodic part of the speech signal: underlying lenis and fortis consonants lie on the extremes points of this dimension ([voice:1] and [voice:0], respectively). The specifications of lenis and fortis consonants along these three dimensions are defined in the Inventory of the language. The idealized representation of the contrast, based on the description of the sounds in the language, is reported in (24).

(24) Inventory: the specification of lenis and fortis consonants

<table>
<thead>
<tr>
<th>Segment</th>
<th>[dur]</th>
<th>[voice]</th>
<th>[tense]</th>
</tr>
</thead>
<tbody>
<tr>
<td>fortis</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>lenis</td>
<td>0.5</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

The preference to maximize the number of distinctive contrasts, and the threshold of distinctiveness are set in the Inventory component by the interaction of the constraints on constrast, MINDIST, and MAXIMIZE CONTRASTS. The system of contrasts in (24) is derived by the constraint ranking in (25). The ranking of MINDIST= [voice]:1 below MAXIMIZE CONTRASTS is justified by the preservation of the lenis-fortis contrast even in contexts in which only a smaller distance between the two segments is available, e.g. in consonant clusters.

(25) MINDIST= [dur]:0.5, MINDIST= [tense]:1

⇒ MAXIMIZE CONTRASTS

⇒ MINDIST=[voice]:1, MINDIST= [dur]:1, MINDIST= [tense]:2
In the Realization component of the grammar, the segments from the inventory are mapped into strings, based on a ranking of correspondence constraints and markedness constraints. We adopt two families of articulatory markedness constraints in the Realization. The constraint, *\[TENSE\] penalizes the occurrence of consonants whose articulation involves some degree of tensing of the vocal tract, \((26)a\). This constraint is an instance of a more general constraint or family of constraints against articulatory effort. The constraint *\[VOICE\] is also an articulatory effort constraint, penalizing obstruents with sustained voicing: this is a gradient constraint which distinguishes between fully voiced, [voice:1], partially devoiced, [voice:0.5] and voiceless [voice:0], \((26)b\). Faithfulness constraints require the faithful realization of the auditory targets specified in \((22)\) and \((24)\). The number of violation marks is calculated as the departure of the output realization from the underlying specification, in steps of 0.5. The tableaux in \((27)\) show a constraint ranking which derives the phonetic realization of lenis and fortis consonants in the Realization. The phonetic detail of the possible candidates is specified in form of superscripts following the consonant. Lenis consonants can have a variable degree of voicing, and fortis consonants can be more or less tense; e.g \([b^{0.5}]\) is a partially devoiced lenis /b/.

\begin{align*}
(26) & \quad a. \quad *\[TENSE:1.5\] \gg *\[TENSE:1\] \gg *\[TENSE:0.5\] \gg *\[TENSE:0\] \\
& \quad b. \quad *\[VOICE:1\] \gg *\[VOICE:0.5\] \gg *\[VOICE:0\]
\end{align*}

\begin{align*}
(27) \quad & \text{Realization: lenis and fortis stops and fricatives in pre-atomic position}
\end{align*}

<table>
<thead>
<tr>
<th>/pamag\ah/</th>
<th>*[VOICE:1]</th>
<th>IDENT [VOICE]</th>
<th>*[VOICE:0.5]</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. 'pamag\ah</td>
<td>*!</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. 'pamako\ah</td>
<td>*!</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. 'pamak'0.5\ah</td>
<td>*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>/pamak\ah/</th>
<th>*[TENSE:1]</th>
<th>IDENT [TENSE]</th>
<th>*[TENSE:0.5]</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. 'pamak\ah</td>
<td>*!</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. 'pamako\ah</td>
<td>*!</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. 'pamak'0.5\ah</td>
<td>*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Stress is final in Copala Trique. The acoustic properties of stops and fricatives are different when these occur in pre-tonic position. In this position, the phonetic realization is determined by the interaction of the constraints in \((27)\) with metrical constraints enforcing the prominence of the stressed vowel \((\hat{V}_{\text{Energy}} \geq X)\). The relative ranking of these constraints determines the minimum required perceptual energy of the stressed vowel. We hypothesize that the prominence of a short vowel is 9 (as approximated for English in Chapter 4), and the prominence of a long vowel 15. As in the cases of phonetic enhancement analyzed above, the satisfaction of the high ranked prominence constraints triggers the phonetic enhancement of adjacent consonants, in Copala Trique the greatest effect is observed in pre-tonic position. The constraint ranking in \((28)\) derives the blocking of prominence enhancement through vowel lengthening, and yields phonetic enhancement through the action of the aerodynamic constraint. The results of increasing subglottal pressure during the articulation of the pre-tonic consonant results in a sharper burst, and in the enhancement of the degree of tenseness, as discussed in Chapter 3. Fortis fricatives and fortis obstruents are therefore more tense in pre-tonic position, than when they occur far from stress. The tableaux in \((29)\)
and (30) show the derivation of the phonetic realization of lenis and fortis consonants in pre-tonic position.

(28) \*FAST vP\textsubscript{SG} \gg \dot{V}_{\text{Energy}} \geq 9 \gg \dot{V}_{\text{Energy}} \geq 15 \gg \text{IDENT V}_{\text{dur}} \gg \text{IDENT C}

The derivation of phonetic enhancement in Copala Trique is virtually identical to the derivation of the same pattern analyzed in Chapter 5 in Maori. The tableaux in (29) shows that in order to attain the required prominence on the final stressed vowel, the subglottal pressure has to be increased during the duration of the preceding consonant. Failure to do so incurs a violation of the high ranked aerodynamic constraint (a). The increased level of subglottal pressure during the production of the lenis consonant increases the loudness of the burst, and the tenseness of the vocal tract, (d). Lenis stops are partially devoiced, the derivation of partial devoicing is triggered by the constraint \*[^{\text{VOICE}}:1] ((27)), although it is not included in these tableaux. The derivation is similar for both long and short stressed vowels, since both prominence constraints outrank the correspondence constraints, (28). The relative ranking of \*FAST vP\textsubscript{SG} and markednes constraints penalizing tense vocal tracts determines the success of a candidate with increase tenseness (d).

The first superscript of the consonant refers to the degree of voicing, the second one to the degree of tenseness (e.g. \texttt{g}^{0.5,0} = [\text{TENSE}]:0.5 and [\text{TENSE}]:0). Subscripts to the stressed vowels indicate their perceptual energy (e.g. \texttt{V}_{17}=\dot{V}_{\text{Energy}}: 17).

(29) Realization: lenis stops in pre-tonic position

<table>
<thead>
<tr>
<th>/daga/</th>
<th>*FAST vP\textsubscript{SG}</th>
<th>\dot{V}_{\text{Energy}} \geq 15</th>
<th>\text{IDENT V}_{\text{dur}}</th>
<th>\text{IDENT C}</th>
<th>*[^{\text{TENSE}}:0.5]</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>dag\textsuperscript{0.5,0} a\textsubscript{15}</td>
<td>*!</td>
<td>*!</td>
<td>*!</td>
<td>*!</td>
</tr>
<tr>
<td>b.</td>
<td>dag\textsuperscript{0.5,0} a\textsubscript{9}</td>
<td>*!</td>
<td>*!</td>
<td>*!</td>
<td>*!</td>
</tr>
<tr>
<td>c.</td>
<td>dag\textsuperscript{0.5,0} a\textsubscript{15}</td>
<td>*!</td>
<td>*!</td>
<td>*!</td>
<td>*!</td>
</tr>
<tr>
<td>d.</td>
<td>dag\textsuperscript{0.5,0} a\textsubscript{17}</td>
<td>*!</td>
<td>*!</td>
<td>*!</td>
<td>*!</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>/dagar/</th>
<th>*FAST vP\textsubscript{SG}</th>
<th>\dot{V}_{\text{Energy}} \geq 17</th>
<th>\text{IDENT V}_{\text{dur}}</th>
<th>\text{IDENT C}</th>
<th>*[^{\text{TENSE}}:0.5]</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>dag\textsuperscript{0.5,0} a\textsubscript{17}</td>
<td>*!</td>
<td>*!</td>
<td>*!</td>
<td>*!</td>
</tr>
<tr>
<td>b.</td>
<td>dag\textsuperscript{0.5,0} a\textsubscript{15}</td>
<td>*!</td>
<td>*!</td>
<td>*!</td>
<td>*!</td>
</tr>
<tr>
<td>c.</td>
<td>dag\textsuperscript{0.5,0} a\textsubscript{17}</td>
<td>*!</td>
<td>*!</td>
<td>*!</td>
<td>*!</td>
</tr>
<tr>
<td>d.</td>
<td>dag\textsuperscript{0.5,0} a\textsubscript{17}</td>
<td>*!</td>
<td>*!</td>
<td>*!</td>
<td>*!</td>
</tr>
</tbody>
</table>

The tableaux in (30) shows the same pattern of phonetic enhancement in words with pre-tonic fortis consonants. The underlying tense consonants are further tensed in order to increase the prominence of the stressed vowel.

Superscript refer to the degree of tenseness (e.g. \texttt{k}^{0.5} = [\text{TENSE}]:0.5). As above, subscripts to the stressed vowels indicate their perceptual energy (e.g. \texttt{V}_{17}=\dot{V}_{\text{Energy}}: 17).

(30) Realization: Fortis stops in pre-tonic position
We have shown how lenis and fortis consonants are phonetically realized in different prosodic contexts. Effort constraints reduce the degree of tenseness of fortis consonants in non stress-adjacent position. The action of the high ranked aerodynamic constraints silences the requirement of *[TENSE] constraints, enforces an increase of vocal fold tenseness in both lenis and fortis pre-tonic consonants. The Evaluation component assesses the distinctiveness of contrasts based on the phonetic realizations in (27), (29) and (30). The ranking of MINDIST constraints in the Evaluation is the same as in the Inventory, and *MERGE occupies the same place in the ranking as MAXIMIZE CONTRAST, (25).

The contrast between lenis and fortis stops and fricatives is neutralized in intervocalic position, since it violates the distinctiveness constraint MINDIST=|tense|:1, (31). The outcome of the neutralization process is a lenis consonant: it emerges from the relative ranking of the two low ranked effort constraints *[TENSE:0.5] and *[VOICE:0.5].

The contrast is preserved in pre-tonic position: the distance between the two sounds along the auditory dimension [tense] is not decreased in this context, (32).

The first superscript of the consonant refers to the degree of voicing, the second one to the degree of tenseness (e.g. g⁰.⁵,⁰ = [VOICE]:0.5 and [TENSE]:0).

(31) Evaluation: Neutralization of the lenis-fortis contrast in pre-atomic position

(32) Evaluation: Preservation of the lenis-fortis contrast in pre-atomic position
6.3.1 Summary

The analysis of Copala Trique stress-sensitive consonant neutralization, demonstrates that the blocking of contrast neutralization in a metrically prominent position arises in the Evaluation from the prominence-triggered enhancement processes in the Realization component. Grammatical pressures to enhance the prominence of the stressed vowel $\dot{V}_{\text{Energy}} \geq X$, and indirect effects of loudness enhancement (*FAST vP$_{SG}$) yield the preservation of segmental contrasts which are neutralized elsewhere in the word, where prominence constraints are not active. We have shown that the pattern of contrast preservation naturally arises from the interaction of prominence constraints in the Realization, and distinctiveness constraints in the Evaluation, not from a special status of prominent positions with respect to the occurrence of segmental alternations. On the contrary, it is precisely the phonetic effects of prominence on the realization of segments in prominent positions which block the neutralization of segmental processes. We have also shown that the grammatical mechanisms deriving the preservation of contrasts in prominent positions are identical to the ones deriving the neutralization of contrasts under stress. The formal equivalence of the analysis of stress-conditioned contrast preservation, and stress-conditioned contrast neutralization emerges from a comparison between the analysis of Copala Trique, and the analysis of Zabiče Slovene.

The constraint ranking which derives the full pattern of stress-conditioning in Copala Trique is presented in Figure 6-2(a) and (b).

6.4 Summary

In this chapter we have proposed an account of stress-conditioned contrast neutralization, and stress-conditioned contrast preservation through the analysis of Zabiče Slovene and Copala Trique, and claimed that they are special instances of the processes analyzed in Chapter 5. Both patterns arise as indirect consequences of one of three grammatical pressures which affect the phonetic phonetic realization of segments in the Realization component.

The first two pressures are markedness constraints which enforce the prominence of a metrically strong position, $\dot{I}_{\text{dur}} \geq X$ and $\dot{V}_{\text{Energy}} \geq X$.

The third pressure is the markedness constraint which regulates the implementation of loudness enhancement on the stressed vowel (*FAST vP$_{SG}$).

The effects of these constraints on the realization of stressed positions affect the contextual evaluation of the segmental contrast. If the alternations triggered in the presence of stress decrease the distinctiveness between contrasting sounds, a pattern of contrast neutralization might arise, which is restricted to the stressed position. If on the other hand the alternations triggered in the Realization increase the distinctiveness between contrasting sounds, a pattern of contrast preservation might arise, which is restricted to the stressed position.

The analysis of Copala Trique is crucially distinct from previous accounts of stress-conditioned contrast preservation: the phonetic realization of consonants which fail to undergo neutralization is responsible for the lack of neutralization, not positional privilege. The alternative analysis presented here relies on the claim that contrast preservation in stressed positions arises from the the specific phonetic properties of segments in these positions, not to Positional Faithfulness effects. In the following chapter we provide experimental evidence to this claim.
Figure 6-2: Zabiče: Full ranking of constraints in the Inventory and Evaluation (a) and Realization component (b)
Chapter 7

Effect of stress on segmental contrast: experimental evidence from two case studies

7.1 Introduction

A central claim of this thesis is that the preservation of segmental contrasts within metrically strong positions exclusively results from markedness constraints enforcing the prominence of these positions ($I_{dur}$ $\geq$ $X$ and $V_{Energy}$ $\geq$ $X$), and from the acoustic side-effects of enhancing the loudness of the stressed vowel (*FAST $v_{PSG}$). This chapter provides the substantive basis of this claim. The experiments reported on in §7.2 show that enhancing the perceptual energy of the stressed vowel affects the phonetic realization of stress-adjacent consonants. These side-effects are of the sort described in Chapter 4. They affect the perceptibility of segmental contrast in a way which mirrors the phonological processes under analysis. Similarly, the experiment reported on in §7.3 shows that the precise nature of stress-conditioned durational enhancement can indirectly affect the perceptibility of a segmental contrast in ways which mirror the phonological distribution of that contrast in a language. The experiments also support the claim that the nature of the effects of stress on adjacent consonants is determined by the kind of prominence requirements which act upon prominent positions in the individual languages ($I_{dur}$ $\geq$ $X$, or $V_{Energy}$ $\geq$ $X$ or both).

It is impossible to provide acoustic analyses and in depth phonetic descriptions of the entire typology of processes analyzed in the two previous chapters. It is for the intrinsic limitations of the analysis of such a very large number of patterns, that we relied on the existing literature on the acoustic correlates of stress, and on the descriptions available in the original grammars for the analysis of most processes. This chapter presents the in depth study of two cases of preservation of consonantal contrast in stress-adjacent position. These studies are parallel to the phonological patterns analyzed in Chapter 5 and Chapter 6. It contains detailed phonetic descriptions and evidence from a perceptual experiment. These experiments are designed to investigate a small part of the large typology. Nevertheless, we claim that their results demonstrate that the present framework precisely accounts for the fine-grained properties of these phonological processes. They also provide experimental support to the validity of this model in accounting for the broader class of neutralization processes described in the previous chapter.
There are two grammatical requirements which can enforce the prominence of a metrically strong position, they are repeated in (1). As shown in the analyses presented in Chapter 5 and Chapter 6, either one, or both of these constraints can be active in the Realization component of a given language.

(1) Metrical requirements on strong positions:
   a. Metrical requirements on the duration of the stressed interval (\( \text{Idur} \geq X \));
   b. Metrical requirements on the perceptual energy of the stressed vowel (\( \text{VEnergy} \geq X \)).

The requirement in (1)a triggers the durational enhancement of segments within the stressed interval. The requirement in (1)b triggers an increase in either the duration, or the loudness of the stressed vowel, or both. Side-effects of the former requirement arise from restrictions on the displacement of subglottal pressure and affect the phonetic realization of pre-tonic and post-tonic plosives. Chapters 6 has shown how both grammatical pressures affect the contextual distribution of segmental contrast in some languages, specifically how they may condition contrast neutralization, or the preservation of contrasts in prominent positions.

This chapter tests whether the effects of the prominence requirements in (1) on the phonetic realization are such as to affect the distinctiveness of segmental contrasts in prominent positions. Experimental support for this claim is gathered through the investigation of two case studies.

The first case study presented here is the stress-conditioned neutralization of the contrast between velar stops and palatoalveolar affricates before high front vowels in the inflection of Italian nouns and adjectives. The contrast is neutralized across the board, but it is preserved exclusively in post-tonic position.

The second case study is the stress-conditioned neutralization of the contrast between voiceless alveolar stops and voiceless alveolar fricatives before high front vowels in the inflection of Finnish verbs. The contrast is always neutralized when the consonants occur far from stress, and it is preserved adjacent to stress.

The choice of these particular languages is motivated by the two distinct prominence requirements which are active in the two languages: in Italian metrical prominence is enforced by the metrical requirement in (1)b, in Finnish on the other hand, durational prominence, (1)a, is required.

Two specific hypotheses are tested here. First, the hypothesis that the nature of the prominence requirements active in the Realization gives rise to different phonetic effects of stress on the segments within a prominent position. We predict that in Finnish prominence requirements on segments within the stressed interval affect the durational properties of segments, whereas in Italian the increase of the perceptual energy of the stressed vowels has side-effects on the realization of burst properties of stress-adjacent plosives (of the sort discussed in Chapter 4). Second, the hypothesis that these phonetic effects affect the perceptibility of segmental contrasts, and therefore affect the phonological distribution of the contrasts in the two languages.

The first hypothesis is tested and supported by the acoustic analysis of the segments which participate in the phonological processes, in different prosodic conditions. This analysis compares the phonetic realization of stress-adjacent consonants, with the realization of consonants far from stress. We show that the extent to which acoustic properties of consonants are affected by prominence requirement is determined by the grammatical constraint which enforces prominence. The realization of stress-adjacent consonants in Italian is conditioned by stress: their burst properties are significantly distinct from properties of non stress-adjacent consonants. We show that these
differences are specifically of the sort that we have attributed to the side-effect of increasing the loudness of the stressed vowel. Stress-adjacent consonants in Finnish on the other hand, are only lengthened. The lack of a loudness increase on the stressed vowel in this language results in the lack of phonetic enhancement.

The second hypothesis is tested and supported by a discrimination experiment. The perception experiment tested the extent to which stress-conditioned acoustic properties of velar stops affect their similarity to palatoalveolar affricates. Subjects are presented with with pairs of [VCi] nonce words that are either the same or differ only as to the features of the consonant ([k] or [ʃi]), and they are asked to judge whether the words are the same or different from one another. Velar stops from two different prosodic conditions (post-tonic and far-from-stress) before /-i/, are compared with palatoalveolar affricates before /-i/.

The key result of this experiment is that the perceptibility of the contrast between velar stops and palatoalveolar affricates before /-i/ varies depending on the presence or absence of prominence-triggered effects on the realization of the consonant. Subjects very often confuse stops and affricates before /-i/, when they have the phonetic properties of consonants far from stress. The rate of confusion is significantly lower, when the velar stop is phonetically enhanced. The perceptual distance between the two sounds is therefore modulated by the indirect effects of loudness increase on their realization. Greater perceptual distinctiveness is found precisely in the context in which the contrast is preserved.

The results of the experiments presented in this chapter provide a substantial basis for the analysis of phonological processes which emerge from the side-effects of metrical requirements to enhance the prominence of the stressed domain. They provide support to the claim that the preservation of segmental contrast in stress-adjacent consonants arises as a side-effect of prominence-enhancement in these positions.

The stress-modulated hierarchy of perceptual distance between /ti/-/si/ and /ki/-/ʃi/ which emerges from the acoustic and the perceptual experiments projects a set of MINDIST constraints favoring neutralization of relatively weak contrasts. These constraints target the auditory dimensions that define the two contrasts.

The chapter is divided into two parts: in the first part we present the case study of stress-conditioned velar palatalization in Italian, §7.2; in the second part, we present the case study of stress-conditioned assimilation in Finnish, §7.3. The first case study begins in §7.2.1 introducing Italian velar palatalization, its phonetic characteristics and its distribution. The acoustic analysis of velar stops in different prosodic conditions is presented in §7.2.2. Section 7.2.3 lays out the prediction which the acoustic data leads us to make, about the effects of stress on the distribution of the /ki/-/ʃi/ contrast. The discrimination experiment testing these predictions is described in §7.2.4. The formal analysis of velar palatalization in Italian nouns and adjectives is developed in §7.2.5. The second case study begins in §7.3.1 introducing the acoustic correlates of Finnish stress, and the distribution of assimilation. Section 7.3.2 presents the acoustic analysis of stops in different prosodic conditions. The formal analysis of Finnish assimilation is developed in §7.3.3.
7.2 1. Case Study: Italian Palatalization

7.2.1 Introduction

The origins of velar palatalization in Romance languages are to be found in Late Latin and Proto-Romance, where palatalization occurred before all front vowels regardless of context, and where neither the position of stress, nor the morphological structure of the word play a role (Väänänen, 1967; Meyer-Lübke, 1901). In contemporary Italian we find traces of the Late Latin velar palatalization process, as shown in (2).

(2) Late Latin Velar Palatalization

<table>
<thead>
<tr>
<th>Trigger vowels</th>
<th>Late Latin</th>
<th>Pr.Rom.</th>
<th>It.</th>
</tr>
</thead>
<tbody>
<tr>
<td>'e', 'i'</td>
<td>a.[k]er</td>
<td>a.[f]er</td>
<td>a.'[t]er</td>
</tr>
<tr>
<td>Lat. 'de.[k]i.mus'</td>
<td>Pr.Rom.</td>
<td>'de.[f]i.mus'</td>
<td>It. 'de.[f]i.mo'</td>
</tr>
</tbody>
</table>

Stress conditioning no: the rule applies across the board
Voicing distinction no: Lat. 'k[i].nis' > Pr.Rom. '[f].i.nis' > It. '[f].e.ne.re' 'ashes'
Lat. '[g].e.nus' > '[d].e.nus' > It. '[d].e.ne.re' 'genre'
Morphological conditioning no: the rule applies across the board

It superficially looks like the phenomenon in Italian is a homogeneous continuation of the original, Late Latin process. I have argued (Giavazzi, 2009) that there are really two separable systems, the verbal and the nominal/adjectival one, which diverged one from the other, forming two independent and coherent domains in which palatalization applies, subject to very different conditioning factors. Considering Italian palatalization as one system consisting of the disordered remnants of the original system misses the regularities underlying two very distinct processes which arose from the restructuring of an originally unified phonological process. Traces of the Late Latin palatalization process in the contemporary language are found morpheme-internally, in the prevalence of palatoalveolars before front vowels (2); they are also found in alternations, (3) and (4). The tables below summarize the distribution of palatalization as it emerges when separating the two domains. In the nominal and adjectival inflection, we observe a change from the original process: first, palatalization is only triggered by the high front vowel /i/, second, the application context is further restricted, in that the masculine morpheme /-i/ does not uniformly trigger palatalization. The distribution of the process is conditioned by the position of stress.

(3) Palatalization in the nominal and adjectival domain

<table>
<thead>
<tr>
<th>Trigger vowels</th>
<th>Sg. [komiko], Pl. [komif[i]]</th>
<th>comic', Masc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sg. [komika], Pl. [komike]</td>
<td>'comic', Fem.</td>
<td></td>
</tr>
</tbody>
</table>

Stress conditioning yes: Sg. [ko.mi.ko], Pl. [ko.mi.[fi]] 'comic'
Sg. [an.'ti.ko], Pl. [an.'ti.ki] 'antique'

Voicing distinction no: Sg. [me.di.ko], Pl. [me.di.[fi]] 'doctor'
Sg. [fi.'lo.lo.go], Pl. [fi.'lo.lo.dji] 'philologue'

Morphological conditioning no: the rule applies to both nouns and adjectives

The picture looks very different in the verbal domain, (4), where the distribution of palatalization is very similar to the original pattern, in (2). The application of palatalization is predictable and subject to both paradigmatic and suffix specific constraints. The process is conjugation dependent: in the 1st conjugation palatalization is blocked; in the 2nd and 3rd conjugations palatalization before /i/ and /e/ applies if the palatoalveolar affricate is present in the infinitive form of the verb.

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4. Palatalization in the verbal domain

<table>
<thead>
<tr>
<th>Trigger vowels</th>
<th>e, i</th>
<th>Late Lat. [vinkere] &gt; [vindo]ere</th>
<th>‘to win’</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Lat. [sinkire] &gt; [sankfere]</td>
<td>‘to ratify’</td>
</tr>
<tr>
<td>Stress conditioning</td>
<td>no</td>
<td>Inf. [vindo]ere, 1Ps.Sg. [vin.ko], 2Ps.Sg. [vin.ifi]</td>
<td>‘to win’</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inf. [ta.‘fere], 1Ps.Sg. [taf:fo], [taf:fi]</td>
<td>‘to be silent’</td>
</tr>
<tr>
<td>Voicing distinction</td>
<td>no</td>
<td>Inf. [vindo]ere, 1Ps.Sg. [vin.ko], 2Ps.Sg. [vin.ifi]</td>
<td>‘to win’</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inf. [voldgere], 1Ps.Sg. [volgo], 2Ps.Sg. [voldfi]</td>
<td>‘to turn’</td>
</tr>
<tr>
<td>Morphological conditioning</td>
<td>yes</td>
<td>1st Conjugation (-are):</td>
<td>Inf. [pit:sikare], 1Ps.Sg. [pit:siko], 2Ps.Sg. [pit:siki]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2nd Conjugation (-ere), 3rd Conjugation (-ire):</td>
<td>Inf. [vin.tfe.re], 1Ps.Sg. [vin.ko], 2Ps.Sg. [vin.ifi]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inf. [kutfire], 1Ps.Sg. [kutfo], 2Ps.Sg. [kutfi] vs.</td>
<td>Inf. [arokire], 1Ps.Sg.[arokisco], 2Ps.Sg. [arokifi]</td>
</tr>
</tbody>
</table>

The morphologically conditioned application of palatalization in verbs is not discussed here; the present case study is about the first kind of velar palatalization in Italian, namely the stress-conditioned process found in the inflection of masculine nouns and adjectives. Palatalization only occurs in antepenultimate stressed words, and it is almost never attested in penultimate stressed words. It is therefore blocked in immediately post-tonic position, (5). This pattern looks very similar to the one of Copala Trique analyzed in Chapter 6. If we treat velar palatalization as the neutralization of the /ki/-/t/j/ contrast, Italian shows like Copala Trique a pattern of consonantal contrast preservation in stress-adjacent position, and the neutralization of the contrast elsewhere.

5. Stress-conditioned velar palatalization


The analysis of velar palatalization as a neutralization process is has been widely proposed in the literature. Guion (1996) investigates the perceptual roots of velar palatalization. Based on acoustic and perceptual analyses, the author concludes that the change from /ki/ to /t/j/ occurs because of the auditory similarity between the velar stop and the palatoalveolar affricate before a palatal vowel. The rate at which the sequence [ki] is misidentified by listeners as [fi] is much higher than the misidentification rate of [ka] as [fa]; the same holds for the voiced alternation, though to a lesser extent. This similarity has been analyzed by Ohala (1994) Guion (1996) as the cause of perceptual reanalysis by the speaker/hearer; similarly Wilson (2006) has proposed that the speaker/hearer gives up on the weak contrast, neutralizing it. A complication arises when trying to extend this claim to account for the distribution of velar palatalization in Italian, since palatalization only occurs in antepenultimate stressed words. Greater acoustic similarity between the velar and the palatoalveolar consonant is required than in other languages (e.g. Late Latin, where velar palatalization applied before front vowels, regardless of prosodic context), in order for the contrast to be neutralized. If the distribution of palatalization in Italian is also the result of a perceptually triggered neutralization, a link between prosodic conditioning context and acoustic realization should be established.

In the following sections, we demonstrate that Italian palatalization is a case of contrast preservation in stress-adjacent consonants, which arises from the side-effects of enhancing the loudness of the stressed vowel. The formal analysis of Italian, 7.2.5, is formally identical to the one proposed for Copala Trique in Chapter 6. The sections leading to the analysis present the results of
two experiments which give it empirical support. The aim of these experiments is to present the substantive base of the constraint families and the formal architecture adopted in the analysis of this specific process. More generally its aim is to demonstrate the validity of our model in accounting for the entire class of phonological processes which are indirectly conditioned by grammatical constraints on prominence.

The following two components of the analysis of stress-conditioned neutralization developed in the previous chapter are proven experimentally here. First metrical requirements which enforce the prominence of the stressed vowel have the predicted side-effects on the realization of stress-adjacent plosives, §7.2.2. Second, the indirect effects of loudness enhancement on the phonetic realization of consonants may affect the perceptual distinctiveness of consonantal contrast, resulting in the contextual preservation of the affected contrasts, §7.2.4.

7.2.2 Acoustic analysis

The acoustic analysis presented in this section tests the effects of stress position on the phonetic realization of stress-adjacent consonants. Specifically its effects on the realization of velar stops and palato-alveolar affricates which are either in post-tonic position, or not stress-adjacent are tested.

7.2.2.1 Background

As Krämer (2009: 2) writes as premise to his attempt at providing a systematic analysis of Italian phonology, the Romance spoken on the Italian peninsula displays remarkable regional variation in all areas of the grammar. Even within what is referred to as Italiano (as opposed to dialetto), there is great regional variation. Although the distribution of palatalization in the inflection of nouns and adjectives seems to be sensitive to the position of stress across regional varieties, there are two variable dimensions. First, the phonetic realization of palatalized velar stops is greatly variable across speakers and regions, ranging from a palatoalveolar affricate to an alveolar fricative. Second, some varieties diverge from Standard Italian in their placement of main stress; this affects the distribution of stress-conditioned palatalization across regional varieties. When referring to this process, we mean to describe palatalization as it is distributed within contemporary Standard Italian. Similarly, examples are taken from forms of Standard Italian.

Contemporary Standard Italian has twenty-two consonants. All stops and affricates display a voiceless and a voice cognate; the voicing distinction is contrastive. Voiced stops show vocal fold vibration, and voiceless stops are unaspirated. While stops and affricates have a full voicing distinction, this dimension of contrast is defective in fricatives. The voiced palatoalveolar fricative is given in brackets, since it occurs in a few loanwords only. All the consonants occur as long, and most of them as short as well. Except at the word boundaries, length is contrastive. The consonant inventory of Italian is given in (6). Additionally, Standard Italian has seven vowels in stressed position /i, e, a, o, u/, and a five vowel inventory of unstressed vowels /i, a, o, u/. The velar stops and palatoalveolar affricates are the subject of the acoustic study reported in the rest of this section.

(6) Italian: consonant inventory (Vincent, 1988:280)
Main stress in Italian occurs on one of the last three syllables. In the majority of words, stress falls on the penultimate syllable, but there are cases of antepenultimate and final stress. Several works tested the phonetic realization and the perception of lexical stress in Italian (among others, Bertinetto, 1981; Farnetani and Kori, 1982; Farnetani and Zmarich, 1997). Results show that stressed syllables entail longer mean durations than unstressed ones, higher values of intensity and can present F0 variations if sentence accents are associated with them. According to such works, duration would be the main acoustic cue of stress in Italian, while fundamental frequency would be related to accent. Avesani et al. (2007) conduct a study of how segmental variation is conditioned by prosody in Italian, by examining the acoustic and articulatory properties of stressed and stressless syllables. Results from this study show that different kinematic properties distinguish unstressed, stressed and accented syllables. Opening and closing gestures of syllables with higher prominence are longer, faster and more displaced. The authors suggest that these properties, together with the longer acoustic duration that distinguish less from more prominent syllables and vowels, are compatible with a strategy that enhances the intrinsic sonority of a segment.

The acoustic study presented here was conducted with the aim of investigating the acoustic effect of stress on the realization of adjacent velar stops. Specifically, the presence of phonetic enhancement in post-tonic position was investigated. In Chapter 4 we reviewed the results from the experimental literature on the phonetic correlates of stress, i.e. of the increased subglottal and glottal pressure centered on the production of a stressed vowel. Ladefoged (2004) suggests that in immediately post-tonic position, stress causes an increased pressure build-up behind the stop closure. The increase in pressure results in a rapid intensity fall after the transient.

We hypothesized that the rapid intensity drop would enhance the burst of the stop causing the /ki/ sequence to be more distinct from /ți/ than it would otherwise be.

Frication is defined here following Hanson and Stevens (2003) as that part of the stop release in which turbulence noise generated at the supraglottal constriction excites the cavity in front of the constriction; it does not include aspiration. We predict that a fast change in frication intensity characterizes stops in this prosodic position; the perceptual consequence of this acoustic property is a sound very distinct from an affricate, whose burst is generally very weak in Italian, and whose frication is evenly spread after the transient. The waveform in Figure 7-1 is an example of a token where the affricate is immediately post-tonic; as in most of the other tokens, there is no clear burst, and the affricate looks almost like a fricative in spite of the prosodic position in which it occurs.

The different realization of stops in different prosodic conditions is shown in the waveforms and schematized by the intensity contours in Figure 7-2: (a) shows the clear-cut burst of a representative
velar stop in immediately post-tonic position, (b) shows the more fricated burst of a velar stop which occurs far from stress.

The present hypothesis does not posit an increase in the overall intensity of the transient due to preceding stress; it only makes the prediction that the slope (i.e. rate of change) of the intensity contour will be steeper in the case of a stop consonant immediately following a stressed vowel, Figure 7-2(a). The alternative hypothesis, namely that an increase in peak intensity at the transient alone blocks neutralization in post-tonic position was also tested in the following acoustic analysis, but it did not receive experimental support.

7.2.2.2 Recordings and speech material

Five native speakers of Italian (age range 24-32; males) were recorded to collect the material for the acoustic analysis; they did not report any history of hearing or speaking impairment. The speakers recorded in this study came from Turin (2), Milan (2) and Venice (1); Standard Italian was their first language.

The speakers were recorded reading the sentences in a sound attenuated booth; they were asked to read sentences of Italian from a computer screen. Each sentence consisted of a target word in a randomly varied carrier sentences. The carrier sentence had the form in (7).

(7) He V pseudo-word [prepositional phrase].

The verb was in the passato remoto, a past perfective tense which requires the inflectional suffix to be stressed (e.g. portó 'carry'-3PSg-passato remoto), this choice was made as an attempt to minimize the effect of secondary stress on the following pseudo-word. Examples of three carrier sentences are given in (8).

(8) Carrier sentences: examples
    Ordinó X per cena. 'He ordered X for dinner'
    Sbucció X per la zuppa. 'He peeled X for the soup'
    Spedí X per posta. 'He sent X by mail'
The speech materials consisted of 48 quadri-syllabic pseudo Italian words containing the sequence /-ki-/ word-medially and 48 pseudo-Italian words containing the sequences /-tʃi-/ word-medially. Words were created in pairs: one block contained two stress conditions in two pseudo-words formed by a permutation of the same 4 syllables. The materials therefore contained 24 blocks of the velar stop category, and 24 blocks of the palatoalveolar affricate category, the two categories formed minimal pairs which only differed for the target consonant-/i/ sequence. A schematic representation of the materials is given in (9). The material also contained 48 filler sentences, which were identical to the testing sentences but contained different stop consonants in the relevant positions of the target words (/t/, /d/, /g/). The position of stress was clearly marked on each target word. Given that the reading task was not easy, speakers were given 10 practice sentences and they were asked to read them out loud before starting the recording session.

(9) Schema of the recording materials:

<table>
<thead>
<tr>
<th>Stress condition</th>
<th>/ki/</th>
<th>/tʃi/</th>
</tr>
</thead>
<tbody>
<tr>
<td>post-tonic</td>
<td>CV.CV.ki.CV</td>
<td>CV.CV. tʃi.CV</td>
</tr>
<tr>
<td>far-from-stress</td>
<td>CV.ki.CV.CV</td>
<td>CV. tʃi.CV.CV</td>
</tr>
</tbody>
</table>

Examples of minimally contrasting target words within a block are given in (10); a complete list is provided in Appendix 1.
### 7.2.2.3 Measurements

The sound files were recorded at a sampling rate of 44.1 kHz and imported into Praat (Boersma and Weenink, 2010) for analysis. Several aspects of each target consonant were measured: closure duration, burst duration, burst to closure ratio, and loudness of the burst at the transient, slope of the intensity contour between the transient and the frication. Duration measurements were obtained through segmentation of the waveform, with reference to the spectrogram. Closure duration is measured from the end of the last period of voicing in the preceding vowel, to the transient. Burst duration is measured from the release of the closure at the transient, to the onset of periodicity in the following vowel. The loudness of the burst at the transient is the peak intensity value at the release of the closure. Figure 7-3 shows how the intensity slope was measured: it was calculated from the point of peak intensity at the transient, and the first minimum intensity point in the frication part of the release. Two sample intensity profiles from a velar stop in different prosodic conditions is shown in Figure 7-4.

![Schematic representation of the measured intensity slope](image)

**Figure 7-3:** Schematic representation of the measured intensity slope

The spectra in Figure 7-5 and Figure 7-6 give an example of a velar stop and a palatoalveolar affricate in the two different prosodic positions, and the relative measuring points.

### 7.2.2.4 Results

This section reports the results of acoustic analysis of Italian velar stops and palatoalveolar affricates before a high front vowels, in two prosodic conditions, far from stress, and post-tonic. Some tokens could not be measured. Tokens were excluded either if the speaker accidentally touched the microphone while talking, or interrupted himself while reading, or read the word by placing the stress on the incorrect vowel.

The durational measures of closure duration and burst duration are presented first. The duration of velar stops is not dependent on their prosodic context, Figure 7-7(a). Velar stops in post-
Figure 7-4: Intensity profile of velar stops in different prosodic positions: (a) intensity (dB) during closure and burst of /k/ in one token of /bokibóra/; (b) intensity (dB) during closure and bursts of /k/ in one token of /matkipo/. Dotted lines indicate the maximum intensity level at the transient, and the first intensity minimum in the frication part of the release.

tonic position have the same duration as velar stops which occur in a post-atomic (far from stress) context \( t(70)=0.1842, P=0.8544 \). This result confirms the findings of Payne (2005): whereas geminate consonants in Standard Italian are longer when they occur in stress adjacent position (pre-tonic, and post-tonic), than non stress-adjacent geminates, the duration of singleton stops and fricatives is not found to vary with prosodic context. On the contrary, palatoalveolar affricates are slightly longer when they occur far from stress, \( t(70)=0.8114, P=0.4891 \). The duration of affricates in the two different prosodic contexts is illustrated in Figure 7-7(b). Affricates were not present in Payne study, so we do not have a comparison for our results on these segments. The duration of affricates varies greatly. In some tokens they are produced as fricatives, see for example the spectrogram in Figure 7-1, these tokens are often longer than their affricated counterparts, especially when far from stress.

There was a tendency both among the stops and among the affricates, for closure duration to be systematically longer in post-tonic segments than in segments far from stress. Among the velar stops, the slight increase in closure duration did not cause a significant increase in the overall duration of the segment: the burst/closure ratio was therefore slightly bigger in the far from stress
condition, Figure 7-8(b). Among the affricates, there was a large increase in closure duration in post-tonic position, or more precisely a smaller number of fricativized affricates. Stress-adjacent affricates have both a longer closure, and are overall slightly shorter than the fricatives produced far from stress.

We also observed stress-conditioned differences in the domain of intensity. Specifically, we collected two measures of intensity: the peak of intensity in the transient, at the release of the burst, and the slope of the intensity profile from the transient into the frication noise. There was no effect of prosodic condition on the intensity peak at the transient, as shown in Figure 7-9. Contrary to what we had expected, intensity was not found to be higher in immediately post-tonic position. The presence of a presumed higher subglottal pressure during the consonant closure did not yield an increased peak intensity. It did however affect the sharpness of the burst of velar stops. As it is also apparent from the example of waveform in Figure 7-4, intensity drops very quickly into a quiet frication noise in post-tonic position, and it drops more gradually in non stress-adjacent position. A linear regression analysis was run to look for an effect of stress on the rate of change of the intensity slope in the velar stop: it indicated an effect of prosodic condition on the intensity contour $[F(3,103), p<0.0001]$: a steeper slope of the intensity contour was found in the release of a stop consonant that is preceded by a stressed vowel, compared to a stop that is far from stress. The difference between coefficients of the two slopes is illustrated in Figure 7-10.

A similar analysis could not be carried out for the affricates, since a clear transient was not often visible (see e.g. Figure 7-1). For those tokens in which the same measurement could be made the intensity slope was not significantly different from 0. Although an analysis of more speakers might reveal an effect of stress on the realization of the affricate burst, these preliminary results

Figure 7-5: (a) /oki/ from /pokitima/; (b) /iki/ from /matikipo/; visible parts are 0.180s long. Arrows indicate the beginning of closure, the beginning, and the end of the burst, as they were measured for all tokens.
suggest that the frication in affricates is homogeneously spread after the transient, without a sharp burst marking its beginning.

### 7.2.2.5 Summary

We collected four measurements of acoustic properties of velar stops and palatoalveolar affricate in two distinct prosodic positions, post-tonic segments, and post-tonic segments. The table in (11) summarizes our findings.

#### (11) Italian: Acoustic analysis (means across subjects)

<table>
<thead>
<tr>
<th></th>
<th>Velar Stops</th>
<th>Palatoalveolar affricates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Post-tonic</td>
<td>Far from stress</td>
</tr>
<tr>
<td>Total duration</td>
<td>0.136s</td>
<td>0.135s</td>
</tr>
<tr>
<td>Burst/Closure ratio</td>
<td>0.820</td>
<td>0.932</td>
</tr>
<tr>
<td>Peak intensity</td>
<td>49.04dB</td>
<td>48.08dB</td>
</tr>
<tr>
<td>Intensity slope</td>
<td>1518.82 dB/s</td>
<td>992.42 dB/s (*** )</td>
</tr>
</tbody>
</table>
Figure 7-7: Total segmental duration: velar stops (a), and palatoalveolar affricates (b). Duration in seconds, averages across subjects. Error bars indicate the 95% confidence interval.

![Velar stops: Total duration](image)

![Affricates: Total duration](image)

(a)  
(b)  

Figure 7-8: Ratio of burst to closure duration. Velar stops (a) and palatoalveolar affricates (b)

7.2.3 Discussion

The acoustic analysis shows that the presence of immediately preceding stress has an effect on the realization of the stop consonant. We observed differences both along the dimension of burst/closure duration, and along the dimension of the intensity slope. More precisely, post-tonic segments have longer closure duration than segments that are far from stress; post-tonic velar stops also have an increased intensity slope compared to stops that are far from stress.

If /ki/ and /tfi/ are neutralized when they are not in post-tonic position, it must be the case that stress-adjacent velar stops and palatoalveolar affricates are distinct enough to block neutralization from eliminating their contrast. There must therefore be one or more auditory dimension which is affected by the position of stress, and which determines the preservation of post-tonic velars. Figure 7-11 provides a schematic illustration of the effects of prosodic condition on the auditory distance between /ki/ and /tfi/, for the four dimensions under analysis. It shows that among them, the slope of intensity at the burst is mostly affected by the presence of a preceding stressed vowel. In post-tonic position, velar stops are produced with a sharp burst, and an abrupt intensity drop; in this position, stops look very different from their affricate counterpart.

I will show that acoustic properties of the transient such as the slope of the intensity contour
determine the distribution of palatalization in the language. This effect of stress on the phonetic realization of post-tonic obstruents is argued to arise as an indirect effect of constraints enforcing the high perceptual energy of the stressed vowel. In spite of the fact that intensity slope could not be measured exactly in palatoalveolar affricates, careful examination of the spectrograms revealed that a clear burst is missing very frequently, and that when it is present, the intensity slope is not significantly different from 0. The process observed here is part of the more general tendency of affricates to become fricatives in Italian, which is attested in many dialectal varieties (e.g. dialect of Rome). The shallow slope observed in non-stress-adjacent velar stops makes the stops in this prosodic condition similar to an affricate: the contrast between the two sounds is marked and therefore prone to neutralization. It is also plausible that further acoustic properties, are responsible for making post-tonic velars distinct from affricates. Future research will look into these two matters, which will hopefully complete the proposed account. The next section looks in particular at the extent to which stress conditioned differences in the intensity profiles of velar stops can modulate the confusability between velar stops and palatoalveolar affricates. It presents the results from a
discrimination study which was conducted to assess whether acoustic consequences of primary stress on neighboring segments, e.g. differences in intensity slope of the sort observed in our data, are indeed perceptible to listeners.

7.2.4 Perceptual experiment

7.2.4.1 Background

We present an experiment aimed at determining whether indirect effects of loudness enhancement on the phonetic realization of stress-adjacent velar stops indeed affect their confusability with palatoalveolar affricate. The experiment is located within a long tradition of studies on the perceptual roots of velar palatalization. Velar palatalization is a very frequently documented sound changes (Bloomfield, 1933; Chen, 1973; Bhat, 1978; Hock, 1991), but there is no consensus on how the sound change happens. The process is viewed by some as articulatorily motivated (Sievers 1876, Grammont 1933, Bhat 1978, Hock 1986, Antilla 1989; Keating and Lahiri, 1993; Ladefoged, 2001; Butcher and Tabain, 2004). Keating and Lahiri (1993) review X-ray and other articulatory evidence of this fronting effect in English and other languages. A perceptual account for the change has been first explicitly suggested by Ohala (1989), but the plausibility of a perceptual basis of velar palatalization had been recognized even in earlier literature. Winitz et al. (1972) and Repp and Lin (1989) show that a velar stop before a front vowel is often inaccurately perceived as a coronal, providing evidence that the sound change from a velar to coronal or to a palatoalveolar may have a perceptual basis. Burst and aspiration noise of a velar before a front vowel are perceptually similar to that of a coronal before front vowel. This perceptual similarity also correlates with acoustic findings (Guion 1996): fronted velars are have a peak spectral frequency of the burst similar to the peak spectral frequency of [f] and [c]; also, the formant transitions of velars before
front vowels are more similar to dentals/alveolars than the formant transitions of velars before back vowels. Guion (1996) investigates the perceptual roots of velar palatalization. The author brings new experimental support from acoustic and perceptual analyses, to the claim that the change from /ki/ to /ʧi/ occurs because of the auditory similarity between the velar stop and the palatoalveolar affricate before a palatal vowel. She shows that the rate at which the sequence [ki] is misidentified by listeners as [ʧi] is much higher than the misidentification rate of [ka] as [ʧa]; the same holds for the voiced alternation, though to a lesser extent. This similarity is cause of perceptual reanalysis by the speaker/hearer. Wilson (2006) has proposed a similar model of the phonological change, in which the speaker/hearer neutralizes the weak contrast.

The experiment presented in the following sections shows that stress-conditioned acoustic properties of the velar stops bursts such as the ones described in §7.2.2 can modulate the confusability of the /ki/-/ʧi/ contrast.

### 7.2.4.2 Hypotheses

The phonetic realization of velar stops in Italian is conditioned by their position relative to stress. Stops which are not adjacent to stress are characterized by a shallow intensity profile, and therefore by a spread frication noise. Velar stops in post-tonic position on the other hand, are characterized by a very steep intensity drop between the transient and the frication phase of the release, and thus by a sharp burst with low intensity frication noise. Non stress-adjacent velar stops are acoustically similar to palatoalveolar affricates in the same prosodic condition. We find that the contrast between velar stops and affricates is neutralized in Italian, precisely in those contexts in which the stop burst is weakest, and most similar to an Italian affricate. The combination of these two observations leads us to make the following hypothesis: velar stops and palatoalveolar affricates which are not stress adjacent are less perceptually distinct than velar stops and palatoalveolar affricates in post-tonic position, (12). This hypothesis predicts that velar stops before /-i/ will be more easily confused with palatoalveolar affricates before /-i/, when they occur far from stress, than when they occur in post-tonic position. This in turn predicts the existence of a pressure to neutralize the segmental contrast in far from stress position, which outranks the pressure to neutralize the contrast of stress-adjacent segments.

(12) First Hypothesis:
\[ \Delta[Vki - Vʧi] > \Delta[Vki - Vʧi] \]

Based on the results of the acoustic analysis in §7.2.2, we can make a further, more precise hypothesis, namely that velar stops with the acoustic characteristics of post-tonic velar stops will be less confusable with palatoalveolar affricates than velar stops with the phonetic characteristics of non stress-adjacent velars. That is, velar stops with a sharp burst and a steep intensity slope between the transient and the frication part of the release and affricates are perceptually more distinct than velar stops with weak bursts and shallow intensity slope and affricates, (13). This second hypothesis makes a stronger prediction. In order to demonstrate the stress modulated confusability between velar stops and affricates one does not need to compare velars in different prosodic conditions with affricates, it is sufficient to compare pairs of sounds with or without the acoustic properties which are known to be affected by stress.

(13) Second Hypothesis:
7.2.4.3 Stimuli

The stimuli which were used for this experiment are pairs of VCV disyllabic nonce words, created by manually splicing recordings of Standard Italian by one of the speakers who participated in the acoustic study. The nonce words only differed by the quality of the intervocalic stop.

The target stimuli had one of two intervocalic consonants, either a velar stop, or a palatoalveolar affricate, which were spliced from one of two prosodic conditions, either post-atonic, or post-tonic. The vowel preceding the consonant was always /a/, and the vowel following it was /-i/, as this is the context for palatalization in Italian, and the most common context for palatalization across languages. The resulting sequences [aki] and [af/i] are possible according to the Italian phonotactics, but they are not existing Italian words.

The stimuli were constructed by cutting and splicing from recordings of one of the speakers also recorded for the acoustic analysis. The speaker was a 29 year old Italian male from Torino (Italy); he was recorded reading the sentences in a sound attenuated booth. He was asked to read sentences of Italian from a computer screen, the sentences contained the target words, and were of this shape: *He V-passato remoto X PP*. The sound files were recorded at a sampling rate of 44.1 kHz. The target words were quadri-syllabic nonce words containing either [aki] or [af/i] in one of the two prosodic conditions, (14). Target words containing filler sequences [ati] and [atsi] were also recorded.

<table>
<thead>
<tr>
<th>Target word</th>
<th>Contained sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>kamakimo</td>
<td>[aki]</td>
</tr>
<tr>
<td>makimako</td>
<td>[aki]</td>
</tr>
<tr>
<td>kamafimo</td>
<td>[af/i]</td>
</tr>
<tr>
<td>mafimako</td>
<td>[af/i]</td>
</tr>
</tbody>
</table>

The recordings were imported into PRAAT (Boersma and Weenink, 2010) for editing. The first step in the editing process was to cut the sequence [aki] from the recorded target word *kamakimo*. The resulting sequence was used as the frames for the final stimulus. Both tokens with the velar stops, and tokens with the affricates in the final stimulus set therefore contained vowels with transitions into and out of the velar stop: /a/ with the formant transitions into /k/ and the unstressed vowel /i/ with the transitions from /k/. Tokens where /i/ was not significantly reduced were chosen as the base. The choice of the stressed vowel /a/ over the unstressed vowel /a/ from *makimako* was made because the absence of full vowel within the stimuli (both [a] and [i] would have been stressless) was judged as slightly deviant in a pilot experiment. The vowels were edited to attain the same duration across both consonants. This was done by manipulating the segmental duration in PRAAT. We are aware of the fact that this introduced a possible artifact; it was nevertheless necessary to enhance the confusability of the pair. The construction of stimuli in Guion’s (1996) perception experiments of velar palatalization provides a good example of the difficulty of getting at confusability scores of velar stops and affricates before front vowels. Although several more editing steps were made in order to isolate the role of the intensity slope in modulating the distinctiveness, the stimuli were not compressed in time, nor noise was added to them, unlike what done by Guion.
Subjects participating in a pilot test with these stimuli were asked to rate the naturalness of the stimuli, and all judged them positively. The result of the first step of the editing is illustrated in (15).

(15) Editing: first step
/k/ stimulus frame: \( \tilde{\alpha}^k \cdot ki \)
/\( \text{tf} /\) stimulus frame: \( \tilde{\alpha}^k \cdot ki \)

Since the hypothesis was precisely targeting the perceptual saliency of intensity slope differences, the subsequent editing steps were made in order to single out this auditory property. In order to create nonce words in which stops and affricates had the acoustic properties of consonants far from stress, we spliced the consonants from *makimáko* and *máfimáko* in the two respective stimulus frames. Nonce words in which the consonant had acoustic properties of a post-tonic segment where created by splicing the consonants in *kamákimo* and *kamáfímo* into the respective stimulus frames. The result of this second editing step are illustrated in (16). We will henceforth refer to consonant with post-tonic properties, or far from stress properties as C' and C, respectively.

(16) Editing: second step
Far from stress properties \( \tilde{\alpha}^k \cdot ki \)
\( \tilde{\alpha}^k \cdot \text{tf} \cdot i \)
Post-tonic properties \( \tilde{\alpha}^k \cdot k\!\!^\ast \cdot i \)
\( \tilde{\alpha}^k \cdot \text{tf} \!\!^\ast \cdot i \)

Two additional editing processes were made in order to obtain stimulus pairs which only contrasted for the nature of the segment and its intensity profile. Since the closure duration of stops and affricates in the same prosodic condition was not comparable, they were reduced and lengthened respectively to an average closure duration by cutting the excessive duration from the mid part of the closure and increasing the closure at the center. The same was done with the burst durations. Cutting was done at zero crossings, and all tokens were carefully checked for possible auditory artifacts. The result of this step was the creation of four stimuli which only differed in whether they contained a velar stop or an affricate, and in whether their intensity profiles had the acoustic properties of post-tonic, or far from stress consonants. The overall duration of the stimuli was exactly the same.

The final process consisted of increasing the peak intensity of the transients of post-tonic stops by 1.5. The need for this editing emerged from a pilot study: this step was necessary in order to increase the confusability of stops and affricates. This increase of the intensity peak did not yield artificially loud sounds: the edited peaks were within the range of the sharp bursts produced by the speaker naturally. This additional editing also caused a slight increase of the intensity slope, compared to the unedited token, but the slope was also within the range of naturally produced sharp bursts. We acknowledge that this final editing actively promotes the acoustic characteristics of post-tonic velars. Nevertheless, the acoustic properties of the post-tonic velars in the stimuli lied within the naturally occurring ranges, along every dimension, as it emerges from a comparison between the results of the acoustic analysis and the acoustic property of the stimuli. A comparison of the stop bursts in post-tonic position is illustrated in (17).

(17) Velar stops in post-tonic position:
Comparing the burst properties of the stimulus in the discrimination task ([\( \tilde{\alpha}^k\!\!^\ast i \)]) with the
Acoustic study

<table>
<thead>
<tr>
<th></th>
<th>Mean intensity slope (dB/sec)</th>
<th>St.Dev. (dB/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1518</td>
<td>687</td>
</tr>
<tr>
<td>Mean intensity peak (dB)</td>
<td>St.Dev. (dB)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>49.04</td>
<td>5.78</td>
</tr>
</tbody>
</table>

Discrimination experiment

<table>
<thead>
<tr>
<th></th>
<th>Intensity slope (dB/sec)</th>
<th>Intensity peak (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1815</td>
<td>54</td>
</tr>
</tbody>
</table>

The spectrograms of the four stimuli are presented in Figure 7-12. Figure 7-12 (a) illustrates the tokens in which the post-tonic consonants have the acoustic properties of non stress-adjacent consonants (áfi and áki). Figure 7-12 (b) illustrates the tokens in which post-tonic consonants have the properties of the burst of post-tonic consonants (áfi and ak'í).

The resulting four stimuli differed in whether they contained a velar stop or an affricate (stop vs. affricate), and in whether the consonant had acoustic properties of a post-tonic consonant, or of a non stress-adjacent consonant (stressed vs. unstressed). Stimuli are put in pairs which fall into one of 8 categories based on the type of consonant and prosodic condition, (18).

(18) Stimulus categories

<table>
<thead>
<tr>
<th></th>
<th>same vs. different</th>
<th>acoustic properties</th>
<th>stimulus pair</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>same pairs</td>
<td>far from stress</td>
<td>aki</td>
</tr>
<tr>
<td></td>
<td></td>
<td>post-tonic</td>
<td>ak'í</td>
</tr>
<tr>
<td></td>
<td>different pairs</td>
<td>far from stress</td>
<td>aki</td>
</tr>
<tr>
<td></td>
<td></td>
<td>post-tonic</td>
<td>ak'í</td>
</tr>
</tbody>
</table>

The presentation order of different pairs was counterbalanced: both orders ([k]–[t] and [t]–[k]). The total number of stimuli in each category was 72, resulting in a total of 576 pairs of stimuli presented to each subject. The same number of filler items was added to the presented material ([t]–[t], [ts]–[ts], [t]–[ts], [ts]–[t]): filler items were only cross-spliced, the full set of editings was not performed on these tokens. The stimuli were divided into three blocks of equal lengths; each block contained 24 stimulus pairs per category. Each block therefore contained 384 stimulus pairs (24 [pairs] x 8 [categories] x 2 [targets and fillers]). The order presentation of the pairs was randomized for each block and every subject.

7.2.4.4 Procedure

Subjects were presented pairs of nonce-words auditorily through a pair of high-quality headphones, while looking at a computer screen. The presentation was programmed with Psyscope X B53. The inter stimulus interval was of 300ms and the time between the first and the second stimulus in the pair was 50ms. During the stimulus presentation the screen was black, at the end for the second
Figure 7-12: Selected stimuli for the discrimination experiment: (a) tokens with [ki] and [ti] from post-atonic contexts, (b) tokens with [k'i] and [t'i] from post-atomic contexts.
stimulus a red question mark appeared on the screen. At this point the subject had to decide whether the nonce words he/she heard were the same or different one from another, by pressing one of two keys labelled S (for same) or D (for different) as fast as possible. The subjects could not respond before having listened to both stimuli in the pair, they had to answer within 500ms of the end of the second stimulus. Any response slower than 500ms was not recorded and the following pair was presented. Subjects were encouraged to respond as fast and as accurately as they could during the instruction phase, and they were prompted to respond faster every time they responded too slowly by a prompt (too slow!) appearing on the screen. Given that the experiment went by very quickly, subjects were given 20 training trials at the beginning of the first block. Responses of the training phase were discarded. The experiment lasted approximately 30min. and subjects were encouraged to take short breaks between blocks. The subjects were 10 native speakers of American English who did not report any hearing or speaking problem. They were compensated for their participation in the experiment.

7.2.4.5 Results

Results support our hypotheses: they show that velar stops and palatoalveolar affricates whose burst properties correspond to those of post-tonic segments are perceptually more distinct than velar stops and palatoalveolar affricates whose burst properties correspond to those of post-atonic segments. They support the claim that the contrast between velar stops and palatoalveolar affricates before high front vowels is neutralized in post-atonic position, because it is perceptually weak. On the contrary, the contrast is preserved in post-tonic position because stress-conditioned changes in the properties of the burst enhance the contrast between the two segments.

The data was analyzed with a contrast coded mixed effect logistic regression. The accuracy of the responses was modeled as the dependent variable; fixed effects were whether the pair was a same pair or a different pair, whether the consonants originated from a post-tonic or post-atonic position, and whether the pair was a filler or a target pair.

Results showed a higher accuracy for the target pairs than for the fillers ($\beta = -0.57509$, $z=9.828$, $p<0.001$). This difference is very likely to be due to the durational differences between target stimuli and fillers, in that fillers were shorter, and therefore hard to discriminate in a very fast task. Figure 7-13 illustrates the difference in accuracy between these two categories of pairs. Fillers were excluded from the subsequent analyses.

The crucial analysis to test our hypotheses showed a highly significant difference between pairs from the post-tonic, and pairs from the far from stress condition ($\beta = -0.84605$, $z=-9.718$, $p<0.001$). Subjects were significantly better at discriminating the [ki]-[fi] when the properties of the consonants corresponded to the ones found in post-tonic position. They miscalculated the contrast between [ki] and [fi] more often if segments originated far from stress. Accuracies from the two prosodic conditions, across subjects, are shown in Figure 7-14.

Finally, the analysis revealed a significant different between same and different pairs ($\beta = -0.31223$, $z=-3.574$, $p<0.001$). Subjects had in general a better performance in the different category; they miscalculated same tokens as different more often than they discriminated different tokens as same. The subjects' performance on same vs. different trials is illustrated in Figure 7-15 across subjects and prosodic positions. There was no interaction between prosodic position and same vs. different trials ($\beta = 0.18679$, $z= 1.074$, $p<1$), indicating that subjects were not only better at perceiving differences among [k*i] and [f*i], they were in general better at perceiving the contrast.
Figure 7-13: Accuracy on fillers and target trials, averaged across subjects and same vs. different. Error bars indicate the 95% confidence interval.

### 7.2.4.6 Summary

The discrimination experiment reported above shows that stress-conditioned effects on the phonetic realization of obstruent bursts affect the perceptual distinctiveness of the perception of the [\textit{ki}]-[\textit{t\text{\raisebox{-0.5ex}{\tiny l}}}] contrast. Properties of post-tonic bursts which can be attributed to a raised subglottal pressure during the stop closure enhance the distinctiveness of a contrast which is otherwise weak. The perceptual asymmetry resulting from differences in the plosives’ release mirror the phonological distribution of the contrast. The contrast between velar stops and palatoalveolar affricates before /-i/ is neutralized in the inflection of Italian nouns and adjectives. It is only preserved in post-tonic position. This is precisely the position in which raised subglottal pressure enhances the distinctiveness between the two sounds, by increasing the sharpness of the burst of velar stops. The absence of this acoustic affect in post-atonic position results in the neutralization of a contrast which, as it emerges from the present experiment, is very weak.

These results provide evidence for a hierarchy of perceptual distance between velar stops and palatoalveolar affricates before /-i/ in different prosodic conditions, (19).

\[ \Delta [\text{Vki}] > \Delta [\text{Vt\text{\raisebox{-0.5ex}{\tiny l}}}] \]

The formal analysis of stress-conditioned palatalization in Italian relies on a fixed hierarchy of MINDIST constraints which is projected from the perceptual asymmetry in (19). The constraint proposed in the following section is one which penalizes the contrast between a velar stops and a palatoalveolar affricate which are distinguished by a small perceptual distance along the dimension of the intensity slope. The action of this set of constraints targeting the slope of the transient at the release reflects the dispreference for perceptually indistinct contrasts. It is supported by the findings of the discrimination experiment.
7.2.5 Analysis

The inflection of standard Italian nouns and adjectives shows a stress-conditioned distribution of velar palatalization, it is repeated in (20).

(20) Stress-conditioned velar palatalization

a. Not stress adjacent: \( (CV).'CV.CV.[ki] \rightarrow (CV).'CV.CV.[i] \)
b. Post-tonic: \( (CV).'CV.[ki] \rightarrow (CV).'CV.[i] \)

The acoustic study presented in §7.2.2 showed that before /-i/, velar stops and palatoalveolar affricates are distinguished by their duration, their burst-to-closure ratio and the slope of the intensity profile at the release of the closure. It has also shown that among the acoustic properties which are most affected by the presence or by the absence of stress is the slope of intensity. In post-tonic position (e.g. [kamáikimo]), the sharpness of the stop burst is enhanced as a side-effect of increasing the perceptual energy of the preceding stressed vowel. In post-atomic (non-pre-tonic) position (e.g. [makimáko] on the other hand, a general process of burst lenition in Italian weakens the sharpness of the burst. The effect of stress assignment is therefore bi-directional: both weakening and enhancing of the contrast are attested, with respect to the target specifications for the intensity slope in the Inventory. The relevant dimension here is the intensity of the slope; this auditory parameter is defined in (21).

(21) Intensity slope

The rate of change of intensity between the transient and the beginning of the frication.
Contrary to the intensity contour dimension, along which stress modulates the difference between velar stops and affricates, results from the acoustic analysis show a pervasive effect of stress on closure duration which does not cause a difference in the distance between the two sounds. A significant lengthening of the closure duration as a consequence of an immediately preceding stressed vowel was found both among the stops and the affricates, therefore the location of the sounds along this dimension is shifted overall, but we could not notice any difference in their distances. Dispersion constraints on this auditory dimension are therefore irrelevant to the analysis.

We expand the hierarchy of perceptual distinctness from (19) to (22).

(22) a. \( \Delta[k^*]-[\text{f}^*] > \Delta[k]-[\text{f}] > \Delta[k]_{\text{far}}-[\text{f}]_{\text{far}} \)
b. \( \Delta 2 > \Delta 1 > \Delta 0 \)

The phonemic contrast between velar stops and palatoalveolar affricates in Italian is derived in the Inventory of the language. To analyze the contrast on the relevant dimension, \text{MINDIST} constraints must specify what is a sufficiently large distance along this dimension, (23).

(23) \text{MINDIST}(\text{Intensity Slope}):X

The minimum perceptual distance in intensity slope between contrasting sounds is X.

We consider here a quantized version of this dimension, along which we consider three steps, (24). The less distinct the contrast along this dimension, the higher-ranked constraints it violates.

(24) \text{MINDIST}(\text{Intensity Slope}):0 \gg \text{MINDIST}(\text{Intensity Slope}):1 \gg \text{MINDIST}(\text{Intensity Slope}):2
The language-specific ranking of these constraints and MAXIMIZE CONTRASTS derives the contrast between [k] and [ʧ] in the Inventory, (25).

(25) Inventory: Phonemic [k] – [ʧ] contrast

<table>
<thead>
<tr>
<th></th>
<th>MINDIST(Int. Slope):1</th>
<th>MAX CONTRASTS</th>
<th>MINDIST(Int. Slope):2</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>[k] – [ʧ]</td>
<td>✓✓</td>
<td>+</td>
</tr>
<tr>
<td>b.</td>
<td>[k]</td>
<td>✓!</td>
<td></td>
</tr>
<tr>
<td>c.</td>
<td>[ʧ]</td>
<td>✓!</td>
<td></td>
</tr>
</tbody>
</table>

The optimal contrast in the Inventory is one in which velar stops and affricates differ by 1 in the slope of intensity. The specifications of the two contrasting sounds in the Inventory is illustrated in (26).

(26) Inventory: Target specifications for consonants

<table>
<thead>
<tr>
<th>Consonant</th>
<th>Intensity Slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>/k/</td>
<td>1</td>
</tr>
<tr>
<td>/ʧ/</td>
<td>0</td>
</tr>
</tbody>
</table>

Stressed vowels in Italian are characterized by greater duration and greater loudness than unstressed vowels; we therefore restrict the representation of the vowels to the two dimensions relevant to the analysis, namely duration and intensity. There is no documented stress-conditioned process of vowel lowering in the language, we will therefore abstract away from height differences among stressed and stressless vowels. We refer to Albano Leoni et al. (1995:406) for the average duration of stressless vowels in Italian, and assume it to be the durational target in the vowel inventory. The specification of vowel intensity is based on our measurements of average intensity values of several stressless Italian vowels. The target perceptual energy of an Italian vowel is derived from its two components as defined in Chapter 4. The relevant subset of auditory targets of an Italian vowel are illustrated in (27).

(27) Inventory: Target specifications for vowels

<table>
<thead>
<tr>
<th>V duration</th>
<th>V intensity</th>
<th>VEnergy</th>
</tr>
</thead>
<tbody>
<tr>
<td>57ms</td>
<td>60dB</td>
<td>5.7</td>
</tr>
</tbody>
</table>

When strings of inventory elements are formed in the Realization, effort constraints are active, which trigger the weakening of plosive bursts, (28). This constraint is belongs the family of effort constraints penalizing the realization of bio-mechanically effortful sounds (Kirchner, 1998). It causes plosives to be realized with a shallower intensity slope and reflects the general tendency to fricativize stops in Italian, velar stops in particular.

(28) *SHARP BURST:
Plosive releases cannot be produced with a high pressure buildup.

It penalizes any plosive release whose intensity slope is equal to or greater than 1.

In the case of a velar stop occurring far from stress, the action of this constraint is not contrasted by metrical requirements. The tableau in (30) derives the phonetic realization of unstressed vowels.
and consonants adjacent to them. Plosives in this position are realized with a shallow intensity slope (b) \(k_{far}: \text{Intensity Slope} < 1\). Candidate (a) is the fully faithful realization of the burst, it is ruled out by the effort constraint. The winning candidate violates a low ranked constraint which requires the faithful mapping of burst specifications from the inventory to the output phonetic realization, (29).

(29) Faithfulness to auditory specifications of the burst (IDENT \(C_{Burst}\)):
Corresponding input and output consonants have the same value for [Intensity Slope].

(30) Realization: Non stress-adjacent stops

<table>
<thead>
<tr>
<th>/ak-i/</th>
<th>*SHARP BURST</th>
<th>IDENT (C_{Burst})</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. aki</td>
<td>*!</td>
<td></td>
</tr>
<tr>
<td>b. (\varepsilon) ak(_{far})i</td>
<td>*</td>
<td></td>
</tr>
</tbody>
</table>

The realization of vowels and consonants is different in stressed position. The set of metrical constraints which is active in the Realization component enforces the prominence of the stressed vowel, setting a threshold on the required prominence \(V_{Energy} \geq X\). The action of this set of constraints is restricted by faithfulness penalizing the unfaithful mapping of segmental duration and segmental intensity, (31).

(31) Scalar faithfulness to vowel duration (IDENT X \(V_{dur}\))
The difference in [duration] between corresponding input and output vowels at least X.
Penalizes a difference of more that X% between the target duration and the duration of the output vowel, i.e.

\[
\begin{align*}
\text{IDENT 0\% } V_{dur} & \gg \text{IDENT 50\% } V_{dur} \gg \text{IDENT 100\% } V_{dur} \\
\text{IDENT 30\% } V_{dur} & \gg \text{IDENT 50\% } V_{dur} \gg \text{IDENT 100\% } V_{dur}
\end{align*}
\]

(32) IDENT \(V_{Height}\):
Corresponding input and output vowels have the same value for [height].

The relative ranking of these faithfulness constraints and of the metrical constraint derives the phonetic realization of stressed vowels, and whether it will affect the realization of stress-adjacents consonants as well. According to the proposed analysis, the required energy level is attained through the lengthening of the vowel and by increasing its loudness. Given the ranking shown in we derive the phonetic realization of stressed vowels and stress-adjacent consonants. The stress-conditioned phonetic realization of post-tonic velar stops is derived in (34). Metrical requirements and aerodynamic constraints outrank the general effort constraint in (28). Since this constraint cannot determine properties of the stress-adjacent bursts, it is left out of the the following tableau. Subscripts to the vowels indicate their perceptual energy \(V_{Energy} = V_{loudness} \times V_{dur}\); subscripts to the consonants indicate the slope of the intensity at the release.

(33) Realization: Post-tonic stops

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The fully faithful vowel is penalized by the metrical requirement $\hat{V}_{\text{Energy}} \geq 11$, since its energy value is lower than the required threshold (a). Similarly, the candidate in which the energy level is increased by increasing the vowel duration, and faithfully realizing the intensity specification (c), does not yield a prominent enough vowel. Albano Leoni et al. (1995:406) report an average duration of 98ms for stressed vowels. Calculating the perceptual energy of lengthened stressed vowel of unchanged intensity yields a value of 9.8 (0.98s X 100), which is smaller than 11. In order to reach the required threshold, the loudness of the stressed vowel has to be increased, in addition to its duration. In candidate (a) the minimum required energy level is attained with a fast subglottal pressure displacement: subglottal pressure is lowered within the transition to the post-tonic consonants, violating the high ranked constraint against fast subglottal pressure movements (*FAST $vP_{SG}$). The winning candidate is (d), which increases the prominence of the vowel by both increasing its duration and increasing its loudness. Unlike candidate (a), the subglottal pressure movement is slow, and it does not violate the aerodynamic constraint. This strategy affects the realization of the post-tonic burst. We showed in the acoustic analysis that in this position the sharpness of the plosive release is enhanced by the raised pressure level behind the closure, and the slope of the intensity contour at the release is steeper ($k^\ast$: Intensity Slope=2).

The phonetic realization of palatoalveolar affricates is derived in a parallel way. We discussed during the presentation of the acoustic analysis that the slope properties of affricates in the two prosodic positions could not be measured precisely. This was due to the frequent absence of a clear transient in these segments. It was however the case that palatoalveolar affricates in post-tonic position were fricativized less frequently than affricates far from stress. We indicate the phonetic realization of a stress-adjacent affricate as $[\mathrm{f}^\ast]$, in which the slope is slightly steeper than 0, but not reliably different from 0 ($f^\ast$: Intensity Slope=0). This indicates the presence of some side-effect from the increased subglottal pressure, although it is smaller than for stop consonants. Importantly this does not entail that the effect of increasing subglottal pressure is smaller if the following consonant is an affricate. The reduced magnitude of the effect is due to the fact that most affricates are produced as fricatives in Italian, and the effect of increased pressure in the absence of a complete closure is significantly smaller. The tableau in derives the phonetic realization of affricates in post-tonic position. Subscripts to the vowels refer to their energy level ($\hat{V}_{\text{Energy}}$).

(34)  Realization: Post-tonic affricates
The outputs of the Realization are subject to the Evaluation of distinctiveness. The phonetic realization of velar stops and palatoalveolar affricates before front vowels is evaluated in different prosodic contexts, post-tonic ([Vk'i]-[Vf'i]) and far from stress ([Vkfari]-[Vtfari]). As in the analysis of Copala Trique developed in Chapter 6, the described effects of stress on the realization of the stress-adjacent consonants affect the distribution of segmental contrast. Specifically, they block the neutralization of the contrast between velar stops and palatoalveolar affricates which is triggered in non stress-adjacent contexts.

The evaluation of contrasts is derived in the tableau in (35) for the far from stress context. The ranking of MINDIST constraints in the Evaluation corresponds to the ranking of these constraints in the Inventory: the minimum level of distinctness that is acceptable between contrasting sounds which differ along the Intensity Slope dimension is 1. This requirement on contrast is violated by far from stress segments (a).

The grammar in (35) correctly derives the prosodic environment of neutralization, but it fails to derive the unique sound to which the contrast neutralizes: it generates a tie between the two neutralizing candidates without choosing between them. The next step is therefore to lay out what considerations prefer the palatoalveolar affricate, i.e. candidate (b) over candidate (c), in (35).

Whereas the basic result of palatalization is a palatalized stop, giving rise to the alternation between velars and palatalized velars, many languages (e.g. Italian and Slavic) show an alternation between velar stops and palatoalveolar affricates. Flemming (1995, 2001) argues that the underlying process is auditory enhancement. The author analyzes palatalization of a velar stop before a high front vowel as a strategy to produce a high F2 at the release of the consonant, to enhance the contrast between /Ki/ and /Ku/ (K=velar stop). In order to produce a high F2 at the release, the primary constriction of the consonant is shifted forward, from velar to palatal. In some languages, the affricate resulting from palatalization is the byproduct of enhancing the contrast in vowel F2 with a further difference: loudness of frication (NL). I follow this line of reasoning to explain which one of the two winning candidates in (35) is the actual result of neutralization: the palatoalveolar affricate maximizes the auditory distance between neighboring sounds (here /ku/) in the auditory space, and therefore gives rise to a better contrast. The feature specifications of the relevant sounds are illustrated in (36).

<table>
<thead>
<tr>
<th>/atf'i/</th>
<th>*FAST vPSC</th>
<th>V_Energy ≥11</th>
<th>IDENT V_dur</th>
<th>IDENT V_int</th>
<th>IDENT C_Burst</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. 'atf'i11</td>
<td>*!</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. 'atf'i5.7</td>
<td>*!</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. 'atf'i0.8</td>
<td>*!</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d. 'atf'i11</td>
<td>*!</td>
<td>*</td>
<td></td>
<td></td>
<td>*</td>
</tr>
</tbody>
</table>

(35) Evaluation: Contrast neutralization far from stress context

<table>
<thead>
<tr>
<th>/akfari/-/atifari/</th>
<th>MINDIST(Int. Slope):1</th>
<th>*MERGE</th>
<th>MINDIST(Int. Slope):2</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. akfari[-atifari]</td>
<td>*!</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>b. atfari</td>
<td>*</td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>c. atfari</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>

(36) Feature specification at VC transition (adapted from Flemming, 2001:105)
The selection of sounds chosen for the inventory can be formalized in terms of the relative ranking of MINDIST constraints pertaining to the vowel and to the consonant contrast (36), and of constraints favoring a larger, over a smaller number of contrasting sounds. The tableau in adapts the analysis of Flemming (2001:106) to Italian; it shows the selection of realizations for velar stops and palatoalveolar affricates before front and back vowels. Both vowel F2 and consonant place of articulation are evaluated, (37). Following Flemming, I write distances on multiple dimensions by conjoining the distances on each dimension with &, e.g trans F2:3 & burst NL:3 is a distance of 3 on the formant transition dimension, and a distance of 3 on the loudness of burst dimension.

(37) MINDIST trans F2:3 & burst NL:3
The distance in formant transition and the distance in loudness of burst frication (NL) between contrasting sounds is 3.

The tableau in (38) derives the selection of realizations in the case of velars occurring far from stress, solving the tie in (35).

(38) Evaluation: Deriving contrasts far from stress

<table>
<thead>
<tr>
<th>/akʃar u/-/akʃar i/-/afʃar i/</th>
<th>MINDIST(Int. Slope):1</th>
<th>*MERGE</th>
<th>MINDIST trans F2:3 &amp; burst NL:3</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. [akʃar u]-[akʃar i]-[afʃar i]</td>
<td>*!</td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>b. [akʃar u][akʃar i]</td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. [akʃar u]-[afʃar i]</td>
<td>*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

This second part of the grammar solves the competition between the two winning candidates in (35) distance between the outcome of palatalization and other segments of the inventory, specifically the distance between velar stop-back vowel sequences and palatalized velars before front vowels.

A remark should be made about the set of relevant sounds that are evaluated in (38). Italian not only contrasts [Vku] and [Vtfi] far from stress (28a) and [Vku], [Vki] and [Vtfi] in post-tonic position (28b), but it also contrasts [Vtfu] with [Vku] and [Vtfi] in both prosodic contexts. While the neutralization of the [ki]-[tfi] contrast to [tfi] far from stress enhances the contrast between [ki]-[ku], it creates the contrast [tfi]-[tfu], which is a less distinct contrast than [ki]-[ku].

Flemming (2002:61) notes that the distance between two contrasting sounds does not only depend on the magnitude of a difference along the relevant spectral parameters, it also depends on the duration of that difference. I argue that the new contrast created by neutralizing to [tfi] instead of [ki], i.e. [tfi]-[tfu], is more distinct than the one which would arise from neutralizing to [ki], i.e. [ki]-[ku], and it is therefore preferred by the grammar. In the former contrast lip rounding cues (e.g. labialization) during the frication are available for longer and they are louder than in the former contrast. If cues to the following vowel, [i] or [u], in the frication (e.g. presence or absence of labialization) are modulated by the length of the segment they are associated with, it will matter whether they are associated with the short burst of a stop (as in [ku'u]), or with the fricative portion of an affricate (as in [tf'u]).
We can now turn to the evaluation of the contrast between velar stops and palatoalveolar affricate in post-tonic position (i.e. [Vk'í]–[Vf'í]).

In the proposed analysis, the neutralization of the segmental contrast is blocked in this position by the side-effects of loudness enhancement on the post-tonic consonant. In post-atomic position, the distinctiveness between a stop and an affricate is diminished by the general effort constraint *SHARP BURST: MINDIST(Int. Slope)<1. By contrast, in post-tonic position increased subglottal pressure yields a greater difference between the burst properties of the contrasting elements: MINDIST(Int. Slope)>1. The derivation of contrast preservation in post-tonic position is shown in (39).

(39) Evaluation: Contrast preservation in post-tonic position

<table>
<thead>
<tr>
<th>/ak'í/-/af'í/</th>
<th>MINDIST(Int. Slope):1</th>
<th>*MERGE</th>
<th>MINDIST(Int. Slope):2</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. [ak'í]–[af'í]</td>
<td></td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>b. [ak'í]</td>
<td></td>
<td>!</td>
<td></td>
</tr>
<tr>
<td>c. [af'í]</td>
<td></td>
<td>!</td>
<td></td>
</tr>
</tbody>
</table>

The tableau in (39) shows how velar palatalization is blocked in post-tonic position. The winning candidate in (39) is one which preserves the segmental contrast (a), since the contrasting sounds are distinct enough. Candidates (b) and (c) on the other hand are penalized by *MERGE, since they are mergers of two input forms.

7.2.6 Summary

This section has presented a detailed case study of stress-conditioned contrast preservation, namely the distribution of velar palatalization in the inflection of Italian nouns and adjectives. The aim of the study was not only to provide a thorough analysis of the specific phonological process, but also to present a substantive base to the two following claims of this dissertation. First, the claim that stress-conditioned processes which are not enforced by metrical requirements (tdur≥X and VEnergy≥X) arise from the side-effects of these requirements on the phonetic realization of stressed vowels and stress-adjacent consonants. We demonstrate that the acoustic realization of plosives is affected by presence of a preceding stressed vowel. The nature of these effects is of the sort predicted by our model of the side-effects of subglottal modulations on stop releases, namely the increased sharpness of the burst and a sharp intensity slope at the transient. We provide experimental support to the claim that these side-effects are perceptually salient, and that they affect the perceptibility of the contrast between velar stops and palatoalveolar affricates, (40). The perceptual asymmetry which emerged from the discrimination experiment mirrors the distribution of the phonological contrast in the language.

(40) Δ[k'í]–[q'í] > Δ[kí]–[ńí] > Δ[kí]far–[ńí]far

Second, the acoustic analysis of Italian demonstrates that contrast preservation is triggered by markedness constraints which enhance the perceptual distance between the contrasting sound in post-tonic position. We show that neutralization is blocked in this position because of the side-effects of loudness enhancement on the phonetic realization of post-tonic velars. This finding
supports our claim that preservation of segmental contrast in metrically strong positions is either
an effect of direct prominence enhancement or an effect of the acoustic side-effects of prominence
enhancement. It therefore arises from markedness pressures acting on these positions, not from the
positional privilege attributed by grammar to these positions.

The formal model of the grammar adopted in this dissertation (Flemming, 2004, 2006) al-

lowed us to derive the stress-conditioned preservation of contrast from a more general process of
enhancement of perceptual distinctiveness. The full constraint ranking for the analysis of Italian
palatalization in the inflection of nouns and adjectives is given below. Since the relative ranking of
constraints in the Evaluation component is the same as the ranking in the Inventory, a cumulative
ranking is given for both, Figure 7-16. The constraint ranking of the Realization is given in Figure
7-17. Dominance relations are indicated by downward arrows.

Figure 7-16: Italian: Full ranking of constraints in the Inventory and in the Evaluation component

Figure 7-17: Italian: Full ranking of constraints in the Realization component
7.3 2. Case Study: Finnish assibilation

7.3.1 Introduction

Assibilation is the creation of sibilants (affricates and/or fricatives) from non-sibilant plosives (Kim, 2001). In Finnish this process is the fricativization of a stem-final plosive /t/ to [s] before /-i/ across a morpheme boundary. The process is morphologically conditioned: in verbs, assibilation has been analyzed as depending on the length of the stem (Laalo, 1988; Anttila, 2003, 2006), (41)a, in nouns on the other hand, assibilation is restricted to a subset of the lexical items. Assibilation is obligatory irrespective of stem length in /e/-final nouns, (41)b, and blocked elsewhere.

69x657 (41) Morphological effects in Finnish assibilation (data from Anttila, 2004:6)
a. /vetä-i/ [ve.ti] *[ve.si] 'pull-PAST'
   /vuota-i/ [vuo.ti] ≈ [vuo.si] 'seep-PAST'
   /kaart-i/ *[kaar.ti] [kaar.si] 'veer-PAST'
b. /sota-i-na/ [so.ti.na] *[so.si.na] 'war-PL-ESS'
   /vete-i-nä/ *[ve.ti.na] [ve.si.na] 'water-PL-ESS'
   /vuote-i-nä/ *[vu.o.ti.na] [vu.o.si.na] 'year-PL-ESS'

This section analyzes assibilation in the verbal domain. It is argued that this process is a case of contrast preservation in a metrically strong position. Assibilation is blocked in immediately post-tonic position (VTi), optional following a post-tonic segment (VC/Vti), and obligatory if the /ti/ sequence is further away from stress (e.g. VVCti). It should be noted that the described assibilation pattern in the verbs is the one found in Standard Finnish; the present analysis focuses on this language. The issue of dialectal variation (Anttila, 2006) is addressed by the formal analysis developed in §7.3.3.

The phonological process in Finnish is similar to the processes found in Copala Trique and Italian; the difference between assibilation and the previously analyzed cases is the metrical requirement of which it is the side-effect. Contrast preservation in Copala Trique and Italian arises as the side-effect of enhancing the loudness of the stressed vowel (VEnergy >X). In Finnish on the other hand, strong positions are only targeted by constraints on durational prominence, §7.3.2.1; assibilation arises as the side-effect of enhancing the duration of the stressed domain. The formal analysis of Finnish proposed here, 7.3.3, is therefore virtually identical to the one proposed for the two languages analyzed previously. Evidence for this analysis of stress-conditioned assibilation is presented in the form of an acoustic analysis of Finnish /ti/ sequences in different prosodic contexts, §7.3.2.

Acoustic analysis of the durational correlates of stress (Suomi et al., 2003; Suomi and Ylitalo, 2004; Suomi et al., 2008) show that the domain of Finnish stress consists of the first two morae of the word (§7.3.2.1. The formal analysis will therefore refer to the stressed domain as the leftmost bimoraic. Section 7.3.3 introduces the set of durational prominence constraints which target this stressed domain.

This case study serves two purposes. First, it provides further experimental support to the claim that the blocking of contrast neutralization in stressed positions arises from the side-effects of prominence enhancement on segments in these positions. Second, it shows that the specific nature of these side-effects is determined by the nature of the metrical requirements targeting stressed positions in a given language.
7.3.2 Acoustic analysis

This section presents the acoustic analysis which was conducted in order to test the effects of stress on the realization of stress-adjacent consonants. Specifically, the acoustic properties of /ti/ sequences were analyzed, in the prosodic contexts in which the /ti/-/si/ contrast is neutralized, and those in which it is preserved. An overview of the acoustic properties of Finnish stress and Finnish plosives is presented as a background to the acoustic analysis, 7.3.2.1. The domain of stress in Finnish is introduced here.

7.3.2.1 Background

In Standard Finnish segmental length is contrastive both among vowels and consonants. The language has eight short vowels and eight long vowels, the inventory of short vowels is illustrated in (42). Although Finnish vowels nasalize in the presence of a tautosyllabic nasal consonant, they are reported to have very little allophonic variation in addition to durational alternation and coarticulatory effects. Stress is also described as having almost no effect on vowel quality. Tautosyllabic vocalic intervals are classified in three ways (Suomi, 2008:23): short (or single) vowels (e.g. tuli, 'fire'), long (or double) vowels (e.g. tuuli, 'wind'), and diphthongs (e.g. tuoli, 'chair'). Durationally and metrically, diphthongs are like long vowels.

(42) Finnish: Vowels

<table>
<thead>
<tr>
<th></th>
<th>high</th>
<th></th>
<th>mid</th>
<th></th>
<th></th>
<th>low</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>i</td>
<td>y</td>
<td>u</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>æ</td>
<td></td>
<td>a</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Finnish has a small consonant inventory which is described as consisting of a core group (Group 1) of consonants common to all varieties of the languages, and 4 groups of consonants which belong only to some variants (Karlsson, 1983; Suomi et al., 2008). We report the comprehensive inventory in (43) below. Consonants belonging to groups other than Group 1 are indicated in parentheses.

(43) Finnish: Consonants (Suomi et al., 2008:38)

<table>
<thead>
<tr>
<th></th>
<th>Bilabial</th>
<th>Labiodental</th>
<th>Dental</th>
<th>Alveolar</th>
<th>Fricative</th>
<th>Glottal - continuant</th>
<th>Nasal</th>
<th>Trill</th>
<th>Lateral-approximant</th>
<th>Central-approximant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plosive</td>
<td>p (b)</td>
<td>ð</td>
<td>d</td>
<td></td>
<td></td>
<td>j</td>
<td>m</td>
<td>r</td>
<td>u</td>
<td>j</td>
</tr>
<tr>
<td>Semiplosive</td>
<td></td>
<td>f</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fricative</td>
<td></td>
<td>s</td>
<td>(j)</td>
<td></td>
<td></td>
<td>h</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glottal - continuant</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Stop consonants are voiceless and unaspirated, the burst is very weak. Suomi (1980:99) reports mean VOT values in word medial position of 11ms for /p/, 16ms for /t/ and 25ms for /k/. Stops consonants are always released when they are the first element of a cluster. They are frequently fully or partially voiced in fast or careless speech. The realization of an inter-vocali /t/ is shown in
7-21. In many varieties of Finnish /s/ and /h/ are the only fricatives. The sibilant is described by Suomi as being “less sharp than the sibilant denoted by the IPA symbol [s]”, and as being realized with great variability, from [s] to [ʃ].

There are ten syllable types which occur in the native lexicon, the basic syllable types are given in (44); the number of morae is also indicated.

(44) Finnish: Syllable structure (adapted from Suomi, 2008:65)

<table>
<thead>
<tr>
<th>N of morae</th>
<th>Syllable type</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>V</td>
<td>o.sa</td>
</tr>
<tr>
<td></td>
<td>CV</td>
<td>ʨa.lo</td>
</tr>
<tr>
<td>2</td>
<td>VV</td>
<td>au.ʦo</td>
</tr>
<tr>
<td></td>
<td>VC</td>
<td>es.ʨe</td>
</tr>
<tr>
<td></td>
<td>CVC</td>
<td>ʨas.ʨu</td>
</tr>
<tr>
<td></td>
<td>CVV</td>
<td>saa.ri</td>
</tr>
<tr>
<td>3</td>
<td>CVCC</td>
<td>kilt.ʨi</td>
</tr>
<tr>
<td></td>
<td>VVC</td>
<td>aal.ʦo</td>
</tr>
<tr>
<td></td>
<td>VCC</td>
<td>ark.ʨu</td>
</tr>
<tr>
<td></td>
<td>CVVC</td>
<td>vieʦ.ʨo</td>
</tr>
<tr>
<td>4</td>
<td>CVVCC</td>
<td>suorʦ.ʨi</td>
</tr>
</tbody>
</table>

Finnish is a bounded stress system and a syllabic trochee language: primary stress always falls on the first syllable following a word boundary, secondary stresses usually on following odd syllables. Hayes (1995) describes Finnish as a typologically rare language: it is one of ten cases of syllabic trochee languages which distinguish syllable weight. In all the other languages, every syllable is usually mono-moraic. If a syllabic trochee language does have a distinction segmental quantity, it usually also exhibits a sensitivity to syllable weight in its assignment of stress, by avoiding stresses on light syllables.
Stress is realized by variations in segment duration: segments have longer durations when they constitute the first or second mora of a word.

“A phonological unit (segment, syllable) has a longer duration when it constitutes, or is constrained within, the sequence of a word’s first two morae, than when the unit occurs outside such a sequence.” (Suomi and Ylitalo, 2004:39)

There is therefore a large variation in the duration of a short vowel in the second syllable, this variation is conditioned by the moraic content of the first syllable. If the first syllable is bimoraic, V2 is short, (45)a, if on the other hand V2 constitutes the second mora of the bimoraic domain, it is ‘half long’ (Suomi and Ylitalo, 2004:60), (45)b. For example, the duration of the second syllable vowel in CV.CV word, is significantly longer as that of the second syllable vowel in CVV.CV words.

(45) Stress-conditioned vowel duration
(average durations from Suomi and Ylitalo, 2004: Table 3)

<table>
<thead>
<tr>
<th>Position of V</th>
<th>Duration V2 (ms.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. CV1.CV2.CV</td>
<td>44</td>
</tr>
<tr>
<td>b. CV1.CV2.CV</td>
<td>80</td>
</tr>
</tbody>
</table>

Consonants are also reliably longer when occurring within the first two morae of the word, (46)a, than when occurring outside this domain,(46)b. Results from Suomi and Ylitalo’s acoustic analysis show that only voiceless consonants (K = /s/, /k/, /t/) within the bimoraic domain, this effect was not found for voiced consonants (/l/, /r/, /n/).

(46) Stress-conditioned consonant duration
(average durations from Suomi and Ylitalo, 2004: Table 2)

<table>
<thead>
<tr>
<th>Position of K</th>
<th>Average duration (ms.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. (C)V.KV</td>
<td>85</td>
</tr>
<tr>
<td>b. (C)V.CV.KV</td>
<td>70</td>
</tr>
</tbody>
</table>

We can summarize the results of previous acoustic studies on the relation of stress and segmental length in Finnish in the following three ways: first, duration is the primary, if not the only proven correlate of stress in Finnish; second, the domain in which stress-conditioned durational enhancement is found consists of the first two morae of the word; third both vowels and consonants are lengthened if they occur within this domain.

The acoustic study presented in this section was conducted with the aim of exploring the hypothesis in (47).

(47) First Hypothesis
The length effect observed by Laalo (1988) in the distribution of assibilation in Finnish is the indirect consequence of the durational enhancement of voiceless consonants within the stressed domain. It is not an effect of Positional Faithfulness to consonantal features within the stressed foot, as proposed by Anttila (2003, 2006).

Note that the distribution of assibilation in Standard Finnish is strikingly parallel to the distribution of consonantal lengthening: assibilation is blocked when /t/ is lengthened, and it occurs when /t/
is not lengthened. The parallel between the two process is illustrated in (48), compare (a) and (b).

(48) Comparing the distribution of stress-conditioned C lengthening assibilation

- In Standard Finnish verbs, assibilation is blocked after a mono-moraic first syllable (μ.ti) and it is obligatory after a trimoraic first syllable (μμμ.ti) and after two or more syllables (σ.σ.ti), adapted from Anttila (2006:9).

- In Standard Finnish a voiceless consonant is lengthened if it immediately follows a monomoraic first syllable ((C)V.KV) and it is not lengthened if it occurs outside of the bimoraic stress domain.

The comparison in (48) ignores the presence of optional or lexically determined assibilation in those verbs in which the /ti/ sequence occurs after a bimoraic first syllable (μμ.ti). We argue that this variability could be due to a slight increase in consonant duration in this position, although durational enhancement is not previously reported after a bimoraic stem. The results of the acoustic analysis address this possibility.

A large literature on the phonetic basis for stop assibilation delineates the mechanism through which consonantal lengthening could block the process. Kim (2001), Hamann and Velkov (2005), Hall et al. (2006), among others, have claimed that the assibilation of a coronal stop before a high front vowels arises from the acoustic properties of the frication noise during the burst of the stop before /i/ (and /j/). Duration, spectral properties and amplitude of the frication noise during the stop burst (friction phase; Hall et al., 2006:60) are greater and similar to the frication of a sibilant fricative. Stridency is generated when the tongue moves from the oral closure of a coronal plosive consonant toward a high vocoid, resulting in a long transient frication. The acoustic similarity between the burst properties of a coronal stop before a high front vowel and an alveolar fricative before a high front vowel allows us to make a second, more precise prediction about the link between consonant lengthening and the blocking of assibilation, (49) and Figure 7-21.

(49) Second Hypothesis

Consonant lengthening after a monomoraic first syllable increases the closure duration and decreases the ratio of burst/total duration. A decreased burst/total duration ratio results in a decreased perceptual saliency of the acoustic properties of the friction phase.

7.3.2.2 Recordings and speech material

Six native speakers of Finnish (age-range 25-58) were recorded in a sound attenuated booth to collect the material for the acoustic analysis; they did not report any history of hearing or speaking impairment. Five of the recorded speakers come from the Uusimaa region around Helsinki (Southern Finland), one speaker comes from Ostrobothnia (Western Finland). Standard Finnish is their first language.

The speakers were recorded reading the words in isolation in a sound attenuated booth; they were asked to read from a computer screen.

The speech material consisted of 27 Finnish nouns whose stem did not end in /-e/, which were inflected for declined for one of the following case in order to contain the /-ti/- sequence: Nom-SG, Nom-Pl., Gen-Pl., Pl-Ess.. Non-/e/-nominals were chosen as the recording materials, since /ti/ sequences in these nouns never undergo assibilation. The material was constructed with the help of a native Finnish speaker. Four classes of nouns were chosen: nouns with either a monomoraic,
Figure 7-19: Hypothesis 2: effect of consonant lengthening on burst-total duration.

a bimoraic, a trimoraic, or a disyllabic stem. Examples from the four categories are given in (50). Eleven filler items were included in the speech material, these were Finnish words with the same syllabic structure. A complete list of the material is provided in Appendix 3. Each speaker read the two times out loud during the recording session. They were also given the time to read the words before the recording, in order to remove the possible surprise of reading declined words out of context.

(50) Speech material: examples

\[
\begin{array}{ll}
\mu.ti & \text{hytín} \quad \text{cabin-NOM-PL} \\
\mu.ti & \text{ruu.tien} \quad \text{gun powder-GEN-PL} \\
\mu.m.ti & \text{män.tien} \quad \text{piston-GEN-PL} \\
\sigma.s.ti & \text{tarjo.tin} \quad \text{tray-NOM-SG} \\
\end{array}
\]

7.3.2.3 Measurements

The sound files were recorded at a sampling rate of 44.1 kHz and imported into Praat (Boersma and Weenink, 2010) for analysis. Two acoustic properties of the target words were measured: closure duration and burst duration. Duration measurements were obtained through segmentation of the waveform, with reference to the spectrogram. Closure duration is measured from the end of the last period of voicing in the preceding vowel, to the transient. Burst duration is measured from the release of the closure at the transient, to the onset of periodicity in the following vowel. An illustration of how the measurements were taken is given in Figure 7-21 shown above. The spectra in Figure 7-20 are an example of the realization of /ti/ in the 4 different conditions.
The analysis of the burst/total duration ratio revealed an overall effect of stem length on the burst/total duration ratio [F(7, 288)=15.15, p<0.001]. It emerges from this analysis that the increase in duration observed in immediately post-tonic position (μ.ti) is due to an increase in closure duration, and not to an increase of both burst and closure. Coronal stops following a monomoraic stem have a significantly longer closure duration than coronal stops following a disyllabic stem (σ.μ.ti), [t(288)=-5.597, p<0.001]. As for the measurements of total duration, no significant difference was found between the burst/total duration in /t/ following a bimoraic stem and stops following a disyllabic stem, [t(288)=0.66, p=0.51]. Coronal stops following a trimoraic stem on the other hand had a slightly shorter closure duration than stops following a disyllabic
stem, \[ t(288)=3.043, p<0.01 \]. They were therefore very distinct from stops in the immediately post-tonic context. The effect of stem length on the burst/total closure ratio is illustrated in Figure 7-22.

### 7.3.2.5 Summary and discussion

The results of the acoustic analysis support the hypothesis that consonant lengthening in immediately post-tonic position is not homogeneously distributed over consonant closure and consonant burst: it primarily affects the closure phase, therefore decreasing the burst/total duration ratio. Results also support the hypothesis that coronal stops in the obligatory assibilation contexts (\( \mu \mu . t i \) and \( \sigma . \sigma . t i \)) have a large burst/total duration ratio, and therefore a long period of frication with respect to the total duration of the segment. Results do not provide evidence to the hypothesis that the context in which variable assibilation is attested, \( \mu . t i \), has a slight lengthening of the closure, or a decrease in burst duration compared to the trimoraic-stem context. The table in (51) summarizes the results of the analysis, grouping the experimental conditions according to their ability to undergo assibilation or not.

<table>
<thead>
<tr>
<th>Moraic structure</th>
<th>Blocking of assibilation</th>
<th>Variable assibilation</th>
<th>Obligatory assibilation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total duration</td>
<td>0.134s (***)</td>
<td>0.117s</td>
<td>0.113s</td>
</tr>
<tr>
<td>Burst/Closure ratio</td>
<td>0.224 (***))</td>
<td>0.310</td>
<td>0.347 (**))</td>
</tr>
</tbody>
</table>

In the the following section it is argued that the assibilation of coronal stops before high front vowels is a process of contrast neutralization triggered by the perceptual similarity between the frication noise of coronal stops in this position and the frication of a sibilant fricative. The analysis builds on previous acoustic findings on the acoustic properties of the frication noise of a coronal stop before /-i/ (among others, Kim, 2001; Hamann and Velkov; 2005, Hall et al., 2006). I suggest following Hamman and Velkov (2005) that the frication noise present in these sequences can be reinterpreted by listeners as underlying fricative or as an affricate: a longer friction phase is more likely to be reinterpreted as fricative than a shorter friction phase. The phonetic similarity decreases the perceptual between /t/ and /s/ before /-i/, yielding a segmental contrast which is prone to neutralization.

In Finnish verbs, this neutralization process does not apply across the board, it is conditioned by the specific phonetic realization of /ti/ sequences. In immediately post-tonic position ((C)\( \bar{V} \)ti) the coronal stops is lengthened by a metrical requirement enforcing the durational prominence of the stressed domain. We have shown that a consequence of this lengthening is that a smaller portion of the consonant is occupied by the strident frication noise. We argue that, this change in the acoustic property of the stop affects the perceptual distance between /t/ and /s/ before /-i/, the two sounds are less similar in this prosodic position, because the strident portion of the stop is less prominent. The segmental contrast is therefore distinct enough to be preserved. In post-tonic position on the other hand, coronal stops are not lengthened, nor is the relation between burst and total duration affected. In this position the strident frication noise occupies a large portion of the stop: /ti/ and
Figure 7-21: Finnish: Effect of stem length on the total duration of [$\ddot{a}$]. Durations in seconds, averages across subjects. Error bars indicate the 95% confidence interval.

Figure 7-22: Finnish: Effect of stem length on the burst/total duration. Averages across subjects. Error bars indicate the 95% confidence interval.
/si/ are acoustically similar and perceptually confusable in this position. Assibilation is therefore not blocked.

It should be noted that relatively to other languages in which coronal stops assibilate before /i/, the strident frication noise in Finnish is short. Hall et al. (2006) for instance report an average friction phase (from the stop release to the onset of the following vowel) of 65ms in German /ti/ sequences. Finnish seems to be more similar to Polish, in which the friction phase (Hall et al., 2006:63) of a coronal stop before /i/ has an average duration of ca. 35ms in Polish. /ti/ sequences. In our recordings of Finnish, the average burst duration (friction phase) was of 36ms in stops following a disyllabic stem, of 38ms in stops following a trimoraic stem, and or 35ms in the variable assibilation condition, after a bimoraic stem. Direct perceptual evidence should be gathered in order to assess whether the burst durations in contemporary Finnish and Polish are long enough to yield an ambiguous percept of the /ti/-/si/ contrast. It is however likely to be the case that in the synchronic development of these languages there was a stage in which bursts were longer, like in German, and thus more salient.

The acoustic data collected in this experiment support the hypothesis about the perceptual origin of assibilation in Finnish, and the link between stress-conditioned lengthening and the distribution of the neutralization process. The data however did not show any significant difference between the acoustic realization of /ti/ sequences following a bimoraic stem, and the realization of /ti/ sequences following a trimoraic and disyllabic stem. Coronal stops which can undergo variable assibilation in Standard Finnish (μμ ti) don’t not significantly differ from coronal stops which always undergo assibilation (μμμμ ti and (σ σ ti): both total duration and burst/total duration patterned with the obligatorily assibilating condition, they did not lie in the middle.

These results do not however are not incompatible with our hypothesis. For instance, it was not found that the burst/closure ratio is larger in the non-assibilating, than in the variably assibilating context. Also, Figure 7-22 suggests that the burst/closure duration is not exactly identical in the bimoraic and in the trimoraic context, the direction of the difference points in the predicted direction. It is possible that a larger study would reveal a more complex pattern of consonant lengthening, and possibly a difference in the consonant realization which more closely resembles the distribution of assibilation in the individual dialects. These possibilities cannot be addressed by the present results.

The following section develops the formal analysis of assibilation in Finnish verbs as an instance of stress-conditioned contrast preservation in a metrically strong position. The analysis takes a cue from the acoustic analysis presented in this section. Although we did not find a perfect correspondence between the distribution of assibilation in Standard Finnish and the acoustic properties of the stop release, we claim that the proposed analysis of assibilation has significant advantages compared to previous analyses of this process. We show that it can account for most of the dialectal typology of Finnish assibilation. Furthermore, it is a restrictive account which does not rely on Positional Faithfulness, whose problematic predictions we have discussed in Chapter 2. These advantages emerge from the analysis proposed in the next section, §7.3.3, and from the comparison with previous approaches in §7.3.3.

7.3.3 Analysis

In this section we develop a formal analysis of assibilation in Finnish verbs; it is argued that the distribution of this process results from a stress-conditioned pattern of segmental contrast preservation within the stressed domain. The distribution of assibilation in Standard Finnish and
in other Finnish dialects is illustrated in (52).

(52) Dialectal typology of assibilation in Finnish verbs (adapted from: Anttila, 2006:9; Laalo, 1988:14-5, 170-6)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th>Attested</th>
<th>Sample dialect</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>ti</td>
<td>si</td>
<td>si</td>
<td>1 dialect Ingria</td>
</tr>
<tr>
<td>b.</td>
<td>ti</td>
<td>ti≈si</td>
<td>si</td>
<td>3 dialects Vermanti and Standard Finnish</td>
</tr>
<tr>
<td>c.</td>
<td>ti</td>
<td>ti≈si</td>
<td>ti≈si</td>
<td>18 dialects Southeast,</td>
</tr>
<tr>
<td>d.</td>
<td>ti</td>
<td>ti</td>
<td>ti≈si</td>
<td>1 dialect Northern Ostrobothnia</td>
</tr>
<tr>
<td>e.</td>
<td>ti</td>
<td>ti</td>
<td>ti</td>
<td>1 dialect Western Savo</td>
</tr>
<tr>
<td>f.</td>
<td>ti</td>
<td>ti≈si</td>
<td>ti</td>
<td>1 dialect Southern Ostrobothnia [si, N=1]</td>
</tr>
</tbody>
</table>

The generalization which emerges from this typology (of which Southern Ostrobothnia is the only counterexample), is that if assibilation occurs in a /ti/ sequence which follows a shorter stem, it also occurs in a /ti/ sequence which follows a longer stem. Although the present analysis focuses on assibilation in Standard Finnish, we will refer to this generalization in the development of the analysis.

The acoustic analysis presented in §7.3.2 showed that the phonetic realization of coronal stops is conditioned by stress: the stop is lengthened if it occurs within the first two morae of the word. The distribution of consonant lengthening resembles the distribution of assibilation: assibilation is always blocked in immediately post-tonic position, i.e. when the consonant is lengthened. This section shows that the preservation of the /ti/-/si/ contrast in immediately post-tonic position is a consequence of consonant lengthening in this position. Specifically, consonant lengthening increases the auditory distance between /ti/ and /si/ along the dimension which is relevant to the preservation of the contrast. We argue that this dimension is the ratio of the burst to the total duration of the consonant. We hypothesize that that the relevant perceptual dimension the Burst/Total duration ratio, (53).

(53) Burst/Total duration (BT-Dur)

The ratio of burst duration to the total duration of the consonant.

Burst is defined as the portion of the consonant which starts that the release of the stop closure and ends at the first period of voicing of the following /i/.

The acoustic data collected, and previous literature on assibilation suggest a link between stress-conditioned lengthening and assibilation which is reflected in the hierarchy of perceptual distinctiveness in (54). This hierarchy states that the contrast between a coronal stop and an alveolar fricative before /i/ is more distinct when the consonants occur in immediately post-tonic position (Yti/-Vsi), than when they occur in post-atonic position.

(54) \Delta [t]_{post-tonic} - [s]_{post-tonic} > \Delta [t]_{post-atomic} - [s]_{post-atomic}

The analysis of the perceptual asymmetry is developed as a fixed ranking of constraints requiring the minimal distance between two sounds along the [BT-dur] dimension. The set of constraints in (55) refers to the auditory dimension in (53) and requires that contrasting consonants differ in at least X on this dimension.
This measure accounts for the fact that coronal stops with are more confusable with sibilant fricatives when they have a longer [BT-Dur], that is when they occur before high front vowels (Hamman and Velkov; 2005, Hall et al., 2006). Assibilation is most frequent in those /tV/ sequences in which the ratio between burst and total duration is greatest. In German for instance, in /t/ before /j/ [BT-Dur] is 60% (ca. 85ms), in /t/ before /i/ it is about 40% (ca. 65ms) (Hall et al., 2006); this ratio is significantly lower for /t/ before /a/ and /t/ before /e/. Hamman and Velkov (2005) propose an articulatory base for the perceptual similarity between /ti/ and /si/. They show that high front vowels have a narrower constriction than the mid, low and back vowels, since they are articulated with a higher and more fronted tongue position. The small constriction causes more air to built up behind the vowel, resulting in longer (and more intense) friction.

Sibilant fricatives differ from coronal stops in having 100% [BT-Dur]: the larger the [BT-Dur] ratio in a /tV/ sequence, the greater the auditory similarity of that sequence to a /sV/ sequence.

We consider here a version of this dimension divided into arbitrary steps, of which we consider the three steps in (56). The less distinct the contrast along this dimension, the higher-ranked constraints it violates.

(56) \[ \text{MINDIST(BT-Dur):0.7} \gg \text{MINDIST(BT-Dur):0.8} \gg \text{MINDIST(BT-Dur):1} \]

The phonemic contrast between /s/ and /t/ is derived by the relative ranking of these constraints with the constraint that favors maximizing the number of contrasting segments, \text{MAXIMIZE CONTRASTS}, (57). These sounds differ along additional auditory dimensions, not just [BT-Dur]. We consider [BT-Dur] in this analysis, since we argue that the perceptual differences along this dimension are crucial in determining the distribution of assibilation.

(57) Inventory: Phonemic /t/-/s/ contrast

<table>
<thead>
<tr>
<th></th>
<th>MINDIST(BT-Dur):0.8</th>
<th>MAXIMIZE CONTRASTS</th>
<th>MINDIST(BT-Dur):1</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>/t/-/s/</td>
<td>✓✓</td>
<td>*</td>
</tr>
<tr>
<td>b.</td>
<td>/t/</td>
<td>✓!</td>
<td>✓</td>
</tr>
<tr>
<td>c.</td>
<td>/s/</td>
<td>✓!</td>
<td>✓!</td>
</tr>
</tbody>
</table>

The relative ranking of these constraints derives the optimal contrast between /t/ and /s/ as a distance of 0.8 along the [BT-Dur] dimension. The inventory specifications of these sounds are given in (58). Note that we are only considering values for singleton /t/, since geminate /tt/ never assibilates.

(58) Inventory: Target specifications for consonants

Consonant | BT-Dur |
----------|--------|
/t/       | 0.2    |
/s/       | 1      |

Consonants and vowels are also specified for their A further auditory dimension of both consonants and vowels which is relevant for the present analysis is duration, since duration is the only
acoustic correlated of word stress in Finnish. Consonant and vowel duration are contrastive in Finnish, duration specifications are illustrated in (59). These specifications refer to the durations of short and long consonants and vowels in stressless and not-lengthened position, as reported by Suomi and Ylitalo (2004:42). These target specifications of short and long segments, [C dur] and [V dur] are a transformation of the average segment durations. Long consonants are 1.7 times longer than short consonants; vowels are 2.9 times longer than short vowels. Since small sonority-based differences in duration do not affect the phonological process under analysis, the specifications refer to average vowel duration.

(59) Inventory: Duration specifications for vowels

<table>
<thead>
<tr>
<th>Segment</th>
<th>V duration (ms)</th>
<th>[V dur]</th>
</tr>
</thead>
<tbody>
<tr>
<td>/V/</td>
<td>45</td>
<td>1</td>
</tr>
<tr>
<td>/V:/</td>
<td>130</td>
<td>2.9</td>
</tr>
<tr>
<td>/C/</td>
<td>70</td>
<td>1</td>
</tr>
<tr>
<td>/C:/</td>
<td>118</td>
<td>1.7</td>
</tr>
</tbody>
</table>

Input sequences of segments drawn from the Inventory are mapped onto phonetic realizations in the Realization. Stress is assigned in this component to the leftmost vowel, and markedness constraints on metrical prominence are active.

We have claimed based on previous work on the correlates of Finnish stress, that only durational prominence is enforced on the stressed domain. The domain within metrical prominence is enforced in this language has been shown to consist of the first two morae of the word. This analysis will therefore be distinct from the other analyses of durational enhancement in this dissertation in positing a different stressed domain. We have noticed in Chapter 4, that the definition of the stressed domain within which durational prominence in enforced is not conclusively settled in this dissertation. We have reviewed experimental evidence in support of the stressed interval as the smallest metrical unit, and we have adopted it as the unit targeted by metrical constraints on durational prominence. We have nevertheless pointed out that a syllabic analysis could also account for these processes. The adoption of a further possible stressed domain which is based on moraic weight is not problematic for our model. The claims of the present model are about the constraints which can refer to stressed position, not about stress domains.

The new set of constraints requires the minimal duration of a stressed domain. It therefore requires the minimal duration of the first two morae of the word. The constraint is dened in (60).

(60) Durational Prominence constraint, moraic version: \((\#\mu\mu)_{\text{dur}} \geq X\)

The total duration of a word-initial bimoraic domain, \((\#\mu\mu)\), should not be smaller than X. The total duration of this domain is the sum of the durations of all segments contained in it.

The stressed domain can consist of either a \([C(\ddot{V}V)_{\mu\mu}]\), a \([C(\ddot{V}.C.\ddot{V})_{\mu\mu}]\), or a \([C(\ddot{V}C)_{\mu\mu}]\) sequence.

Other markedness constraints are active in the realization component. Markedness constraints targeting specifically /ti/ sequences are important for the present analysis. We adopt Clement’s (1999) and Kim’s (2001) findings that the transition noise in these sequences is generated because of the narrow stricture of the following high vowel. The sequence /t/ plus /i/ always creates
strident frication noise, which is longer than the noise produced at the release of a coronal stop followed by a non-high vowel (Hall and Hamman, 2006). We argue that an articulatory markedness constraint penalizes the realization of coronal stops which are realized without a strident frication noise, (61). We indicate phonetic realizations of stops which satisfy this constraint as [tʰi], and phonetic realizations which are penalized by this constraint as [ti].

(61)  
\*T

The release of a coronal stop before a high front vowel is realized with a strident frication noise.

This articulatory markedness constraint interacts with faithfulness constraints. One faithfulness constraint penalizes the unfaithful mapping of durational specifications from the inventory to the phonetic realization, (62). A second faithfulness constraint penalizes the unfaithful mapping of [BT-dur] specifications from the inventory to the phonetic realization, (63).

(62)  
Durational faithfulness (IDENT_{dur}):  
Corresponding input and output segments have the same value for [dur].

(63)  
Faithfulness to the ratio of burst duration to the total segmental duration (IDENT_{BT-dur}):  
Corresponding input and output segments have the same value for [BT-dur].

There are two possible strategies to create a strident frication noise. The first possibility involves increasing the both burst and closure duration of the same amount, therefore being faithful to the the target ratio of burst/total duration. The second strategy involves only increasing the duration of the frication noise, therefore being faithful to the target duration of the consonant. We indicate the phonetic realization of a candidate which adopted the first strategy as [tʰi] and the the phonetic realization of a candidate which adopted the second strategy as [t.33i]. The subscripts refers to the ratio of burst/total duration. The relative ranking of these constraints blocks the lengthening of /t/ before /i/ and yields the increase of ratio of burst/total duration of the stop. The tableau in (64) shows the derivation of the phonetic realization of /ti/ sequences. We consider the case of sequences outside of the bimoraic stressed domain for explanatory ease; the same constraint act within the stressed domain, but they interact with metrical constraints, see (66).

(64)  
Realization: /ti/ sequences outside of the stressed domain

<table>
<thead>
<tr>
<th>/σ.σˌ0.2t.pa/</th>
<th>IDENT_{dur}</th>
<th>IDENT_{BT-dur}</th>
<th>*TI</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. [σ.σˌ0.2^{a}i.pa]</td>
<td>*!</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. [σ.σˌ0.2₁i.pa]</td>
<td>*!</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. [σ.σˌ0.33^{a}i.pa]</td>
<td></td>
<td>*</td>
<td></td>
</tr>
</tbody>
</table>

Candidate (b) is the fully faithful candidate, which does not have a strident frication noise, and is thus ruled out by the articulatory markedness constraint. Candidate (a) on the other hand has a strident frication but it is also lengthened, violating the high ranked faithfulness to to segmental duration. The winning candidate, (c), has an increased ratio of burst/total duration, which corresponds to the ratio measured in the acoustic analysis for /ti/ sequences in this position.

The realization of /ti/ sequences is different when they occur within the domain of stress, i.e.
when they are within the second mora of the stressed domain (e.g. *vé,*ti*). In this position, they are targeted by metrical constraints requiring the durational prominence of the stressed domain, $\#(\mu)_d \geq X$. The relative ranking of this constraint and durational faithfulness constraints sets the threshold duration of a stressed domain; in Finnish this thresholds is attained by lengthening all segments within the stressed domain. Crucially, in order to reach the threshold, the closure of the consonant is increased; this results in a decreased burst/total duration ratio.

Although both vowels and consonants are lengthened within the stressed domain, the length contrast is not neutralized: short vowels in this domain have an average duration of 80ms, they are significantly shorter than both long vowels outside of the domain (130ms) and long stressed vowels (152ms), Suomi and Ylitalo (2004:42). The table in (65) illustrates this point reporting the segmental durations in the Realization, relative to a reference duration. The threshold on the required durational prominence is attained by lengthening all segments within the domain, without neutralizing the length distinction. The column IN/OUT indicates whether or not the segment is within the stressed domain.

(65) Realization: Consonant and vowel durations (data from Suomi and Ylitalo, 2004:42)

<table>
<thead>
<tr>
<th>Segment</th>
<th>IN/OUT</th>
<th>Duration (ms)</th>
<th>[dur]</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>OUT</td>
<td>44</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>IN</td>
<td>80</td>
<td>1.8</td>
</tr>
<tr>
<td>V:</td>
<td>OUT</td>
<td>130</td>
<td>2.9</td>
</tr>
<tr>
<td></td>
<td>IN</td>
<td>152</td>
<td>3.8</td>
</tr>
<tr>
<td>C</td>
<td>OUT</td>
<td>70</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>IN</td>
<td>85</td>
<td>1.2</td>
</tr>
<tr>
<td>C:</td>
<td>IN</td>
<td>118</td>
<td>1.7</td>
</tr>
</tbody>
</table>

The tableau in (66) derives the phonetic realization of /tí/ sequences within the stressed domain. As in the tableau in (64), subscripts indicate the ratio of burst/total duration. Subscripts to the brackets refer to the total duration of the domain.

(66) Realization: /tí/ sequences within the stressed domain

```
<table>
<thead>
<tr>
<th>/v(éti)2/</th>
<th>(#(μμ)d) ≥3</th>
<th>IDENTdur</th>
<th>*TI</th>
<th>IDENTBT-dur</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. v(éti)2</td>
<td>*</td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. v(éti)3</td>
<td>*</td>
<td>*</td>
<td>!</td>
<td></td>
</tr>
<tr>
<td>c. v(éti3i)3</td>
<td>*</td>
<td>*</td>
<td>!</td>
<td></td>
</tr>
<tr>
<td>d. v(éti3i)3</td>
<td>*</td>
<td>*</td>
<td>!</td>
<td></td>
</tr>
</tbody>
</table>
```

The winning candidate in (d) satisfies both the articulatory effort constraint and the metrical constraint on durational prominence. The comparison between this candidate and the winning candidate outside of the stressed domain, (64)(c) highlights the differences between the realization of the stops in difference prosodic position. Coronal stops before high front vowels have a longer portion of strident burst when they occur outside of the stressed domain (e.g. [(pápa)t0.33iipa]) compared to when the occur within it ([v(éti2i)])).

The phonetic realization of sibilant fricatives is also conditioned by its position relative to the stressed domain. However, given the absence of a closure phase, this effect is limited to the presence
or to the absence of durational enhancement.

The phonetic realization of coronal stops and alveolar fricatives before front vowels is evaluated in the Evaluation component for both prosodic contexts, i.e. within- and outside of the stressed domain. The analysis of the effect of consonantal lengthening on the distribution of the segmental contrast is very similar to the analyses of Copala Trique and Italian presented in previous sections of this dissertation. The difference between the present case studies and the previous ones, is the markedness constraint which triggers the stress-conditioned phonetic effect in the Realization. In Copala Trique and in Italian the preservation of contrast in stress-adjacent consonants is a side-effect of enhancing the loudness of the stressed vowel. In Finnish on the other hand, the preservation of the [ti]-[si] contrast in post-tonic position is a consequence of stress-conditioned lengthening on the relative duration of a strident burst.

The evaluation of surface contrasts is derived in the tableau in (67) for segments occurring outside of the stressed domain. The ranking of MINDIST constraints with respect to *MERGE in the Evaluation corresponds to the ranking of MINDIST with respect to MAXIMIZE CONTRASTS in the Inventory: the minimum level of distinctness that is acceptable between two contrasting sounds which differ along the [BT-dur] dimension is 0.8.

(67) 
**Evaluation: Contrast neutralization outside of the stressed domain**

<table>
<thead>
<tr>
<th>[(\sigma.\sigma.\text{[t]}_{0.33^*}i.p)]-[(\sigma.\sigma.s_i)]</th>
<th>MINDIST(BT-Dur):0.8</th>
<th>*MERGE</th>
<th>*(T^S_i)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. (\sigma.\sigma.\text{[t]}_{0.33^*}i.p)]-[(\sigma.\sigma.s_i)]</td>
<td>*!</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>b. (\sigma.\sigma.\text{[t]}_{0.33^*}i.p)]</td>
<td>*</td>
<td>*!</td>
<td></td>
</tr>
<tr>
<td>c. (\sigma.\sigma.s_i)</td>
<td>*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The contrast between the surface realizations of [t] and [si] in the context of a following [i] violates this constraint (a). The contrast is neutralized in the two remaining candidates. The preference of candidate (c) over (b) arises from the action of a lowanked markedness constraint which penalizes the occurrence of a coronal before [i], if it is not completely assibilated. This constraint, *\(T^S_i\), is one of a fixed hierarchy of assibilation favoring articulatory markedness constraints (Hall and Hamann, 2006), of which *TI is a higher ranked member, (68).

(68) \(*T^T_J \gg *T_I \gg *T^S_i \gg *S_i\)

The evaluation of the [ti] and [si] contrast within the stressed domain yields contrast preservation. Contrast preservation in this position is derived in (69).

(69) 
**Evaluation: Contrast preservation within the stressed domain**

<table>
<thead>
<tr>
<th>[(\sigma.\sigma.\text{[t]}_{0.2^*}i.p)]-[(\sigma.\sigma.s_i)]</th>
<th>MINDIST(BT-Dur):0.8</th>
<th>*MERGE</th>
<th>*(T^S_i)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. (\sigma.\sigma.\text{[t]}_{0.2^*}i.p)]-[(\sigma.\sigma.s_i)]</td>
<td>*!</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>b. (\sigma.\sigma.\text{[t]}_{0.2^*}i.p)]</td>
<td>*!</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. (\sigma.\sigma.s_i)</td>
<td>*!</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The difference between this prosodic context and the one described above is the different phonetic realization of the [ti] sequence. Within the stressed domain a long and strident burst is produced without altering the target [BT-dur] value specified in the Inventory (\(t: [BT-dur]=0.2\)).
The auditory distance in this context is large enough to be preserved (a). The assibilating candidate (c) is ruled out by *MERGE, which penalizes neutralization of contrasts.

We have so far derived the pattern of assibilation for the two extreme prosodic contexts, namely one in which the /ti/ sequence occurs far from the stressed domain (σ.σ.ti) and on in which the sequence is within the stressed domain, and immediately post-tonic (μ.ti). We have not yet considered the behavior of realization /ti/ when it occurs out side of the stressed domain but immediately following a stressed vowel. This is the context in which /ti/ follows a bimoraic stem (μμ.ti), and the stressed domain is either a long vowel or a diphthong ([C(VV)μμ], e.g. huuti, vuoti).

These are the contexts which may pattern like the [σ.σ.ti] and [μμμ.ti] contexts in showing obligatory assibilation (e.g. Ingria dialect), or show variable assibilation (e.g. Standard Finnish). The acoustic analysis of Standard Finnish speakers presented in §7.3.2 has not revealed that [ti] sequences in this context are realized in a significantly different way from [ti] sequences which are obligatorily assibilated in verbs. The analysis has only shown a tendency in the predicted direction: the ratio of burst/total duration in the variably assibilating context is smaller than after a trimoraic stem (obligatory assibilation), 0.31 vs. 0.35. This difference was shown in Figure 7-22. Closure duration is slightly increased in immediately post-tonic position, even after a long vowel or a diphthong: 75ms after [μμμ.ti] and [σ.σ.ti], and 81ms after a stem, [C(VV)μμ].

We suggest that variable assibilation in this context might arise from the variable ranking of MINDIST(BT-Dur) constraints relative to *MERGE, (70). The dotted lines indicate the two possible ranking permutations of the two MINDIST(BT-Dur) constraints is allowed, they do not indicate that the constraints are unranked.

(70) Variable assibilation in Standard Finnish verbs, following a bimoraic stem

<table>
<thead>
<tr>
<th>[huu.t0.3i.pa]–[huu.s1i]</th>
<th>MINDIST(BT-Dur):0.7</th>
<th>*MERGE</th>
<th>MINDIST(BT-Dur):0.8</th>
<th>*r3i</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. [huu.t0.3i.pa]–[huu.s1i]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. [huu.t0.3i.pa]</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. [huu.s1i]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The tableau in (71) shows that the variable constraint ranking does not yield variable assibilation in the case of a [ti] sequence following a trimoraic stem. This ranking also does not change the predicted outcome of obligatory assibilation after disyllabic stems.

(71) Obligatory assibilation in Standard Finnish verbs, following a trimoraic stem

<table>
<thead>
<tr>
<th>[kaar.t0.33i.pa]–[kaar.s1i]</th>
<th>MINDIST(BT-Dur):0.7</th>
<th>*MERGE</th>
<th>MINDIST(BT-Dur):0.8</th>
<th>*r3i</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. [kaar.t0.33i.pa]–[kaar.s1i]</td>
<td>*(!)</td>
<td></td>
<td>*(!)</td>
<td>*</td>
</tr>
</tbody>
</table>
| b. [kaar.t0.3i.pa] | | * | | *
| c. [kaar.s1i] | | | | |

A grammar which allows for the possibility of a variable ranking of the three constraints MINDIST(BT-Dur):0.7, *MERGE and MINDIST(BT-Dur):0.8 derives the distribution of the pro-
cess in dialects with variable assibilation after a bimoraic stem and dialects in this assibilation is only blocked after a monomoraic stem, (72).

Dialectal typology of assibilation in Finnish verbs (adapted from: Anttila, 2006:9; Laalo, 1988:14-5, 170-6)

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Sample dialect</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. $\text{MINDIST}(\text{BT-Dur}):0.7 \gg \text{MINDIST}(\text{BT-Dur}):0.8 \gg \ast\text{MERGE}$</td>
<td>Ingria</td>
</tr>
<tr>
<td>ti si si</td>
<td></td>
</tr>
<tr>
<td>b. $\text{MINDIST}(\text{BT-Dur}):0.7 \gg \text{MINDIST}(\text{BT-Dur}):0.8 \gg \ast\text{MERGE}$</td>
<td>Standard Finnish</td>
</tr>
<tr>
<td>ti ti si</td>
<td></td>
</tr>
</tbody>
</table>

Although the full dialectal typology of assibilation in Finnish verbs, (52), could be derived by the ranking of the same constraints families, allowing for variable rankings, the derivation of the full typology is beyond the scope of this chapter.

### 7.3.4 Summary

This section has developed an analysis of a pattern of stress-conditioned contrast preservation within a stressed domain, namely the assibilation in Finnish. This study has the following two aims. **Fist,** to provide a thorough formal analysis of this process, supported by an acoustic analysis. **Second,** to demonstrate a further case of contrast preservation which arises as the consequence of prominence enhancement. In this analysis, the blocking of assibilation arises as a consequence of markedness constraints enforcing the durational prominence of the stressed domain, it does not arise from the action of Positional Faithfulness constraints to $[\pm\text{strident}]$ (see §7.3.5 for a comparison with a Positional Faithfulness analysis this process. This case study falls within the the greater class of contrast preservation in stressed positions, or in the vicinity of stress analyzed in this dissertation. It is a further demonstration of how metrical requirements affecting the stressed domain, or the stressed vowel, can have side-effects of the phonetic realization of segments in the adjacency of stress.

The acoustic analysis of Finnish $[ti]$ sequences supports the proposed account: coronal stops within the stressed domain are realized with an increased closure duration, in order to satisfy the metrical constraint on durational prominence which is active in the language. The result of this enhancement is that even before high front vowels, the burst/total duration ratio is small. We have argued that these side-effect are perceptually salient. Although a discrimination experiment was not carried out for Finnish, we claim that the differences in phonetic realizations observed in the acoustic analysis give rise to a perceptual asymmetry in the discrimination of the $[ti]-[si]$ contrast, (73). Sequences of $[t]$ plus $[i]$ in this position ($\mu_{.ti}$) are perceptually distinct from a $[\mu_{.si}]$ sequence in the same context.

\[
(73) \quad \Delta [t_{0.2\delta i}]-[si] > \Delta [t_{0.3\delta i}]-[si] > \Delta [t_{0.33\delta i}]-[si]
\]

The analysis of this process was cast within the formal model adopted in this dissertation (Fleming, 2004, 2006). The full constraint ranking for this analysis of the stress-conditioned assibilation in Finnish verbs is given in Figure 7-23 below. A separate constraint ranking is provided for the Inventory and the Evaluation components, since the variability in the constraint ranking is only attested in the former component, Figure 7-23(a) and Figure 7-23(b). A ranking is provided for
the Realization in Figure 7-23(c).

Figure 7-23: Finnish: Full ranking of constraints in the Inventory (a), Evaluation (b) and Realization component (c)

7.3.5 Comparison with previous analyses

Anttila (2003, 2006) has proposed a radically different analysis of assimilation in Finnish verbs. The analysis is built around two central claims. The first claim is that segmental features occurring within the main stressed foot cannot be altered. The crucial constraints in Anttila’s analysis are listed in (74), from Anttila (2006:12).

\[(74)\]

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IDENT\(\varphi(F)\)  Do not alter the features of a segment within a foot.
PARSE-\(\sigma\)  Syllables belong to feet.
*TERNARY  Prosodic constituents are at most binary.
*TI  No ti-sequences (Kim, 2001)

The first grammatical constraint in (74), \((\text{IDENT-}\varphi(F))\), belongs to the large family of Positional Faithfulness constraints which have been proposed in the literature (among others, Beckman, 1998; Smith, 2002). We have argued against Positional Faithfulness analyses of prosodic conditioning in Chapter 2, demonstrating that this model is not able to generate the attested typology of stress-conditioned segmental alternations. Specifically, this theory greatly overgenerates the predicted patterns of faithfulness to features within a metrically strong position. It has been shown that the challenge of Positional Faithfulness to restrict the set of features which can be the targeted by stress-conditioned processes increases greatly if the stressed foot is included among the phonetically privileged positions. The existence of IDENT-\(\varphi(F)\) constraints predicts all sort of non-attested cases of Positional Faithfulness to any feature within the stressed foot.

We have argued that Positional Faithfulness analyses of contrast preservations within metrically strong positions, be they stressed syllables of main-stressed feet, are inadequate. The analysis of Finnish assibilation, like the analysis of other similar processes (e.g. Italian palatalization), are developed as a theoretically, and typologically adequate alternative to positional faithfulness.

The second claim of this analysis is a model of variation. Anttila develops the analysis of the full dialectal typology of Finnish assibilation in terms of the Multiple Grammar Theory (Anttila, 2002; Kiparsky, 1993; Kroch, 1989). The central assumption of this theory is stated in (75) (Anttila, 2006:14). Within Optimality Theory, this assumption means that “any combination of strict rankings is a possible grammar ” (Anttila, 2006:14).

The Multiple Grammar Theory:
Variation results from multiple invariant grammars within or across individuals.

Our analysis of assibilation, though fundamentally distinct from Anttila’s, adopts a similar version of this assumption to account for the variability across and within dialects. The variability in our analysis was introduced in a small part of the grammar, it was not introduced as a model of variation. It is very likely that a version of the mechanisms proposed by Anttila will be proved necessary to extend out account to the full typology. The addition of a theory of variation is not incompatible with our account.

The tableaux in (76) shows three examples of the constraint violations of three stem types analyzed in the previous sections, monomoraic, bimoraic and disyllabic stems. We follow Anttila in indicating harmonically bounded candidates by \#. Every grammar is a permutations of these rankings give rise to a factorial typology which covers 24 out of the 25 dialects in Laalo’s corpus.

\[ \text{Assibilation (Anttila, 2006:13)} \]

<table>
<thead>
<tr>
<th>/vet(\text{-})i/</th>
<th>IDENT(\varphi(F))</th>
<th>*TI</th>
<th>PARSE-(\sigma)</th>
<th>*TERNARY</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. (\text{aw} ) (v(\text{-})ti)</td>
<td>#</td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. (v(\text{-})si)</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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We have tested the hypothesis that the nature of the prominence requirements active in the Realization gives rise to different phonetic effects of stress on the segments within a prominent position. We predicted that in Finnish prominence requirements on segments within the stressed interval affect the durational properties of segments, whereas in Italian the increase of the perceptual energy of the stressed vowels has side-effects on the realization of burst properties of stress-adjacent plosives. This hypothesis is supported by the acoustic analysis of the segments which participate in the phonological processes, in different prosodic conditions. We have shown that the extent to which acoustic properties of consonants are affected by prominence requirement is determined by the grammatical constraint which enforces prominence. The realization of stress-adjacent consonants in Italian is conditioned by stress: their burst properties are significantly distinct from properties of non stress-adjacent consonants. Stress-adjacent consonants in Finnish on the other hand, are only lengthened. The lack of a loudness increase on the stressed vowel in this language results in the lack of phonetic enhancement.

The second test in by the experiments presented in this chapter is that the phonetic effects of stress on the realization of adjacent consonants affect the perceptibility of segmental contrasts, and therefore affect the phonological distribution of the contrasts. It was shown that the perceptibility of the contrast between velar stops and palatoalveolar affricates before /-i/ varies depending on the presence or absence of prominence-triggered effects on the realization of the consonant. The results of the experiments presented in this chapter provide a substantial basis for the analysis of phonological processes which emerge from the side-effects of metrical requirements to enhance the prominence of the stressed domain. They provide support to the claim that the preservation of segmental contrast in stress-adjacent consonants arises as a side-effect of prominence-enhancement in these positions.

### 7.4 Summary

We have tested the hypothesis that the nature of the prominence requirements active in the Realization gives rise to different phonetic effects of stress on the segments within a prominent position. We predicted that in Finnish prominence requirements on segments within the stressed interval affect the durational properties of segments, whereas in Italian the increase of the perceptual energy of the stressed vowels has side-effects on the realization of burst properties of stress-adjacent plosives. This hypothesis is supported by the acoustic analysis of the segments which participate in the phonological processes, in different prosodic conditions. We have shown that the extent to which acoustic properties of consonants are affected by prominence requirement is determined by the grammatical constraint which enforces prominence. The realization of stress-adjacent consonants in Italian is conditioned by stress: their burst properties are significantly distinct from properties of non stress-adjacent consonants. Stress-adjacent consonants in Finnish on the other hand, are only lengthened. The lack of a loudness increase on the stressed vowel in this language results in the lack of phonetic enhancement.

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Chapter 8

Conclusion

This dissertation opens with the striking empirical observation that there are very few segmental processes that show sensitivity to stress: the major segmental processes affecting consonants (e.g. place assimilation, nasalization and voice neutralization) are not sensitive about whether their trigger or target is in a stressed position. The dissertation is aimed at developing a novel account of metrical conditioning which can account for the restricted number, and for the specific nature of these processes. We summarize the main parts of the model presented here.

Three main claims are presented and argued for in this dissertation. First, we have shown that every stress-conditioned process is enforced by a markedness constraint requiring the perceptual prominence of a metrically strong position. There are two strategies used by languages to implement this prominence: to increase the duration of the stressed position, or to increase the perceptual energy of the stressed vowel. Since increasing the loudness of the stressed vowel has side-effects on the realization of stress-adjacent stop releases, there is an additional class of stress-sensitive processes which are not directly enhancing the prominence of the stressed position, but which are the consequence of these side-effects. Second we have argued that the phonological processes which don’t show stress-sensitivity cannot be sensitive to stress, since they do not they arise as side-effects of loudness enhancement on the stressed vowel, nor are they triggered by markedness constraints enforcing the perceptual prominence of the stressed position. The set of segmental features which may be targeted by stress-sensitive processes is extremely limited since it is restricted to those features which can be affected by one of three processes: duration, loudness and effects of raised subglottal pressure on stop releases. Third, both the effects of prominence requirements and the side-effects of prominence enhancement on the phonetic realization of segments in stressed positions may affect the perceptual distinctiveness between contrasting sounds in stressed positions. If the perceptual distinctiveness between contrasting sounds is decreased in a stressed position, contrast neutralization might arise. If the perceptual distinctiveness between contrasting sounds is increased in a stressed position, stress-conditioned contrast preservation might arise. Contrast preservation in stressed positions emerges as the indirect consequence of prominence enhancement. This analysis departs from previous analyses that rely on the notion of positional privilege. These accounts analyze the range of possible stress-sensitive alternations as arising from either the grammatical pressure to be preferentially faithful to segmental features within a stressed position, or the grammatical pressure to enhance the perceptual prominence of the stressed position. The experimental results presented in this dissertation show that cases of contrast preservation in stress-adjacent consonants coincide with the increased perceptibility of segmental contrasts in these positions.
compared to far from stress environments. This perceptual asymmetry does not arise because of the greater attention to segmental contrasts in the vicinity of stress. The asymmetry is determined by the acoustic properties stress-adjacent stop consonants, which are affected by either directly by prominence requirements (e.g. Finnish), or by their side-effects (e.g. Italian). These results are important since they provide support to the claim that stressed positions are not loci of positional privilege. Instead they are metrically strong positions which are the targets of prominence requirements and of the side-effects of prominence requirements, which affect the phonetic realization of segments within them, and in their adjacency.
Chapter 9

References


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