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The Interaction of Domain-initial Effects with Lexical Stress: Acoustic Data from English, Spanish, and Portuguese

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THE INTERACTION OF DOMAIN-INITIAL EFFECTS WITH LEXICAL STRESS: ACOUSTIC DATA FROM ENGLISH, SPANISH, AND PORTUGUESE

by

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DISSERTATION

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DEDICATION

To all women in science

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ABSTRACT

The phonetic implementation of domain-initial boundaries has gained considerable attention in the literature. However, most studies of the phenomenon have investigated small samples of articulatory data in which target syllables were lexically prominent and/or phrasally accented, introducing important potential confounds. This dissertation tackles these issues by examining how domain-initial effects operate on the acoustic properties of fully unstressed word-initial CV syllables in phrasally unaccented words. Similar materials were designed for a reading task in which 14 speakers of English, Spanish and Portuguese, languages that differ in how lexical prominence affects segmental makeup, took part. Results from the acoustic analyses show that domain-initial effects extend further than previously suggested, and that these interact with lexical stress in language-specific ways. These findings highlight how the marking of domain-initial boundaries relates to both the prominence and grouping functions of prosody, and suggest a linguistic, rather than purely biomechanical, motivation for domain-initial effects.

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CHAPTER 1

INTRODUCTION

1.0 Dissertation Overview

This dissertation presents an experimental and theoretical investigation of prosodic boundaries and how they relate to language-specific phonological patterns. Concretely, it looks at how boundary marking at the left edges of prosodic domains influences the realization of unstressed syllables in three languages with differing phonetic correlates of lexical stress. Although various studies have addressed prosodic boundaries and lexical stress separately, few have examined how their interaction may impact the phonetic characteristics of segments and, by consequence, of the syllables that contain these segments as a whole. This investigation examines the interplay of lexical stress and boundary marking through a cross-linguistic acoustic study of English, Spanish, and Portuguese.

1.1 Motivations for the Current Study

In written language, capitalization generally signals the beginning of a new sentence and punctuation often marks its end. In speech, various phonetic adjustments play a role similar role to capitalization and punctuation by marking the beginnings and endings of prosodic phrases. In addition to the suprasegmental nature of prosodic structure, a growing body of experimental investigations suggests that it also influences the phonetic realization of individual SEGMENTS in systematic ways (see Fougeron 2001, Cho 2015 for detailed reviews). What's more, the results of these studies show that speakers use language-specific gradient phonetic detail to group their speech into meaningful units (e.g. Keating et al. 2003, Cho & McQueen 2005).

From a top-down perspective, the edges of prosodic phrases contain information that may aid in speech comprehension, since speakers manipulate prosodic boundaries to divide up the speech stream (e.g. Carlson 2009). The investigation of the ways in which prosodic structure modulates phonetic information thus offers important contributions to our understanding of how speech is organized (see also Shattuck-Hufnagel &Turk 1996, Fletcher 2010, Wagner & Watson 2010) and perceived (Mo & Cole 2010). Moreover, the examination of how fine-grained segmental content may signal prosodic domain edges provides insight into the phonetic reality of language-specific prosodic structure.

From a bottom-up (segmental) viewpoint, results from various languages suggest that prosodic structure might play a more important role in the phonetic makeup of vowels and consonants than previously estimated. In particular, three aspects of prosody may affect segmental properties in relevant ways: lexical stress, phrasal accent, and prosodic phrasing (see Section 1.3 below). The investigation of the initial edges of prosodic phrases can offer useful data to explain why consonant strengthening (or fortition) and weakening (or lenition) are observed in specific prosodic positions (cf. Keating 2004, see also Cole & Hualde 2013).

The study presented here examines the interplay of two aspects of prosody, namely lexical stress and phrasing. Specifically, it addresses how the phonetic implementation of phrasing affects unstressed syllables at the left edge of a prosodic domain. Three languages in which stress patterns affect the phonetic makeup of syllables were selected for comparison: English, Spanish, and Portuguese.

This investigation is partially motivated by the vast evidence suggesting that unstressed syllables show both phonetic and phonological differences from their stressed counterparts (Crosswhite 2001, Gordon 2011). One of the arguments put forward in this dissertation is that such quantitative and qualitative differences are best accounted for when various levels of prominence are considered simultaneously. In order to support that claim, this study explores the phonetic and phonological factors that influence the marking of the left edge of prosodic domains.

The need for such an in-depth exploration also stems from the observation that despite a great deal of research on prosodic domain endings (e.g. Fletcher 2010, Cho 2015) the phonetic encoding of the BEGINNING of prosodic units is much less understood. Aiming for a clearer assessment of domain-initial boundaries and of prosody more broadly, this dissertation tackles four main unresolved issues:

i. The relationship between boundary-initial marking and other levels of prominence such as lexical stress.
ii. The scope of the temporal effect of boundary-initial marking with regards to the prosodic boundary.
iii. The role of language-specific phonology in the phonetic manifestation of domain-initial effects.
iv. The ways in which domain-initial boundaries are expressed in the acoustic signal.

The current study aims to address these four issues by investigating domain-initial boundaries on unstressed syllables in American English, Mexican Spanish, and Brazilian Portuguese. The examination of unstressed syllables at an initial boundary has the benefit of isolating domain-initial effects from lexical stress, hence allowing for a clearer estimation of their scope of influence. Moreover, a direct comparison (i.e. through similar experimental materials) of languages whose unstressed syllables show distinct phonetic properties allows for a more straightforward assessment of how language-specific patterns influence the phenomenon. Finally, the acoustic results presented here based on the analysis of 52 speakers of the three languages, provide robust quantitative data that may disentangle some of the issues in previous small-scale articulatory studies.

The next section introduces the broad context in which the dissertation is framed, that is, prosody.

1.2 The Functions of Prosody

Prosody refers to the grouping of speech units into larger groupings as well as to the prominence relations both within and between those units (e.g. Selkirk 1984, Nespor & Vogel 1986/2007, Beckman & Pierrehumbert 1986). Each of these groupings constitutes a prosodic constituent or DOMAIN. In turn, inside each prosodic domain, given elements are assigned special status or PROMINENCE. The specific section of the speech stream that receives prosodic marking as a function of either grouping or prominence then constitutes the LOCUS of the effect (White 2002).

The prominence function of prosody serves to create contrasts within and across individual domains. For instance, stress languages like English, Spanish, or Portuguese distinguish a prominent syllable from less prominent ones in the domain of the word (see Section 1.3.1). Since all segments that comprise the prominent syllable are affected by stress (see below), the locus of word prominence is thus one syllable within the word domain. In a larger domain like the prosodic phrase, prominence can be employed to differentiate an entire word or noun phrase from neighboring units (Jun 2005b). For instance, if the sentence *I saw my cousin Camilla* is uttered as a neutral declarative statement, the main phrase-level prominence would distinguish *Camilla* from all the words that precede it. If the same phrase were being uttered as a correction in response to *You saw your ex-wife Camilla?* the main phrasal prominence would likely fall on *cousin*. The locus of phrase-level prominence in this example is hence a contextually determined word (see also Section 1.3.2 below). In contrast to a smaller domain like the word, the effects of phrasal prominence go beyond the stressed syllable, and may encompass the entire phrasally prominent word (e.g. Turk & Sawusch 1997, Frota 2000).

It is noteworthy that the main phrasal prominence in languages with lexical stress tends to be associated with in the stressed syllable of a given word within the domain (Beckman 1996). This particular co-occurrence of two levels of prominence is illustrative of the CULMINATIVE aspect of prosody, in that higher level prominence is implemented on already salient (i.e. the stressed syllable) units in a domain (Trubetskoy 1969, Beckman 1996). This is the case in all three languages in the current sample (e.g. Pierrehumbert 1980 for English; Hualde & Prieto 2015 for Spanish; Frota et al. 2015 for Portuguese, *inter alia*). For instance, the stressed syllable in the word *Camila* from the example above is the locus of lexical prominence AS WELL AS the anchoring point for main phrasal prominence.

The grouping function of prosody - its DELIMITATIVE component - serves a key organizational role in speech, whereby prosodic boundaries delimit units that facilitate language processing (cf. Krivokapić 2014). In this view, depending on speakers' choices and on the phrasing possibilities available, speech may be structured in units that are independent of the syntactic structure of a given language (see Wagner & Watson 2010, Cole 2015 for overviews). Although allowing for more variation than syntactic constituents, the grouping of prosodic units manifests patterns that characterize a type of structure in its own right. This insight was developed within the concept of the PROSODIC HIERARCHY, detailed below.

1.2.1 The Prosodic Hierarchy

Nespor and Vogel (2007/1986) present the theory that prosodic groupings are hierarchically arranged domains that constitute the sphere of application of language-specific phonological and phonetic processes. In the prosodic hierarchy, domains at lower levels group together to form higher level domains. For instance, syllables (σ) group into a Foot (Σ), Feet group into Phonological Words (ω), Phonological Words group into phrases like the Intonational Phrase (IP), which in turn are grouped into the Utterance (U) at the highest level (Nespor & Vogel 2007/1986, see also Selkirk 1984, Pierrehumbert & Beckman 1986). Different types of prominence mark distinct domains of the hierarchy: stress is associated with the phonological word level, whereas pitch accents are associated with above-the-word domains (see next section). Although the number of prosodic domains postulated for each language varies, all languages appear to group smaller units into larger domains (Nespor & Vogel 2007/1986, Jun 2005a, 2014, Ladd

2008, Büring 2016). This study makes use of this shared property to test its hypotheses. Figure 1-a depicts a version of the prosodic hierarchy that highlights the edges of the domains.

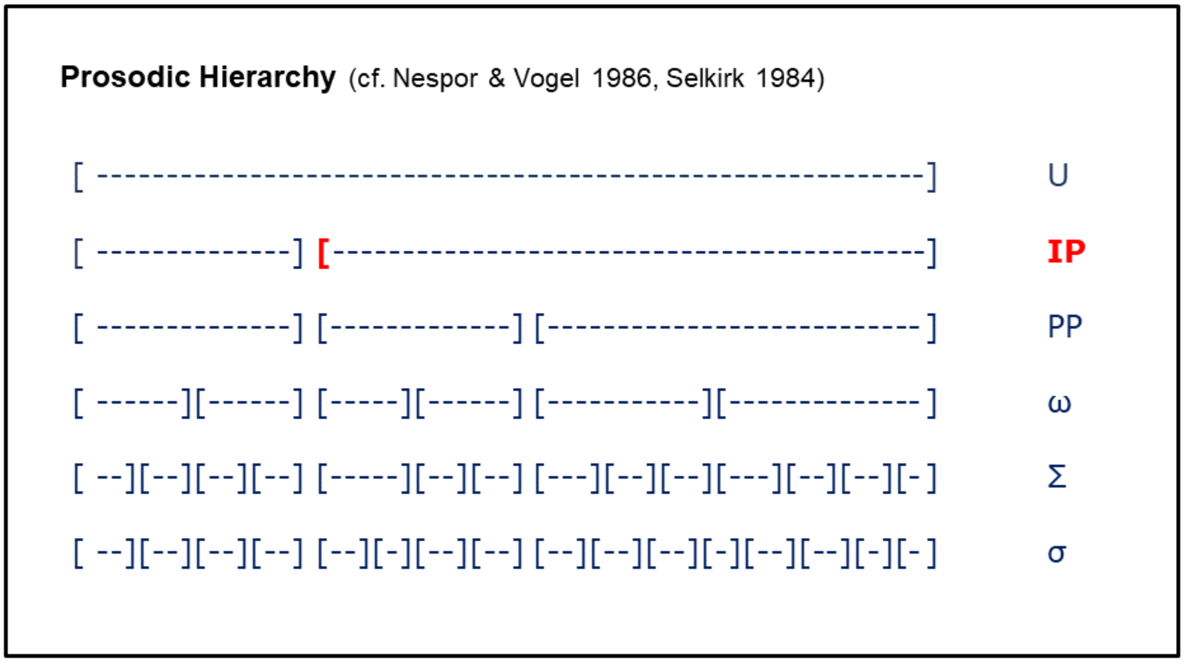

Figure 1-a. Prosodic hierarchy showing various domain levels and boundaries

The domain levels depicted in the diagram are the Utterance (U), the Intonational Phrase (IP), the Phonological Phrase (PP), the Phonological Word (ω), the Foot (Σ), and the Syllable (σ). The diagram depicts a single Utterance comprised of two Intonational Phrases, and the respective domains that are grouped within each IP. The prosodic domain and the boundary investigated in this dissertation are shown in red.

This dissertation investigates how segmental information signals prosodic structure in terms of one of its initial boundaries (shown on the left edge of each domain in Figure 1-a). The notion of PROSODIC BOUNDARIES derives from the common cross-linguistic association of a domain edge with various combinations of spatiotemporal, pausal and pitch events. As mentioned above, although languages can differ in what domains are clearly evidenced and how these are implemented, there is enough evidence to suggest that the prosodic hierarchy may be universal. The association of spatiotemporal events with prosodic domain boundaries can be illustrated by a recent acoustic description of prosodic domains in European Portuguese.

Frota (2014) presents acoustic data that illustrate how a segmental process signals the domain of the IP in European Portuguese. In many varieties of Portuguese, a historically voiceless alveolar /s/ palatalized to [ʃ] in word-final position, as in *livros* /ˈlivɾus/ > [ˈlivɾuʃ] 'books'. However, when a word that follows a word-final /s/ begins with a vowel, the word-final fricative may be pronounced [z], for instance in *livro***[z]** ***ó****timos* 'great books'.

Frota's study compared various instances of word-final <s> followed by a word-initial vowel across different prosodic domains through a reading experiment. In order to determine the role of prosodic domain levels in the alternation between [ʃ] and [z], one version of the sentences introduces punctuation marks to elicit different prosodic groupings of the words containing the target sequence /s/ # *vowel*. The following examples, in which square brackets represent prosodic boundaries, adapted[1] from Frota (2014) for clarity purposes, summarize her findings (2014:14):

1.1 A**s** **a**luna**s** **o**btiveram boa**s** **a**valiaçõe**s**.
[a**[z]** aluna**[z]** obtiveram boa**[z]** avaliaçõe**[ʃ]**]$_{\mathbf{IP}}$
The female students got good grades

1.2 A**s** **a**luna**s**, **a**té onde sabemo**s**, **o**btiveram boa**s** **a**valiaçõe**s.**
[a**[z]** aluna**[ʃ]**]$_{\mathbf{IP}}$ [até onde sabemo**[ʃ]**]$_{\mathbf{IP}}$ [obtiveram boa**[z]** avaliaçõe**[ʃ]**]$_{\mathbf{IP}}$
The female students, as far as we know, got good grades

[1] Prosodic phrasing and phonetic transcriptions are Frota's; translations and graphic enhancements added by the present author.

In Example (1.1), all instances of word-final <s> and a vowel in the following word are pronounced [z], as in *a*[z] **a***luna*[z] **o***btiveram* 'the female students got'. The only occurrence of word-final [ʃ] is in the last word of the sentence, *avaliaçõe*[ʃ] 'grades'. However, when an additional Intonational Phrase is added in 1.2, introducing a new prosodic break after the word *alunas*, Frota reports that a word-final [ʃ] then also occurs in that word: *aluna*[ʃ]. Furthermore, the break introduced by the insertion of a new IP also affects the last word in it, *sabemo*[ʃ] 'we know'. That is, prosodic breaks elicit the occurrence of [ʃ] despite the fact that *alunas* and *sabemos* are immediately followed by /a/ and /o/ in the following words (***a****té* and ***o****btiveram*, respectively).

Frota (2014) concludes that the process of fricative voicing is restricted to domains BELOW the Intonational Phrase, since words ending in <s> show [z] anywhere but before an IP boundary (pp. 12-14). The author also suggests that the differences in the production of word-final fricatives in Examples (1.1) and (1.2) indicate that word-final [ʃ] is one of the phonetic cues that mark the end of an IP in European Portuguese. Frota's data indicate that the distinct possibilities for grouping words in speech play a role in how a segmental process operates. In other words, the processes of voicing and palatalization of word-final /s/ are segmental reflexes of two levels of the prosodic hierarchy, namely the final boundaries of the Prosodic (Phonological) Word and the Intonational Phrase.

The prosodically conditioned phonetic manifestation of word-final European Portuguese fricatives is by no means an isolated example. Direct evidence for the hierarchical organization of prosodic structure is often found in systematic differences in the phonetic encoding of different domain boundaries in various languages (Nespor & Vogel 2007/1986, Shattuck-Hufnagel & Turk 1996, among others).

The concept of BOUNDARY STRENGTH refers to the correlation of domain prosodic contexts and phonetic cues. Prosodic research has found that prosodic domains that are higher in the hierarchy (e.g. the IP) show a fuller range of phonetic markings of their boundaries than smaller ones such as the Word (de Pijper & Sanderman 1994, Prieto, van Santen, & Hirschberg 1995, Fougeron & Keating 1997, Frota et al. 2007, among others). Major phonetic cues to boundary markings may include specific pitch contours, occurrence of long silent pauses, changes in speech rate, among others. Because the range of phonetic events associated with higher domain boundaries is assumed to accrue incrementally, levels of the prosodic hierarchy can thus be assessed by comparing the phonetic properties of the boundaries themselves. The specific effects of prosody on the phonetic makeup of segments is explored in more detail in the next section.

1.3 Prosodically Conditioned Phonetic Variation

The prosodic structure of a language and the phonetic manifestation of its segments are intrinsically intertwined. Along with extralinguistic factors, prosody is one of the main sources of speech variation that influences segmental information. In this section, four types of prosodic markings are reviewed in terms of their effects on segments. Special attention will be devoted to those markings in the languages of the sample. Thus, lexical stress, phrasal accent, domain-final lengthening, and domain-initial effects (the latter two falling under the prosodic phrasing category) are explored here, whereas the last part of this section addresses how these different levels of prosodic structure operate in concert.

In order to avoid the confusion between similar terms for different phenomena, the terms STRESS and ACCENT will be used consistently henceforth to refer to lexical and main (nuclear) phrasal prominence respectively, with no overlap between the uses of the two words. The term PITCH ACCENT (Beckman & Edwards 1994) will be used to refer to the specific f0 contours that signal other types of phrase-level prominence other than the phrasal accent. The umbrella term that covers all of these manifestations is referred to as PROMINENCE throughout the dissertation.

1.3.1 Lexical Stress (Word-level Prominence)

LEXICAL STRESS is defined here as the strongest acoustic prominence in a polysyllabic word. By definition, it is a type of prominence that refers to the level of the (Phonological) Word. In turn, the locus of the effect of lexical stress is a specific SYLLABLE within the word. Lexical stress operates by increasing the salience of the stressed syllable in relation to the other syllables within the word (van der Hulst 2014). In lexical stress languages such as English, Spanish, and Portuguese, there is one syllable in every polysyllabic word that shows a combination of acoustic and articulatory properties that sets it apart from all the other syllables. The examples below use capitalized letters to depict lexically stressed syllables in words with antepenultimate, penultimate and final stress in the three languages:

(1.3) MEDical, toMAto, braZIL ENG[2]

(1.4) MÉdico[3], toMAte, braSIL SPA

(1.5) MÉdico, toMAte, braSIL POR

In terms of phonetic properties, vowels in lexically stressed syllables tend to show increased duration, rises in f0 movement, amplitude, intensity or a combination of some or all of these (Lehiste 1970, Beckman 1986). Consonants in stressed syllables may also show phonetic differences such as increased duration, longer voice onset time (VOT), tighter closure of the different articulators, wider jaw movement, reduced coarticulation between segments, among others (cf. de Jong, Beckman & Edwards 1993, Beckman & Edwards 1994, Krakow 1999, Browman & Goldstein 2000). Research shows that lexically stressed syllables tend to be marked by several parameters simultaneously (for a thorough review, see Fletcher 2010). One view of lexical stress is that it is a type of localized hyperarticulation in lexically prominent syllables (de Jong 1995, see also Lindblom 1990), which also implies that lexical stress highlights the acoustic properties of the stressed syllable.

The specific combination of parameters that set stressed syllables apart from other syllables in the polysyllabic word varies according to language. Furthermore, the phonetic difference between stressed and unstressed syllables in a given word also differs depending on the language. In addition to quantitative variations (e.g. durational differences), many languages also show qualitative distinctions between stressed and unstressed syllables. PHONOLOGICAL VOWEL REDUCTION refers to the observation that in

[2] ENG = English, SPA = Spanish, POR = Portuguese
[3] In both Spanish and Portuguese, the word *médico* means 'doctor'.

languages such as English and Portuguese, only a subset of vowels that appear in stressed syllables occur in certain unstressed environments. In examples (1.3-5) above, the vowel /o/ in the first syllable of ‘t**o**mato’/***to**mate* is shorter than the /a/ in /ma/ in all three languages as /to/ is an unstressed syllable in English, Spanish, and Portuguese alike. It has noted since Lindblom (1963) that centralization is inversely proportional to duration in some languages with lexical stress. In English and Portuguese, the first /o/ in ‘tomato’/*tomate* is also centralized to [ə] and [ʊ], respectively, indicating that phonological vowel reduction takes place in these languages (see Section 2.4).

The choice of the languages in the current sample is partially motivated by the fact that English, Spanish, and Portuguese differ in how stress is implemented phonetically. The ways in which lexical stress impacts syllables in these languages will be explored in more detail in Chapter 2. The next section explores the phonetic effects of phrase-level prominence on segments.

1.3.2 Phrasal Accent (Phrase-level Prominence)

The second of the three main aspects of prosody that influences individual speech sounds is PHRASAL ACCENT. For the purposes of this investigation, phrasal accent is defined as the most salient pitch accent within a phrase (cf. Jun 2005b), in which f0 movements highlight a word or group of words according to speakers’ intentions. In many languages, including English, Spanish, and Portuguese[4], phrasal accent can be moved around within the phrase, potentially falling on any word or constituent receiving emphasis (Beckman

[4] Despite oft-cited claims to the contrary, Vogel, Athanasopoulou, and Guzzo (2018) show that Spanish and Portuguese may use prosodic/phonetic cues to signal phrasal accent at least in words under narrow focus. Data in the present study confirm Vogel and colleagues’ findings.

& Edwards 1994, Ladd 2008, Frota & Prieto 2015, Frota & Moraes 2016). Following from the definition above, the term ‘unaccented’ will be used henceforth to describe words that are not bearing the phrasal accent in an Intonational Phrase.

In terms of its locus, there is evidence that phrasal accent operates on whole words, including in the three languages in the sample (e.g. Turk & Sawusch 1997 for English; Rao 2010 for Spanish; Cantoni 2013 for Portuguese). Besides the specific pitch contours that accompany them, phrasal accents are encoded through the temporal expansion of phonetic properties of the stressed syllable and those adjacent to it (e.g. Klatt 1976, Sluijter & van Heuven 1996, Turk & Sawusch 1997, Pierrehumbert 2000, White 2002, Ladd 2008, among others).Figure 1-b below illustrates the durational effects of phrasal accent on the same trisyllabic word uttered in non-phrasally accented context in comparison to a context when the word receives the phrasal accent.

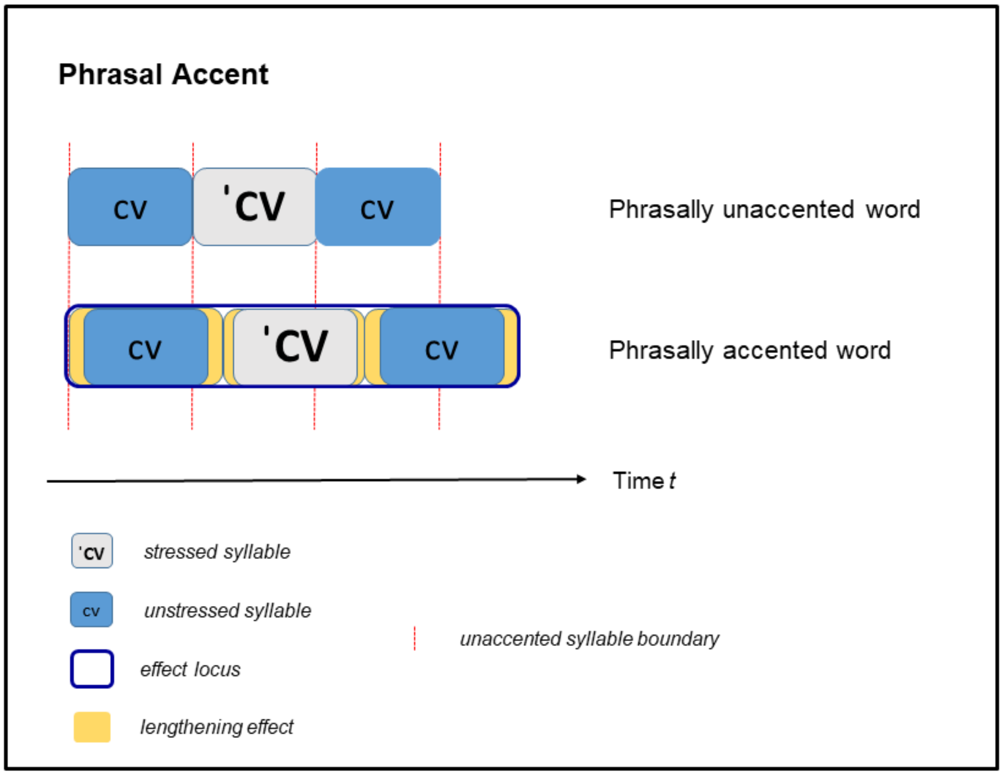

Figure 1-b. Schematic depiction of the durational effects of phrasal accent

In languages with lexical stress, the entire accented word gets lengthened, with unstressed syllables showing considerable differences in duration. The diagram depicts a trisyllabic word with penultimate stress (e.g. ENG 'toMAto', SPA/POR 'toMAte') uttered in neutral/unaccented (top) context, compared to when it occurs in a context where it is phrasally accented (bottom). Vertical lines represent syllable boundaries in the phrasally unaccented context as for time reference.

In pragmatically neutral communicative contexts (e.g. broad focus statements), phrasal accents are associated with the rightmost content word in a phrase in all three languages in the sample (e.g. Ladd 2008, Frota & Prieto 2015). However, as mentioned above, speakers of English, Spanish, and Portuguese can highlight any word within an IP for context-specific purposes by placing a phrasal accent on it. Changes in phrasal accent placement are a common strategy used in the three languages to express focus, such as when correcting an erroneous assumption. Supposing that Examples (1.6-8) below are given in response to the question *Is it true that radishes are a type of fruit?*, the person responding might choose to highlight the word 'tomatoes' to clarify that tomato is the fruit that many people may consider a vegetable. The sentences below illustrate the locus of the phrasal accent effect on English, Spanish, and Portuguese according to previous literature (accented words appear in smalls caps and are highlighted in the examples):

- *Is it true that radishes are a type of fruit?*[5]

(1.6)	- no, [TOMATOES are actually fruit] **IP**	ENG
(1.7)	- no, [el TOMATE sí es una fruta] **IP**	SPA
(1.8)	- não, [o TOMATE que é fruta] **IP**	POR

This brief discussion of phrasal accent relates to the fact that the segmental phonetic correlates of phrasal accent overlap with those of lexical stress. It is also relevant to note that a phrasally accented word may show spatiotemporal expansions beyond the stressed syllable. For that reason, controlling for the placement of phrasal accent is crucial when evaluating any correlate of prosodic prominence (see also Section 2.1). The next section delves into the third and final main aspect of prosody that influences segmental make-up: prosodic phrasing.

1.3.3 Prosodic Phrasing

PROSODIC PHRASING is understood here as the grouping of units in smaller domains to form domains that are higher and larger in the prosodic hierarchy, such as Intonational Phrases (IPs) within Utterances. Articulatory and acoustic research have demonstrated that at least some of the segmental variation found in languages can be directly attributed

[5] SPA: *¿Es verdad que el rábano es una fruta?*
POR: *É verdade que o rabanete é uma fruta?*

to the location of segments within prosodic domains (Fougeron 1999, Keating 2004, Cho 2011). As every phrase contains two edges, one initial and one final, the effects of prosodic phrasing are manifested twice in every domain. Given the differences in how prosodic phrasing is phonetically expressed in each edge, domain-final and domain-initial edges are treated separately below.

1.3.3.1 Domain-final lengthening (Pre-boundary effects)

The pattern of temporal expansion of segments near the end of a prosodic unit is one of the most commonly reported phonetic correlates of prosodic phrasing. Usually discussed in the context or larger prosodic domains such as the IP, this type of effect is referred to as PHRASE-FINAL LENGTHENING in the literature. Words that immediately precede a larger prosodic domain boundary have been found to be consistently longer than those occurring elsewhere in the domain (e.g. Beckman & Edwards 1994, Wightman et al. 1992, Gussenhoven & Rietveld 1992, Berkovits 1994, Byrd, Krivokapić & Lee 2006, Fougeron 2001, Turk & Shattuck-Hufnagel 2000, Frota & Prieto 2015, among many others). Because it is so commonly reported, pre-boundary lengthening is assumed to be a pervasive phenomenon in the world's languages (Cho 2011).

Although the specific locus of phrase-final lengthening may vary across languages, the largest and most consistent effects seem to encompass the phrase-final syllable, that is, those segments closest to the domain-final edge.Figure 1-c below depicts the durational effects of phrase-final lengthening on the most commonly reported locus. The diagram depicts the same trisyllabic word with penultimate stress in two prosodic contexts: in phrase medial position (top), and when it precedes a putative domain-final edge (bottom).

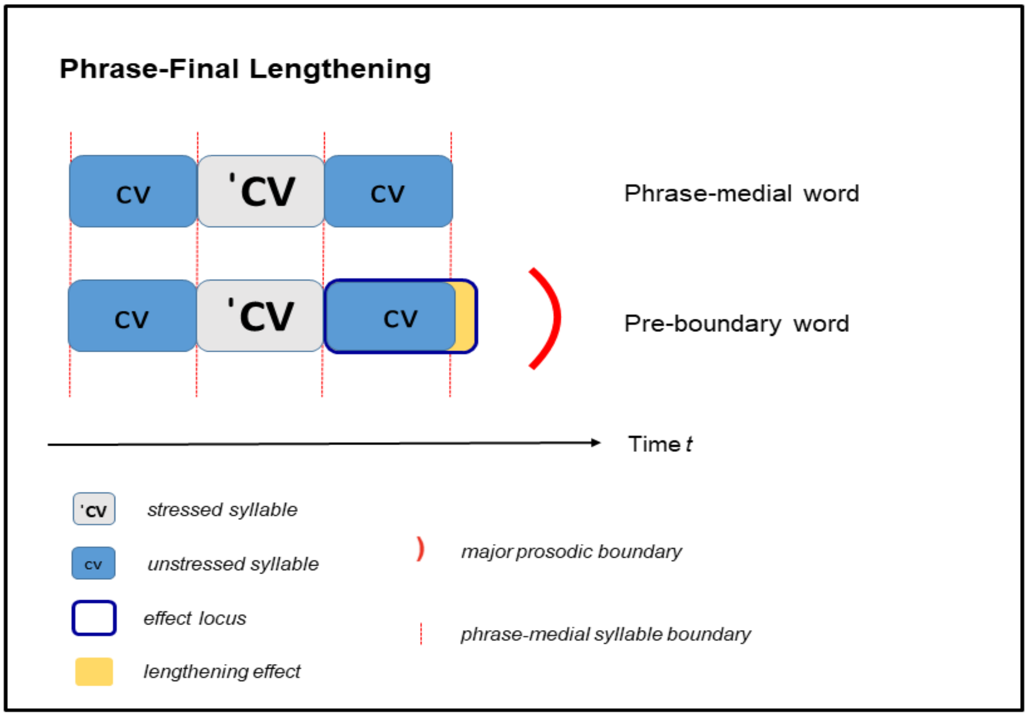

Figure 1-c. Locus and durational effects of phrase-final lengthening

The diagram depicts a trisyllabic word with penultimate stress (e.g. ENG 'toMAto', SPA/POR 'toMAte') uttered in phrase-medial position (top) compared to when it occurs immediately preceding a major domain boundary (bottom). Vertical lines represent syllable boundaries in the phrase-medial context for time reference.

In English, Spanish, and Portuguese, word-final syllables show longer duration when they immediately precede a phrase edge (e.g. Edwards, Beckman & Fletcher 1991, Byrd & Saltzman 2003, Wightman et al. 1992, for English; Ortega-Llebaria 2006, Ortega-Llebaria & Prieto 2007, Hualde 2012, for Spanish; Moraes 1998, and Cantoni 2013, for Portuguese). The examples below show how phrase-final lengthening would affect English, Spanish, and Portuguese words according to results from previous studies (Spanish and Portuguese examples are direct translations of the English sentence; phrase-final lengthening is shown in italics):

(1.9) [… the university is hiring medical doc*tors*] **IP** ENG

(1.10) [… la universidad está contratando a médi*cos*] **IP** SPA

(1.11) [… a universidade está contratando médi*cos*] **IP** POR

In addition to the lengthening observable in the last syllable, phrase-final boundaries are also marked by specific pitch movements that vary according to the type of utterance (e.g. questions, broad focus statements, narrow focus etc.). Specific f0 shapes indeed cue all of the types of prominence described hitherto. Despite being perhaps the acoustic dimension most prototypically associated with prosody, pitch will not be investigated in the present study. Nonetheless, overall pitch movement in a phrase was one of the criteria used to determine whether a test word in the experiment described in Section 3.6 was produced according to the elicitation criteria (see also Section 3.6.2).

1.3.3.2 Domain-initial effects (Post-boundary effects)

Compared to reports on domain-final lengthening, the pattern of spatiotemporal expansion of a given segment near the beginning of prosodic domain is less commonly explored in the literature. Boundary-initial marking is often described as a reinforced articulation of segments that immediately follow a major prosodic boundary - such as the left edge of an IP, when compared to elsewhere in the domain (cf. Fougeron & Keating 1997, Cho & Keating 2001, 2009, Keating et al. 2003, Cho & McQueen 2005, Georgeton & Fougeron 2014, among others). Because these effects are clearest in the articulatory realm, boundary-initial marking is most often referred to as “domain-initial strengthening” in the literature. However, for the purposes of the current study, the term DOMAIN-INITIAL EFFECTS is proposed since it encompasses both the articulatory and acoustic correlates of boundary-initial marking, which may not always be accurately characterized as strengthening.

The phonetic marking of domain-initial boundaries differs in a number of ways from other types of prosodically influenced segmental variation. For one, pitch movement does not necessarily accompany phrase-initial boundaries (see Jun 2005a, 2014, for cross-linguistic comparisons). Secondly, domain-initial effects are hypothesized to operate in both segment- and language-specific ways (see next chapter). Thirdly, the locus of the phonetic marking of domain-initial boundaries is reported to be rather restricted: a single segment, whether a consonant or vowel, typically shows the effects of boundary marking (e.g. Fougeron & Keating 1997, Cho & Jun 2000, Keating et al. 2003; but see Cho, J. Kim & S. Kim 2013 for a discussion on locality). The diagram in Figure 1-d depicts how domain-initial effects operate on the same syllable in two prosodic contexts: in phrase medial position (top), and when it FOLLOWS a putative domain-initial edge (bottom).

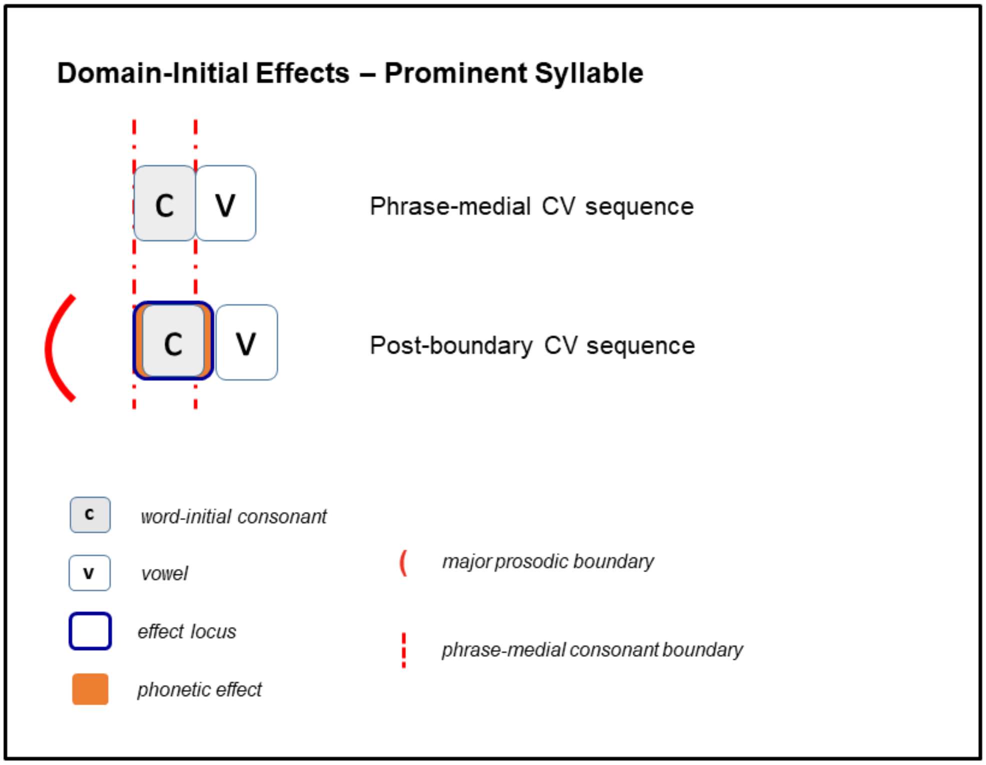

Figure 1-d. Most commonly reported locus of domain-initial effects

The diagram depicts a word-initial CV syllable, uttered in IP-medial position (top) versus in a domain-initial position such as at an IP-initial edge (bottom). The word-initial syllable is divided into C and V components to illustrate the locus of the effect. Vertical lines represent syllable boundaries with respect to time.

Previous research reveals that domain-initial boundaries are marked segmentally by variations in nasal airflow, constriction degree, closure duration, glottal adduction, among others (cf. Dilley, Shattuck-Hufnagel, & Ostendorf 1996, Fougeron & Keating 1997, Fougeron 1999, Cho 2011). Articulatory correlates of boundary-initial prominence have been observed in several prosodically distinct languages such as Dutch (Cho & McQueen 2005), English (Pierrehumbert & Talkin 1992, Fougeron & Keating 1997, Byrd, Krivakopić, & Lee 2006, inter alia), Estonian (Gordon 1997), French (Fougeron 2001, Tabain 2003), Greek (Katsika 2016), Japanese (Onaka 2003), Korean (Jun 1993, Cho & Jun 2000), Spanish (Lavoie 2001, Parrell 2014), Taiwanese (Hsu & Jun 1999), and Turkish (Barnes 2001). To the best of my knowledge, no study in this area has investigated Portuguese so far. It should be noted that the levels at which the articulatory correlates of domain-initial effects show statistically significant differences vary depending on language (Cho 2015), as well as among different studies (see Ch. 2).

Acoustic evidence for domain-initial effects also exists for a variety of languages (e.g. Hacopian 2003, for Armenian; Katsika 2016, for Greek; Cho & McQueen 2005, for Dutch; S. Kim, J. Kim, & Cho 2018, Cho & Keating 2009, Oller 1973, for English; Georgeton & Fougeron 2014, for French; Onaka et al. 2003, for Japanese; Jun 1993, Cho 1998, for Korean; Lavoie 2001, and Parrell 2015, for Spanish; Hsu & Jun 1999, for Taiwanese and Korean). Some of the acoustic dimensions of consonants that have been reported to reflect domain-initial marking include: variation in voice onset time (VOT), differences in burst amplitude values, longer closure duration, variation in degrees of voicing, reduced duration of nasal murmur, among others. For vowels occurring immediately after a prosodic boundary, acoustic dimensions that may be modified include glottalization and spectral variation. It should also be noted that most acoustic evidence for domain-initial effects cited above was obtained as secondary data in articulatory studies and is therefore much more limited.

Despite the relative sparseness of acoustic data, research seems to converge in supporting the idea that the marking of initial boundaries influences the phonetic properties of segments in non-trivial ways. The examples below illustrate the expected locus of influence of domain-initial effects on words with penultimate stress in English, Spanish, and Portuguese according to previous findings. Because domain-initial effects have been found most consistently in words following an IP boundary (e.g. Keating et al.

2003), the sentences below illustrate the effect only at that level by introducing a prosodic break (represented by a comma) in the middle of the utterance (segments undergoing domain-initial effects appear in bold and underlined):

- *Is it true that Concordia University is hiring health professionals?*[6]

(1.12)	it's true, [**c**oncordia is hiring doctors this year] $_{\mathbf{IP}}$	ENG
(1.13)	es verdad, [**c**oncordia está contratando a médicos este año] $_{\mathbf{IP}}$	SPA
(1.14)	é verdade, **[c**oncordia está contratando médicos este ano] $_{\mathbf{IP}}$	POR

Beyond the very first segment of a word occurring at the initial boundary of the Intonational Phrase, as marked in examples (1.12-14), no other segment of the IP-initial word is expected to show consistent domain-initial effects (see Cho 2011, 2015, for discussions of locality). Some of the segmental properties of the IP-initial /k/ that could manifest boundary-related change include variation in VOT, variation in closure duration, occurrence of stop burst releases, and changes in burst amplitude (Cho 2016).

This short introduction to domain-initial effects aimed to present an overview of their phonetic characteristics without going into much detail about the unresolved issues identified in Section 1.1. These issues will be explored in more detail in the next chapter, so as to contextualize the gap in knowledge about domain-initial effects that this dissertation aims to fill (see Section 1.5). The phonetic effects of the multiple levels of prosodic structure discussed hitherto are summarized below.

[6] SPA: *¿Es verdad que Concordia está contratando a profesionales de salud?*
POR: *É verdade que Concordia está contratando profissionais da saúde?*

1.3.4 The Prosody-Phonetics Interface: Summary

This section presented a condensed overview of how prosodic prominence influences segmental variation in relevant ways. The overview of prosodically conditioned phonetic variation aimed to demonstrate that different levels of prosodic structure contribute to the articulation of segments, while also offering an insight into how acoustic information may vary as a function of prosody. This review also aimed to highlight the fact that all levels of prosodic structure must be taken into consideration in phonetic and phonological studies. While treating each kind of prominence separately is informative in terms of providing a general outline, in reality prosodic prominence is considerably more complex.

One important reason for considering multiple levels of prosodic structure is that the grouping and prominence-marking functions of prosody operate simultaneously (cf. Trubetskoy 1969, Beckman 1986, Hirst & Di Cristo 1998), often through similar phonetic correlates (Cole 2015). This dual functionality entails that different prosodic aspects may affect the same word/group of words concomitantly. In a final reiteration of the ‘Concordia University’ example, sentences in 1.15-17 below illustrate how the different types of prominence discussed above may operate simultaneously within a prosodic domain such as the Intonational Phrase (IP).

- *You said Concordia Hospitals are hiring?*

(1.15) no, [**<u>c</u>**onCORdia UNIVERSITY is HIR*ing*] **IP** ENG

(1.16) no, [**<u>c</u>**onCORdia la UNIVERSIDAD esTÁ contraTAN*do*] **IP** SPA

(1.17) não, [**<u>c</u>**onCORdia a UNIVERSIDADE esTÁ contraTAN*do*] **IP** POR

ALL CAPS	**<u>bolded & underlined</u>**	SMALL CAPS HIGHLIGHED	*italics*
lexical stress	domain-initial effects	phrasal accent	domain-final lengthening

In sum, there is considerable evidence that fine-grained phonetic segmental detail is connected to prosodic structure in any given phrase. Moreover, different types of prosodic marking may affect the same words simultaneously (see also Xu & Xu 2005). Prosodic effects may be compounded, such as when phrasal accent is combined with lexical stress, or when stressed syllables in words with final stress are lengthened when they occur at the end of a prosodic domain. The next section describes the research questions and goals of this dissertation in light of the findings reviewed above.

1.4 The Current Study

This dissertation investigates how domain-initial effects influence the segmental nature of unstressed syllables, and the possible implications of the interaction between these two types of prosodic patterning. The language-specific nature of these patterns is examined by comparing English, Spanish, and Portuguese, which (for reasons explained in Chapter 2) are likely to show different types of interactions between phrasal prosody (domain-initial effects) and word-level prosody (the effects of lexical stress). Through the study of these patterns, the dissertation goes on to explore the relationship between phonetics and the culminative and delimitative functions of prosody. The three overarching goals of this project are: (i) to assess the extent to which domain-initial effects operate distinctly from lexical prominence, (ii) to evaluate the role of language-specific phonology in how domain-initial boundaries are phonetically expressed, and (iii) to provide an acoustic characterization of domain-initial effects that would complement the existing articulatory data. Finally, a fourth underlying goal of the dissertation is to establish whether the interplay of domain-initial effects and unstressed syllable reductions could provide a phonetic explanation for the emergence of given types of syllable structure (see Chapter 2).

1.4.1 Research Questions

The three broad research questions addressed in this dissertation stem from the goals listed above while also considering the issues raised in Section 1.1. The first research question is phrased as follows:

> **RQ 1:** *How does the marking of prosodic boundaries impact the phonetic expression of segments in fully unstressed syllables in unaccented words in domain-initial position?*

The primary hypothesis in this dissertation is that the phonetic makeup of segments will reflect the strength of the adjacent boundary. Segments in the CV syllables under examination will show greater or lesser effects depending on where the boundary that they are adjacent to falls in the prosodic hierarchy. In the present data, word-initial segments at an Intonational Phrase boundary are expected to manifest enhanced acoustic characteristics compared to those occurring mid-phrase. This prediction follows from the fact that the IP constitutes a higher level in the prosodic hierarchy than any of those below it, which entails that a wide range of phonetic correlates would be observed following an Intonational Phrase boundary (see also Sections 1.2.1 and 1.5.1).

The second main hypothesis put forward here is that the marking of domain-initial boundaries influences the phonetic properties of unstressed syllables in different ways from those of stressed and/or accented syllables (Cho, D. Kim, & S. Kim 2017). Specifically, domain-initial effects are hypothesized to impact unstressed syllables to a greater extent than stressed and/or accented ones (S. Kim, J. Kim, & Cho 2018). Once the confounding factors of lexical stress and phrasal accent are removed, unstressed syllables in unaccented words will hypothetically be more susceptible to domain-initial effects than their stressed/accented counterparts. There are two mutually exclusive ways that domain-initial effects could influence the phonetic makeup of segments in an unstressed syllable.

The research briefly reviewed in Section 1.3 suggests that only the individual segment that follows an initial boundary shows domain-initial effects (the LOCALITY CONDITION hypothesis, see 2.2.1). However, it should be noted that many of these studies looked at syllables that were stressed and/or phrasally accented, and from an articulatory perspective. If those findings hold in the present data, only the initial consonant of the unstressed CV-syllable will show boundary effects, without affecting the following vowel. Hence, the two prosodically conditioned phenomena – lexical stress and domain-initial effects - would operate on the same syllables in opposing ways. That is, the CV syllables under investigation would show a localized effect of boundary marking on the initial consonant, while stress-related reductions would affect the vowel nucleus regardless of the type of boundary near which the syllable occurs.

On the other hand, there is also more limited data showing that domain-initial effects may extend beyond the first post-boundary segment (see Cho 2015). If domain-initial effects operate beyond the boundary-adjacent segment in the present data, boundary marking could affect the unstressed vowel in ways that may potentially neutralize stress-related reductions. That is, a vowel occurring in the CV syllable near a stronger prosodic boundary would be less reduced than the same vowel occurring elsewhere in the domain. In either one of these outcomes, the unstressed syllable under examination would show more marked differences between prosodic contexts than a CV sequence that is stressed/accented and already showing spatiotemporal expansion.

The second question relates to the role of phonology in the phonetic manifestation of prosodic structure. It is formulated as follows:

> **RQ 2:** *To what extent does language-specific phonology determine the phonetic makeup of segments in unstressed syllables occurring in domain-initial position adjacent to boundaries of different levels in the prosodic hierarchy?*

There is evidence that prosodically conditioned phonetic variation operates in ways that highlight language-specific phonological contrast (e.g. Cho & McQueen 2005, de Jong 1995). It is hypothesized that phonology may play a role in the phonetic expression of domain-initial effects in two ways. First, individual languages may show distinct articulatory parameters for similar categories of consonant, as demonstrated by cross-linguistic research on VOT values for stops (Cho & Ladefoged 1999, Chodroff, Golden & Wilson 2019). Secondly, language-specific phonological patterns may explain phonetic differences between stressed and unstressed syllables, especially in terms of vowel reduction. Overall, it is expected that different phonological factors will lead to more apparent domain-initial effects in the languages in which duration is a more robust correlate of stress. These predictions are detailed below.

It is expected that the phonetic makeup of the stops under investigation here may also show differences based on the role of VOT in establishing phonological contrasts for stops in each language. In English, VOT may be considered the primary acoustic correlate that identifies voiceless stops (Lisker & Abramson 1964, 1967). Spanish and Portuguese, on the other hand, are both considered 'true voicing' languages, which implies that voicing during closure may play a more relevant role in cueing phonological contrast between stops than VOT alone (cf. Ahn 2018, Cho, Whalen & Docherty 2019, but see Cristófaro-Silva et al. 2019 for a recent overview of VOT values in Brazilian Portuguese). It follows from these observations that, if domain-initial effects modulate subphonemic properties of segments by referencing phonological contrasts, differences in VOT values may be more pronounced in English than in Spanish, particularly, with Portuguese showing intermediate effects[7].

[7] Recent research suggests Brazilian Portuguese may be more accurately characterized as a language with intermediate degree of aspiration (Cristófaro-Silva), following Riney and colleagues' (2007) proposal. In their study of Japanese, Riney and his colleagues find that voiceless stops have an intermediate degree of aspiration, and as such "constitute an exception to the short lag and long lag dichotomy of voiceless stops said to characterize many languages" (2007: 439).

In terms of stress-related vowel reduction, unstressed vowels are considerably shorter than their stressed counterparts in both English and Portuguese (see 1.5.2). If domain-initial effects are restricted to a single post-boundary segment, unstressed vowels in CV syllables under domain-initial effects may be more likely to show the influence of the preceding stop. For instance, increases in VOT in post-boundary /p t k/ may lead to a greater overlap between this acoustic property of the voiceless stop and those of the unstressed vowel. It is thus expected that vowels in unstressed syllables at the initial edge of an IP boundary will show reductions (e.g. devoicing) in English, and likely also in Portuguese as a result of the boundary-related effects. The phonetic processes that would lead to this outcome are explained as follows.

There is evidence that increased consonant-to-vowel coarticulation may induce the occurrence of partially or fully devoiced vowels (e.g. Torreira & Ernestus 2011), which are especially common in the vicinity of voiceless consonants (Gordon 1998). Devoiced vowels can be characterized by the occurrence of aperiodic, greater energy noise at and above the frequencies corresponding to the second and third formants, but a lack of energy at lower frequencies (Smith 2003). Similarly, in stops with long-lag VOT, the consonant is produced with a glottal abduction gesture that manifests itself as a period of high frequency energy (i.e. aspiration, see Abramson & Whalen 2017). If there is an increase in this glottal gesture, it may extend over a vowel and result in devoicing (cf. Chitoran & Iskarous 2008). Since vowel devoicing is more likely to occur in shorter, non-prominent vowels (e.g. Chitoran & Iskarous 2008, Torreira & Ernestus 2010, Meneses & Albano 2015, see also Smith 2003 for a review), one possible outcome of prosodically induced longer VOT would be the occurrence of devoiced vowels in English and Portuguese.

Finally, the third and last broad research question is framed as follows:

RQ3: *To what extent are the acoustic manifestations of domain-initial effects consistent with the results obtained in articulatory studies?*

It is hypothesized that articulatory enhancements linked to domain-initial boundaries will be apparent in the acoustic signal. In order for listeners to be aware of prosodic organization, they must be able to perceive it acoustically. It is predicted that domain-initial effects will translate into differences in one or more of the acoustic parameters investigated, but especially VOT for consonants. The present study also explores the hypothesis that mismatches between articulatory and acoustic results observed in previous investigations may have derived from the use of very small samples (see also next Chapter for a discussion).

1.4.2 Conceptual Framework

This dissertation investigates different aspects of the interaction of phonetics and phonology. The types of phonetic detail under examination here are taken to be an integral part of phonological representations, as in Usage-based Phonology (Bybee 2001) and Exemplar Theory (Pierrehumbert 2001, Johnson 2007). Additionally, the current study is informed by insights from Autosegmental-Metrical Theory (Beckman &

Pierrehumbert 1986). Most importantly it follows the tenets of Laboratory Phonology (Pierrehumbert, Beckman & Ladd 2000) in its approach to data collection and analysis.

In Usage-based Phonology, individual tokens of production and perception contribute to the building of phonological - and prosodic - structure. The production of many aspects of prosody can vary substantially depending on the particular speech situation. Prosody in many languages, including those discussed here, contributes to conveying pragmatic and social information and thus is intertwined with situation-specific-usage. The notion that the frequent occurrence of words in given prosodic contexts may have a permanent impact on their phonological representation (see also Bybee & Napoleão de Souza, submitted) underlies some of the research questions investigated here.

In turn, Exemplar Theory contributes the notion that phonological representation incorporates phonetic detail in a probabilistic fashion. The fact that some languages develop a system of phonological vowel reduction in unstressed syllables (e.g. centralization of vowel formants) can be interpreted as a direct result of how phonetic facts shape the phonology of a language. In contemporary Brazilian Portuguese, duration is strongly associated with lexical stress, and unstressed vowels in the language are not only shorter but also centralized in most positions within the word, so that unstressed /i e/, /o u/ and /a/ turn into /ɪ/, /ʊ/ and /ə/ in final position (Câmara 1972, Barbosa & Albano 2004, among others; see Section 2.3 below). Given the highly frequent occurrence of the phonologically reduced vowels /ɪ ə ʊ/ in word-final position (most Portuguese words end in vowels), these now occupy the center of the word-final unstressed vowel category in the exemplar cloud. Similarly, if the phonetic properties of a voiceless stop are always reinforced at the left edge of a prosodic domain by an increase in VOT, this characteristic may lose its association with a specific context and be generalized, so that the phonological representation of words beginning with stops may come to include aspiration (e.g. word-initial /p^h t^h k^h/ in English).

The insight that prosodic structure is organized hierarchically into phonetically delimited units is key to the formulation of the hypotheses investigated here. This idea developed in the context of the Autosegmental-Metrical tradition (Beckman & Pierrehumbert 1986, Ladd 2008), which posits that prosody is organized into phrases with phonological properties that are a function of their level in the prosodic hierarchy (Nespor and Vogel 1986/2007, Jun 2005a). Although this dissertation deviates in many ways from work conducted within the Autosegmental-Metrical framework, it builds on its notion of hierarchical structure in prosody, and uses some of the same terms for prosodic levels employed in Autosegmental-Metrical studies. Some levels of the prosodic hierarchy that are important cross-linguistically include, from higher to lower, the Utterance, the Intonational Phrase, the Word, and the syllable (Jun 2005a, 2014). Studies such as those cited in Section 1.3 above, have shown that in general, these levels impact segmental properties in cumulative ways. Despite the variation in the number of levels that will be evidenced in a particular language, research suggests that the higher the prosodic domain level, the more pronounced the influence of that level of prosodic structure on segments. All things being equal, the final syllable in an IP is likely to be longer than a syllable that is final only in the Word. It is expected that the phenomenon investigated here will manifest significant phonetic differences based on syllable position within a phrase, but no claims are made in reference to more than one domain level.

Finally, this dissertation is firmly anchored in the tenets of Laboratory Phonology (Pierrehumbert, Beckman & Ladd 2000, Cho 2011). As a research framework, it promotes one of principles that guided the design of the current study, that the accumulation of results obtained through instrumental studies and rigorous methodology strengthens the scientific foundations of phonological theory. Laboratory Phonology researchers strive to conduct quantitatively sound analyses that can be tested, reexamined, confirmed, or refuted in accordance with the scientific method (Pierrehumbert et al. 2000).

In summary, the ideas that variation is an intrinsic part of language and that speakers use prosodically conditioned phonetic detail to cue prosodic structure form the theoretical bases of this dissertation. Consistent with this view, the category of prosodic prominence is hypothesized here to be one of the main sources of segmental change.

The next section gives a condensed overview of the aspects of the prosodic systems of English, Spanish, and Portuguese that are relevant to this investigation.

1.5 Prosodic Aspects of English, Spanish, and Portuguese

The current investigation examines how domain-initial effects operate on acoustic properties of fully unstressed syllables in unaccented words. This section summarizes the aspects of the prosody of English, Spanish, and Portuguese that are relevant to the goals of the current study (see Pierrehumbert 1980, Hualde & Prieto 2015; Frota et al. 2015 for comprehensive overviews). Among the most important factors are the prosodic domains, and the phonetic effects of stress.

1.5.1 Prosodic Structure in English, Spanish, and Portuguese

The grouping function of prosody is assumed here to follow a hierarchical structure, meaning that higher levels of structure contain lower levels, both of which are language-specific (Jun 2014). However, the two highest levels in the prosodic structure, namely the Utterance (U) and the Intonation Phrase (IP), are among the most frequent across languages (cf. Jun 2005a, Jun 2014). Specifically, the IP has been identified as the major prosodic level around which the phonetic correlates of domain-initial boundaries can be measured (cf. Keating et al. 2003). As hinted in the examples in previous sections, the IP has been identified as major domain in English, Spanish, and Portuguese alike (e.g. Beckman & Pierrehumbert 1986, Prieto, van Santen & Hirschberg 1995, Frota 2000).

The three languages investigated in this dissertation also share other prosodic features. In English, Spanish, and Portuguese, final IP boundaries in declarative utterances are associated with acoustic markings such as final lengthening, pitch declines, and pauses (Beckman & Pierrehumbert 1986, Prieto, van Santen & Hirschberg 1995, Frota 2000). Additionally, the locus of the phrasal accent is also similar in the three languages. In neutral declarative sentences, phrasal accent tends to fall on the rightmost lexical word of the IP, and is anchored on the stressed syllable of that word (Pierrehumbert 1980, Hualde & Prieto 2015, Frota & Moraes 2016). Moreover, phrasal accent can be moved around within the phrase in English, Spanish, and Portuguese, so that any word can potentially receive emphasis (Beckman & Edwards 1994, Ladd 2008, Frota & Prieto 2015, Frota & Moraes 2016; see also Vogel, Athanasopoulou & Guzzo 2018). This prosodic feature common to the three languages was useful in the design of the stimuli for the reading task explained in Chapter 3.

Below the level of the IP, there is less agreement in the literature for each of the three languages about the midlevel domains (cf. Shattuck-Hufnagel & Turk 1996, Frota & Prieto 2015). In English, Beckman and Pierrehumbert (1986) identify intermediate phrases (ip) that occur between the IP and the Prosodic Word. The status of an intermediate phrase (ip) is more controversial in Spanish (see Beckman et al. 2002 for a discussion), whereas most analyses of Portuguese have excluded intermediate phrases altogether (Frota et al. 2015). On the other hand, the Phonological Phrase has been identified as a midlevel domain in Portuguese (Sândalo & Truckenbrodt 2003, Frota 2014), but not necessarily in Spanish (Aguilar, De-la-Mota, & Prieto 2009).

In terms of accentuation, the distribution of (non-nuclear) pitch accents also differs in English, Spanish, and Portuguese. Spanish and (Brazilian) Portuguese are described as languages with a dense distribution of pitch accents in non-question intonation (Frota & Prieto 2015), so that "essentially every prosodic word (…) receives a pitch accent" (p. 397). In English, pitch accents other than the phrasal accent are less common than in Romance, though speakers may accent prenuclear elements (Ladd 2008). Factors influencing the placement of pitch accents in English include semantic/pragmatic factors, structural factors, and rhythmic factors (Shattuck-Hufnagel & Turk 1996).

1.5.2 Word Prosody in English, Spanish, and Portuguese

1.5.2.1 General characteristics of lexical stress

As hinted above, English, Spanish, and Portuguese all have culminative lexical stress on the word level. In polysyllabic words in each of these languages, one syllable contrasts with all others in terms of its prominence. The main acoustic correlates of lexical stress in the three languages are duration, f0 anchoring, and amplitude (Beckman 1986, Hualde 2012, Mateus & D'Andrade, 2000).

Lexical stress is also contrastive in all three (e.g. English [ˈpʰɝ˞mɪt] 'a permit' vs. [pʰəɻˈmɪt] 'to permit'; Spanish [ˈnumeɾo] 'number' vs. [nuˈmeɾo] 'I number' vs. [numeˈɾo] 'she numbered'; Portuguese[8] [ˈmɛdʒɪkʊ] 'a doctor' vs. [meˈdʒikʊ] 'I medicate' vs. [medʒɪˈko] 'she medicated'). Additionally, lexical stress is obligatory for content words in these languages (Liberman & Prince 1977, Hualde 2012, Mateus & D'Andrade 2000).

Stress placement is considered free and difficult to predict in English (e.g. Liberman & Prince 1977). In Spanish and Portuguese, stress follows somewhat more regular patterns. In polysyllabic words, lexical stress generally falls on any one of the three last syllables[9] (Hualde 2012; Mateus & D'Andrade 2000). Although variable, the placement of lexical stress in Spanish and Portuguese can usually be determined based on a series of morphosyntactic and phonological factors.

1.5.2.2 Characteristics of unstressed syllables in English, Spanish, and Portuguese

This investigation focuses on the characteristics of unstressed syllables occurring near a prosodic boundary. Despite the similarities described above, the three languages differ substantially in the degrees to which lexical stress impacts *unstressed* syllables. Fully

[8]Brazilian variety.

[9]Verbal forms with stress placed earlier than the antepenultimate syllable such as Spanish *comiéndoselo* [koˈmjen.do.se.lo] 'when eating it', or Portuguese *comprávamo-lo* [kõˈpɾavɐmʊlʊ] 'we used to buy it'. Note that in Brazilian Portuguese, such forms occur only in formal written language (e.g. Kato & Martins 2016); meaning that stress placement in the spoken language can be said to fall regularly within the final three-syllable interval.

unstressed syllables (i.e. not bearing secondary stress) are much shorter than their stressed counterparts in both English and Portuguese (cf. Plag, Kunter, & Schramm 2011, Cantoni 2013), whereas that difference is less pronounced in Spanish (e.g. Ortega-Llebaria & Prieto 2007). Unstressed consonants show phonetic differences in both English and Spanish, but not in Brazilian Portuguese (Cristófaro-Silva et al. 2019). These differences in consonantal makeup due to stress were not tested in this study and will therefore not be discussed further.

Fully unstressed vowels in English are often centralized to [ə], whereas none of the Spanish five vowels /i e a o u/ shows much qualitative change when unstressed (e.g. Nadeu 2014). In Portuguese, fully unstressed vowels show several patterns of reduction, depending on vowel quality, distance from the stressed syllable and position within the word (Crosswhite 2001, Mateus & D'Andrade 2000, Cristófaro-Silva et al. 2019). In fact, one of the key characteristics of Portuguese that distinguishes it from closely related Spanish is the large number of unstressed vowel reduction phenomena that have continuously affected its phonology since the Middle Ages (Câmara 1972, Teyssier 1984, Mateus & D'Andrade 2000).

Unstressed vowels have undergone a further series of reductions in Brazilian Portuguese. These include neutralization of open-mid vowels [ɛ ɔ] to [e o]; raising/centralization of final [e a o] to [ɪ ə ʊ] (Callou, Leite, & Moraes 2002, Ribeiro, 2007); extreme reduction, devoicing and/or deletion of unstressed high oral vowels [ɪ ʊ] (cf. Bisol & Hora 1993, Napoleão de Souza 2014, Meneses & Albano 2015), and deletion of unstressed final [ə] when followed by a stressed vowel across words (Bisol 2000). It also is noteworthy that raised vowels are also subject to deletion (Soares & Barbosa

2010). The diagram below depicts the system of oral vowels in contemporary Brazilian Portuguese.

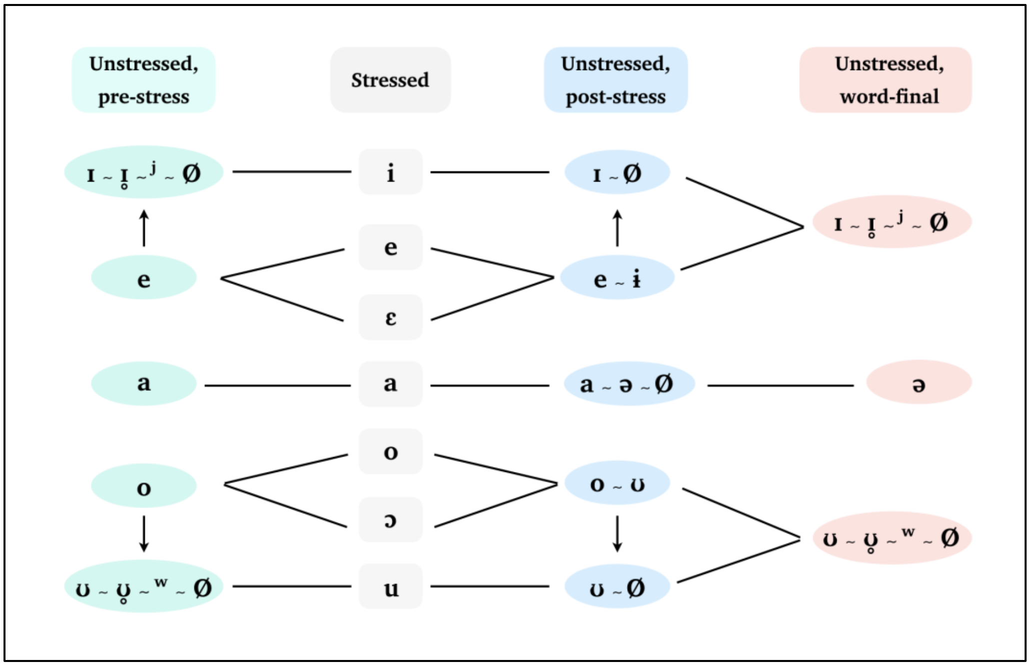

Figure 1-e. Variation in oral vowels in Brazilian Portuguese given stress placement.

In the diagram, different colors represent variation in unstressed syllables with regards to word boundaries. Common allophonic variation shown within each oval; pointed arrows represent the direction of ongoing sound change.

The diagram in Figure 1-e depicts a distinction in the behavior of unstressed syllables in Brazilian Portuguese that could be relevant given the goals of the current study. First, there is phonetic variation in unstressed syllables based on their position with regards to the word boundary. Vowels in word-final unstressed syllables, (inside the pink ovals) are the most reduced, for instance in the last vowel of a word like *livr**o*** ‘book’ [ˈli.vɾʊ] ~ **[ˈli.vɾʊ̥]** ~ [ˈlivɾʷ]. Unstressed vowels in word-INITIAL position, shown inside the light green ovals in Fig 1e (e.g. in ***a**lunos* [**a**ˈlu.nʊs] ‘male students’), on the other hand, show less phonological reduction and less variation than unstressed vowels occurring elsewhere in the word, especially for historical /e a o/. The investigation of domain-initial effects in word-initial unstressed syllables could shed light on prosodic factors that may be behind these distinctions.

Because English, Spanish, and Portuguese share important prosodic characteristics whilst also showing marked prosodically related differences, a direct comparison of the three is informative since language-specific characteristics of those systems may interact with boundary marking in distinct ways. Unstressed syllables, in particular, present several language-specific phonetic and phonological characteristics in these languages (e.g. Ramus, Nespor, & Mehler 1999, Frota & Vigário 2001, Hualde 2012). The distinct effects of lexical prominence on unstressed syllables in English, Spanish, and Portuguese thus allow for a fine-grained evaluation of how boundary marking may change the phonetic makeup of these syllables. A summary of the main commonalities and differences in the prosodic systems of the languages examined in this study is given below.

Table 1.1
Summary of main prosodic characteristics of English, Spanish and Portuguese

Language	Lexical stress contrastive?	Unstressed vowel reduction?	Phrasal accent placement
English	yes	yes	IP-final
Spanish	yes	no	IP-final
Portuguese	yes	yes	IP-final

1.6 Structure of the Dissertation

The remainder of this dissertation is structured as follows. Chapter 2 addresses some of the issues and specificities regarding domain-initial effects, in addition to discussing how those may have influenced previous studies. The experimental design and methods used for data collection and analysis are presented in Chapter 3. Chapter 4 reports the results obtained in the study, followed by a detailed discussion in Chapter 5. Chapter 5 also addresses limitations of the present study and outlines possible avenues for future research. Finally, the Conclusion in Chapter 6 reexamines the findings of the dissertation in light of the goals it aimed to achieve.

CHAPTER 2

THE INTERACTION OF LEXICAL PROMINENCE AND PROSODIC PHRASING: UNRESOLVED ISSUES AND THE ROLE OF PHONOLOGY

2.0 Chapter Overview

The main argument presented in this dissertation is that the grouping and prominence functions of prosody are closely related, and that the phonetic encoding of that interaction is mediated by language-specific phonological patterns. This chapter examines evidence in the previous literature that demonstrates that prosodic phrasing interacts with lexical prominence, especially with regards to lexical stress. Additionally, it discusses how the specificities of domain-initial effects relate to phonological categories. Some issues in previous investigations of domain-initial boundaries are also discussed in Section 2.2 of this chapter. Finally, Section 2.3 introduces how the present study aims to address the issues it raises.

2.1 Interactions of Prominence and Phrasing

The previous chapter introduced how each aspect of prominence and phrasing can affect different parts of the same domain, especially the Intonational Phrase. Section 1.3.4 then discussed how all those aspects could operate simultaneously on the same prosodic phrase (e.g. **c**onCORdia uniVERsity is HIR*ing*). What Chapter 1 purposely left out is a discussion of how different levels of prosodic structure might interact with one another, and the consequences of this interaction in terms of segmental content.

In contrast to the simplified picture presented above, this chapter explores the complex INTERPLAY of different aspects of prosodic structure. One important theoretical point that this dissertation addresses is the relation between PROMINENCE and LOCUS, and the ways in which the two contribute to mark the boundaries of a given DOMAIN. Specifically, this chapter highlights the role of lexical prominence in determining the locus of the prosodically conditioned segmental variation that cues prosodic boundaries. By focusing on word-level prominence with respect to the effects of an IP-domain process, this dissertation also addresses the fact that prosodic effects can often span units at different levels in the hierarchy.

The prosodic hierarchy is structured into units that immediately contain the next domain down, for instance a Phonological Word (ω) is comprised of Syllables (σ). In general, it is assumed that higher domains determine (or 'dominate') the segmental material at the next level down the hierarchy (Selkirk 1984, Nespor & Vogel 2007/1986). In languages like English, Spanish, and Portuguese, lexical stress operates within the Phonological Word domain, but its locus is the syllable. That is, the phonetic effects of word-level prominence occur within the domain of the syllable.

However, there is evidence that some prosodic domains may directly determine segmental information two or more levels down (Shattuck-Hufnagel & Turk 1996: 206). Phrasal accent, for instance, operates within the IP domain in English, Spanish, and Portuguese but the locus of the prominence effect is the Word. An additional factor that is noteworthy in the phonetic expression of phrasal accent is the observation that the STRESSED SYLLABLE plays a special role within the accented word. As mentioned above, in the three languages in the sample, the stressed syllable functions as a reference point for the specific f0 contours associated with the different types of phrasal accent (e.g. Pierrehumbert 1980, for English; Hualde & Prieto 2015, for Spanish; Frota et al. 2015, for Portuguese). This evidence suggests that the effects of prosodic phrasing also span multiple domains.

While the connection between phrasal accent and lexical stress has been widely documented, the relationship between phrasing itself and lexical stress is much less explored in the literature. In order to provide a wider context for some of the issues the dissertation addresses, this section discusses how that interaction may have introduced confounds into previous studies of prosodic phrasing. Because most properties of lexical stress (e.g. placement, rhythmic characteristics, phonetic correlates, etc.) are language-specific, lexical stress will be discussed here as part of each language's phonology. Domain-final lengthening is addressed first, followed by a discussion of the marking of domain-initial edges.

2.1.1 Domain-final Lengthening and Lexical Stress

There is some experimental evidence to suggest that the scope of the final lengthening effect may be linked to the position of the lexically stressed syllable with respect to the final boundary of a domain (e.g. White 2002, Turk & Shattuck-Hufnagel 2007). A number of acoustic studies that controlled for lexical stress placement in pre-boundary words have found that, when the stressed syllable is further away from the boundary, the effects of final lengthening are not restricted to the segments in boundary-adjacent syllables. For instance, domain-final effects have been reported for stressed syllables not immediately next to the boundary in stress languages like Estonian (Krull 1997), German

(Kohler 1983), Greek (Katsika 2016), Modern Hebrew (Berkovits 1994), and Italian (Petrone et al. 2014). Similar patterns have been found for the three languages in the current study.

In English, phrase-final lengthening has been observed to increase the duration of the stressed syllable even when that syllable does not immediately precede the phrasal boundary (e.g. Oller 1973, White 2002). In English words with penultimate stress, Turk and Stattuck-Hufnagel (2007) found that, although the IP-final syllables showed the most lengthening, stressed syllables were also lengthened. For instance, when a word like 'Jamaica' /dʒəˈmeɪ.kə/ immediately precedes a final IP boundary, both the stressed syllable /ˈmeɪ/ and the word-final syllable (i.e. /kə/) show a lengthening effect, albeit more pronounced in the word-final syllable. In a study of the test word 'banana' /bəˈnænə/ across different prosodic contexts, Cho, J. Kim, and S. Kim (2013) found evidence of boundary lengthening extending all the way to the vowel in the prestressed syllable /bə/ when the word 'banana' preceded an IP boundary.

Similar results have been reported for Spanish and Portuguese. Rao (2010) found that in Spanish words with penultimate stress (e.g. *manzanas* [manˈsa.nas] 'apples'), both the stressed syllable /sa/ and the word-final unstressed syllable /nas/ were significantly longer when the word *manzanas* preceded the IP boundary than when the word occurred elsewhere in a phrase (see also Gendrot, Adda-Decker & Santiago 2018). In a study of European Portuguese, Frota (2000) describes the scope of domain-final lengthening as the final syllable AS WELL AS the (non-final) stressed syllable in a pre-boundary word. Unlike the English pattern described above, she finds that preboundary lengthening systematically increases the duration of the stressed syllable in words with penultimate stress like *nível* /ˈnivɛɫ/ 'level'. In fact, Frota claims that "the bulk of the pre-boundary lengthening is consistently carried by the I[P]-final *stressed* element" (p. 191, emphasis in the original, see also Frota & Vigário 2007).

Based on these results, Examples 2.1-3 below might give a more accurate graphic rendering of the effects of proximity to a final boundary than (1.9-12) in Section 1.3.3. In this depiction, the unstressed syllables immediately preceding the final boundary (*-ing* in English, *-do* in Spanish and Portuguese) as well as the stressed syllables that precede them (*HIR-* in English *-TAN-* in Spanish and Portuguese) would be longer than if the word occurred elsewhere in the phrase:

(2.1)	[… concordia university is *HIRing*]**IP**	ENG
(2.2)	[… la universidad de concordia está contra*TANdo*]**IP**	SPA
(2.3)	[… a universidade de concórdia está contra*TANdo*]**IP**	POR

In sum, studies of boundary marking that control for stress placement above seem to indicate that lexical stress may also play a role in the marking of the final boundary. One possibility is that the locus of domain-final effects may be dual in words with non-final stress: the phrase-final, unstressed syllable, and the stressed syllable (cf. the DUAL TARGET hypothesis in Turk & Shattuck-Hufnagel 2007). Cross-linguistic differences in the extent to which the stressed syllable is affected, however, still need further investigation.

The findings discussed in this section further underscore the relevance of considering lexical prominence also in studies of prosodic phrasing (see Hyman 1977, Gordon 2014, and Roettger & Gordon 2017 for discussions). Because comparatively few studies have investigated domain-final effects beyond the phrase-final syllable, it is possible that we only have a partial understanding of how pre-boundary lengthening operates. The investigations of phrase-final lengthening reviewed in this section present relevant evidence to suggest that the position of lexical stress may be an additional determining factor in the phonetic encoding of prosodic phrasing (see also Katsika 2016). The potential association of lexical stress with a domain-final edge raises the question of how it may be implicated also in the phonetic marking of the initial boundary. This possibility is discussed below.

2.1.2 Domain-initial Effects and Lexical Stress

Evidence for the interplay between lexical stress and domain-initial effects is less conclusive than for domain-final lengthening. Many of the studies of domain-initial effects investigated languages with other types of word prosody systems (e.g. head/edge-prominence or edge prominence languages, cf. Jun 2014) such as French, Korean, or Japanese. As such, the role of lexical stress as a word prominence type still needs to be explored.

What's more, work on domain-initial effects tends to focus on individual segments that occur immediately after the left boundary of a domain. As a result, the influence of lexical stress, which typically operates at syllable- or word-level, still deserves attention. A careful review of studies that reported acoustic correlates of the phenomenon in English and Spanish reveals that most failed to isolate domain-initial effects from other types of prominence. To the best of my knowledge, Portuguese has never been investigated for domain-initial effects. Table 2.1 summarizes those observations.

Table 2.1 Prominence in studies of domain-initial effects (English and Spanish)

The studies below report on acoustic correlates of domain-initial effects in English and Spanish (NB. no study has investigated Portuguese hitherto)

Study	Language(s)	Target Cs	Prominence on target syllable
Fougeron & Keating (1997)	ENG	/n/	Stressed, possibly accented
Keating et al. (1999)	ENG	/t d k s ʃ ʒ tʃ dʒ/	Stressed, possibly accented
Choi (2003)	ENG	/p b/	Stressed, accented and unaccented
Lavoie (2001)	ENG SPA	all [a]	Stressed and unstressed, possibly accented
Cole et al. (2007)	ENG	/t d/	Stressed accented and unaccented
Cho & Keating (2009)	ENG	/n t/	Stressed (secondary), accented and unaccented
Parrell (2014)	SPA	/p t k b d g/	Stressed, possibly accented
Kim et al. (2018)	ENG	/p b/	Stressed and unstressed, accented and unaccented

[a] With the exception of Cs with distribution restrictions (i.e. ENG: /h ʒ ŋ/ and SPA /ɾ/). SPA /b d g/ collapsed with /β ð ɣ/. The Spanish dialect measured lacks /θ/.

Studies of English that tested the influence of phrasal accent (e.g. Cole et al. 2007, Cho & Keating 2009, Cho, Lee, & S. Kim 2014) have found an interaction between domain-initial effects and phrasal prominence. These authors find that VOT in syllables bearing phrasal accents showed limited expansion due to domain-initial effects. When the syllables were unaccented at the phrasal level, on the other hand, a boundary effect was observed on the post-boundary segment.

In order to address the role of lexical and phrasal prominence in domain-initial affects, S. Kim, J. Kim, and Cho (2018) study manipulated both phrasal accent and lexical stress in disyllabic English words. The examination of word-initial /p b t d/ in stressed (e.g. '**p**anel', '**t**anner') compared to words like '**p**anache' or '**t**enise', in which the word-initial stops occur in unstressed syllables, yielded mixed results. Interestingly, in unstressed syllables in unaccented words, the authors find a boundary effect only for voiced stops (e.g. '**b**anal', '**d**enise'), with /p t/ showing no increase in VOT values when occurring at an IP-initial boundary. Put differently, while [p t] in unstressed syllables showed an increase in VOT, the same was not observed for [p^h t^h]. At the same time, in phrasally accented words, both [p t] and [p^h t^h] showed increases in VOT, but the difference was not significant when the prosodic context was compared. These findings suggest that domain-initial effects manifest themselves in ways that relate to other types of prominence.

To the best of my knowledge, no investigation has evaluated how domain-initial effects on fully unstressed syllables in unaccented English words apart from S. Kim, J. Kim and Cho (2018). While Lavoie's (2001) study of English and Spanish did examine unstressed syllables, it is likely that her choice of a carrier sentence of the type '*Say _____ again'* may have inadvertently elicited contrastive focus (a type of phrasal accent) on the words she measured. Additionally, neither S. Kim and colleagues' nor Lavoie's investigations provide data on the non-boundary-adjacent stressed syllable for comparison. For these reasons, it is yet to be determined if the stressed syllable in a word like 'potato' would show any effect of proximity to the initial boundary.

Still, the results above and those related to domain-final lengthening described in the previous section all seem to indicate a close interconnection between the prominence and phrasing functions of prosody. The well-established association between lexical stress and phrasal accents already points in the direction of a mutual dependency between different levels of prosodic structure. The findings showing domain-final lengthening on stressed syllables that are not adjacent to the boundary lead to the hypothesis that final lengthening may indeed be anchored in the stressed syllable of a domain-final word, and extend rightwards towards the right edge of a domain, as shown in Table 2.2 below. Studies with tighter experimental control have yet to establish if a similar pattern may be found in words at a domain-initial boundary.

Table 2.2. Hypothesized scopes and loci of boundary marking effects

Based on current evidence, the locus of domain-final lengthening is assumed to be the nucleus of the stressed syllable in a phrase-final word, for domain-initial effects the locus is the phrase-initial consonant. Phrasal accent scope and locus given for comparison.

Prosodic effect	Associated with lexical stress?	Extends rightwards from locus?	Extends leftwards from locus?
Phrasal accent	yes	yes	yes
Domain-final lengthening	yes	yes	no
Domain-initial effects	unclear	unclear	no

Although the body of work presented above demonstrates that some phonetic variation in segments can be associated with the position of a word following a domain-initial boundary, a cohesive account of this phenomenon is still lacking. There are three possible explanations for this observation. First, the number of distinct segmental modulations attributed to domain-initial effects reduces comparability among different studies of domain-initial effects. Secondly, the interaction of boundary markings with different kinds of prosodic prominence has often been overlooked in previous research, thereby potentially introducing important confounds. Thirdly, methodological choices in previous studies, including the choice of materials and sample sizes, introduce non-trivial challenges in the interpretation of results. These issues are taken up in more detail below as they served to inform the current study in various ways.

2.2 Specificities and Unresolved Issues Regarding Domain-initial Effects

The phonetic marking of domain-initial boundaries differs in a number of ways from the marking of domain-final edges. As mentioned in the Introduction, pitch contours that frequently occur near the right boundary of higher-level domains are at best optional at the left edge of a prosodic constituent (see Jun 2005a, 2014 for cross-linguistic data). Additionally, whereas the locus of domain-final lengthening possibly encompasses entire words (e.g. Cho, J. Kim & S. Kim 2013), the locus of domain-initial effects has been shown to be rather restricted, often affecting individual segments.

2.2.1 Specificities: Locality Condition and Subphonemic Modulation

The observation that the locus of domain-initial effects is often restricted to the immediate vicinity of the initial boundary has led to the hypothesis of a LOCALITY CONDITION (Cho 2016) for the phonetic marking of the boundary. Unlike other types of prosodic markings, the literature suggests that the phonetic effects that encode an initial boundary are most reliably found in the initial segment of a boundary-adjacent word, whether it be a consonant or vowel. Previous studies of English indicate that vowels following a stop in domain-initial CV syllables show little or no effect of boundary marking. A few other studies have found some indication of boundary-induced expansion of vowels in CV syllables, but not as consistently so (Byrd 2000, Byrd, Krivokapić & Lee 2006, Cho 2005, Cho & Keating 2009).

One of the implications of the locality condition is that it is possible that domain-initial effects and lexical prominence may operate independently of one another. As mentioned in the Introduction, this state of affairs would imply that an unstressed syllable following a domain-initial boundary could potentially be "strengthened" and "weakened" at the same time. This interaction of opposing phonetic forces would then explain why in certain languages, consonants in unstressed syllables often remain even after a vocalic segment is lost due to stress-related reductions.

The role of acoustic duration, as opposed to articulatory measures, is also much less clear in the encoding of domain-initial boundaries than in other prosodic effects. Duration seems to be a primary acoustic correlate of lexical and phrasal prominence in many stress languages, and it plays an important role in the marking of domain-final boundaries, hence the term final LENGTHENING. On the other hand, the marking of initial boundaries operates in segment-specific ways, relating to subphonemic properties of consonants and vowels (Fougeron 2001). For instance, voiceless stops may show differences in VOT values between prosodic contexts (Jun 1993, Cho & McQueen 2005), whereas voiced ones may show decreased voicing as a correlate of domain-initial effects (S. Kim, J. Kim & Cho 2018). Nasal consonants show differences in nasal murmur and reduced duration based on the type of boundary (Cho, D. Kim & S. Kim 2017). Some fricatives may show no phonetic effects of boundary-initial marking (e.g. Fougeron 2001, Lavoie 2001 for /s z/ in French, English and Spanish, respectively), while others may be longer after higher-level boundaries (Byrd & Choi 2010, Kuzla, Cho & Ernestus 2007). Data on liquids are exceedingly scarce.

Another complicating factor that relates to domain-initial effects is that different languages show distinct phonetic expressions of the same segment class (e.g. Cho & Ladefoged 1999, Gordon, Barthmaier & Sands 2002). The segments chosen for the current study are a case in point. The voiceless consonants /p t k/ may occur as [p^h t^h k^h] in English whereas Spanish and Portuguese are more likely to show [p t k] (J. Beckman, Jessen, & Ringen 2013, Ahn 2018). Their voiced counterparts /b d g/, which are not investigated in this dissertation, show even more distinct language-specific behavior. English /b d g/ may actually be more accurately transcribed as [p t k] (Beckman et al. 2013), Brazilian Portuguese /b d g/ show consistent voicing and closure (Ahn 2018), whereas Spanish /b d g/ show a range of phonetic expressions: [b ~ β, d ~ ð, g ~ ɣ] or even Ø (Hualde 2005). The literature on domain-initial effects suggests that such that phonological specificities play an important role in how these effects operate.

In a study of Dutch stops, Cho and McQueen (2005) report that voiceless /t/ had *shorter* VOT in domain-initial position than when it occurred in the middle of a phrasal domain. S. Kim, J. Kim, and Cho (2018) find that VOT for English /b d/ shows more consistent effects of boundary marking in unstressed syllables than /p t/. Results for Taiwanese, Korean, and most findings on English show the opposite pattern (Hsu & Jun 1999, Cho & Keating 2001). In a study of German fricatives, Kuzla, Cho, and Ernestus (2007) show that the fricatives /f v z/ were longer when immediately following major prosodic boundaries than at the left edge of an IP-medial word. On the other hand, Fougeron's (2001) results for French /s/ showed a lack of clear distinctions between initial boundaries of different domain levels.

Cho (2011, and subsequent work) proposes that cross-linguistics differences in the way domain-initial effects operate can be accounted for by language-specific prosodic and phonetic structure. Because languages differ in their grouping of prosodic units, different languages mark initial boundaries for certain domains but not others (e.g. Keating et al. 2003). Additionally, rather than enhancing general phonetic characteristics such as voicing, aspiration, or frication, domain-initial effects highlight contrasts between neighboring segments in ways reinforce those subphonemic properties (e.g. Pierrehumbert & Talkin 1992, Fougeron & Keating 1997, Fougeron 1999, S. Kim, J. Kim, & Cho 2018). For example, sequences of a nasal consonant and vowel at the boundary of a higher prosodic domain such as the IP may show reduced coarticulation compared to the same NV sequence at lower level. That is, the pronunciation in a syllable like /no/ would be expected to be more oral at a higher level of the prosodic hierarchy (i.e. [no]), whereas [nõ] would occur at a lower level, in which [õ] is less distinct from [n]. More comprehensive studies with more languages are needed to expand on these proposals.

2.3 Unresolved Issues and the Present Study

The main unresolved issues with regards to domain-initial effects are: their relationship to lexical stress (and other types of word prominence), their scope of influence, and how they interact with language-specific segmental phonology.

While domain-initial effects are undoubtedly complex, it is possible that the lack of uniformity in results may be due to experimental design and/or to sample size. As mentioned above, many investigations fail to control for other levels of prosodic prominence in test words, creating difficulties for the interpretation of their findings (cf. Fougeron 2001:112). While some studies manipulated phrasal accent (e.g. Cho, D. Kim & S. Kim 2017), others may have inadvertently introduced focus accents by having speakers repeat similar or identical carrier sentences (e.g. Lavoie 2001 and Parrell 2014 for Spanish), which would have likely elicited contrastive focus accents on test words (see Roettger & Gordon 2017 for a discussion).

Another important caveat lies in the fact that most research on domain-initial strengthening has focused on articulatory data. Due to the challenges of collecting such data, many studies have been conducted using small samples of three to five speakers per study. Nonetheless, the understandably limited number of speakers in these studies may have allowed idiosyncrasies in the speech materials or the behavior of participants to skew the results. In smaller samples, individual differences in speaker behavior may skew results in ways that make it difficult to distinguish the effects of the variables being tested from those relating to idiosyncrasies in the speech of participants.

The present study tackles these issues by employing the following strategies:

a) Separating domain-initial effects from lexical prominence by investigating word-initial unstressed syllables.
b) Controlling the placement of phrasal accent in the target sentences through elicitation of narrow focus away from the initial boundary.

c) Avoiding excessive influence by individual idiosyncrasies on the overall results by recording a larger group of speakers per language.

d) Evaluating the role of language-specific phonology by performing a direct comparison of three languages using similar materials.

2.4 Chapter summary

This chapter discussed cases of interactions between prosodic phrasing and lexical prominence reported in studies of several languages. It also delved into the specificities of domain-initial effects, and how those relate to language-specific distinctions between categories of segments such as voiceless stops. Issues in previous investigations of domain-initial boundaries are also discussed in this chapter, along with an outline of how this dissertation aims to contribute to the field of study of domain-initial effects. The next section details how this endeavour was undertaken.

CHAPTER 3

METHODOLOGY

3.0 Chapter Overview

This study investigated domain-initial effects on segments in fully unstressed syllables in three lexical stress languages. The data come from speech sampled under experimental control. Separate reading tasks were conducted with native speakers of American English, Mexican Spanish, and Brazilian Portuguese using the same experimental procedure and analysis methods. Section 3.2 describes how the experiment was designed, including how the stimuli for the two experimental conditions were created for each language, followed by the description of recording procedures in 3.3. Section 3.4 details how the data were extracted, while 3.5 explains how the data were evaluated through the choice of variables, as well as how these were measured. The initial assessment of the dataset is described in Section 3.6 along with the criteria for inclusion in the statistical models detailed in 3.7.

3.1 Participants

In total, 52 participants aged between 18 and 31 took part in the experiment described here. English and Spanish speakers were undergraduate students enrolled in linguistics classes at the University of New Mexico at the time of the data collection, and they received extra credit for their participation. Portuguese speakers were undergraduate and junior graduate students from the University of Minas Gerais in Brazil, who were recruited through a mailing list. Speakers in Brazil received gift cards in compensation for their participation.

Fourteen speakers of each of the three languages make up the sample of 52 individuals (English: 8 female 6 male, Spanish: 12 female 2 male, Portuguese: 8 female 6 male). All participants were native L1 speakers of their language with no known hearing issues. Most speakers of English were self-reportedly monolingual. Portuguese speakers had knowledge of English to different degrees. The Spanish speakers recruited for this study were fully bilingual in English, although all reported having first acquired Spanish from both (Mexico-born) parents in the home[10].

No specific efforts were made to control for dialect representation within country varieties (i.e. Mexican Spanish, Brazilian Portuguese, and American English). However, all English speakers reported having grown up in the western half of the United States, mostly in the state of New Mexico. All Brazilian Portuguese speakers were from the state of Minas Gerais, the great majority of them from the city of Belo Horizonte. Most Mexican Spanish speakers self-reported having acquired the Chihuahua dialect, although there were also participants who had been exposed to Jalisco and Sonoran varieties by one or both parents. Any dialect differences that may exist among speakers of the individual languages were not examined.

[10] Although research suggests late bilinguals' phonetic categories may shift (e.g. Sancier & Fowler 1997, but see Tobin, Nam & Fowler 2017 for a discussion), the VOT data produced by Spanish-dominant early bilinguals in the current study does not deviate from values reported in previous studies of monolingual Spanish speakers (e.g. Lisker & Abramson 1964, Rosner et al. 2000). More research is needed to evaluate these findings.

All participants were naïve to the purpose of the study and reported having no speech hearing or vision impediments. The University of New Mexico's Office of the Institutional Review Board Committee approved all protocols reported here.

3.2 Experiment Materials

3.2.1 Test Words

Trisyllabic words with penultimate stress were selected for testing in each language. The motivation for using three-syllable words is twofold. First, the /σˈσ.σ/ pattern reduces the possibility of secondary stress on the target syllable that could arise if there were two or more syllables that preceded it, due to rhythmic constraints (e.g. Liberman & Prince 1977, Shane 1979, for English; Roca 1986, Hualde & Nadeu 2014, for Spanish; Major 1985, Moraes 1998, for Portuguese). Secondly, while trisyllabic words with penultimate stress are the most frequent word shape in both Spanish and Portuguese words (Davies 2006, for Spanish; Cardoso-Martins 1995, and references therein, for Portuguese) this pattern is not uncommon in English either (cf. Cutler & Carter 1987, Cutler 2005).

The focus of this study is the word-initial unstressed CV sequences. In all test words, this CV sequence consisted of a voiceless stop /p t k/ and a monophthong. The choice of a CV shape for the target syllable was made in order to facilitate cross-linguistic comparison given its frequency in the world's languages (Maddieson 2013).

In the English stimuli, the vowel in the target CV syllable was always /ə/, whereas in Spanish and Portuguese, both high and low vowels were tested (see examples below). Different vowels were used in the Spanish and Portuguese target syllables because unstressed syllables in the Romance languages show a wider variety of vowel qualities than in fully unstressed syllables in English. In prestressed position, /i e a o u/ may occur in both Spanish and Portuguese, whereas only /ə/ occurs in English (see Flemming & Johnson 2007 for a recent acoustic account of unstressed vowels in English). Furthermore, the choice of comparing high and low vowels specifically is motivated by important differences in duration between these two vowel heights in these languages (Nadeu 2014, for Spanish; Cantoni 2013, for Portuguese). Target syllables were always followed by a voiceless segment in the onset of the following syllable, so as to avoid the effects of possible vowel lengthening due to an adjacent voiced consonant (Chen 1970).

This dissertation also reports observations on durational properties of the stressed syllables in test words, which immediately followed the target CV syllable in the stimuli. Although not targeted by the experimental design and thus less controlled for, describing the general pattern of the stressed syllable in test words is informative since it turned out to provide relevant results.

The size of the stressed syllable varied between two and four segments, depending on the language, with two segments being the most common pattern (e.g. / tʰ/ and /ɪ/ in English 'pe<u>ti</u>tion'). All stressed syllables in Portuguese test words were composed of two segments (e.g. /p/ and /ɛ/ in Portuguese *ca<u>pe</u>la* 'chapel'), but some English and Spanish words had three segments (e.g. /tʰ/, /ɹ̥/ and /i/ in English '<u>katri</u>na', or /p/, /ɾ/ and /i/ in Spanish *ca<u>pri</u>cho* 'a whim'). The stressed syllable in a single English word, 'patrolmen', contained four phonemes, /tʰɹoʊɫ/, and was the only test word to contain a coda consonant. The quality of the vowel in the stressed syllable varied to different degrees depending on the language. Finally, the voicing of the consonant following the stressed vowel also varied, although voiced segments predominate in the stimuli as a whole.

3.2.1.1 English test words

Six trisyllabic English words with penultimate stress were tested in this investigation. As mentioned above, the vowel in the target syllable nucleus was always /ə/. Words matching the criteria for both target syllable and stress placement were found through a search of the phonetic context dictionary by Carnegie Mellon University, the CMU Pronouncing Dictionary (1998).

Table 3.1 Test words used in the English stimuli

All words shown in phonetic transcription; target syllables shown in bold.

Word- initial Stop		
/p/	**/t/**	**/k/**
pʰəˈtʰɪʃənz	**tʰə**ˈkʰilə	**kʰə**ˈpʰeɪʃəs
‘petitions’	‘tequila’	‘capacious’
pʰəˈtɹ̥oʊɫmən	**tʰə**ˈkʰɑɾəs	**kʰə**ˈtɹ̥inə
‘patrolmen’	‘toccatas’	‘Katrina’

As shown in the transcriptions, it was expected that all word-initial stops in target syllables would be produced with aspiration. With regards to the stressed syllable, two words had complex onsets (‘patrolmen’ and ‘Katrina’), whereas ‘patrolmen’ also had a coda consonant. As mentioned above, vowels in the stressed syllable varied along different quality and phonological duration parameters (i.e. /ɪ i eɪ oʊ ɑ/). Overall, the English test words had the largest number of segments per word. Additionally, the only test words that deviated from the /CVˈCV.CV/ pattern used in the study occurred in the English stimuli.

Due to a minor error in sentence design, the word ‘toccatas’ was used in the singular (‘toccata’) in the carrier sentence in one of the experimental conditions (i.e. the IP-medial condition, see Appendix A). However, the phonetic influence of the plural marker on the target syllable is assumed to be negligible, so that data referring to both ‘toccatas’ and ‘toccata’ were kept in the dataset and analyzed as a single test word.

3.2.1.2 Spanish test words

Table 3.2 shows the six trisyllabic Spanish words with penultimate stress investigated in this study: *pitada, patrulla, tipazo, tacada, cuchara*, and *capricho*. Target syllables in Spanish test words contained either the low vowel /a/, or a high vowel (/i/ or /u/). Two different high vowels were used in the target syllables due to phonotactic constraints in the distribution of sequences of voiceless stop and high vowel in the language. Spanish words that met the criteria for inclusion were found through a dictionary search.

Table 3.2 Test words used in the Spanish stimuli

All words shown in phonetic transcription; target syllables shown in bold.

Vowel height/Stop	**/p/**	**/t/**	**/k/**
High vowel	**pi**ˈtaða ‘whistling’	**ti**ˈpaso ‘stud’	**ku**ˈtʃaɾa ‘trowel’
Low vowel	**pa**ˈtɾuja ‘patrol (car)’	**ta**ˈkaða ‘a strike’	**ka**ˈpɾitʃo ‘whim’

3.2.1.3 Portuguese test words

Table 3.3 shows the six trisyllabic Portuguese words with penultimate stress selected for investigation: *pitada*, *patola*, *tutela*, *tacada*, *cutelo*, and *capela*. As in the Spanish stimuli, target syllables contained either a low vowel (i.e. /a/) or a high vowel (/i/ or /u/). Whenever possible, the Portuguese words were nearly identical to the Spanish stimuli, although some of the words' meaning may differ between the two languages. A dictionary search was also used to find test words in Portuguese.

Table 3.3 Test words used in the Portuguese stimuli

All words shown in phonetic transcription; target syllables shown in bold.

Vowel height/Stop	/p/	/t/	/k/
High vowel	**pɪ**ˈtadə	**tʊ**ˈtɛlə	**kʊ**ˈtɛlʊ
	'a pinch of'	'guardianship'	'cleaver'
Low vowel	**pa**ˈtɔlə	**ta**ˈkadə	**ka**ˈpɛlə
	'stocky'	'smart move'	'chapel'

In addition to the lack of words containing the same high vowel following the three target consonants in the phonetic context examined here, the sequence /ti/ is absent in the variety of Portuguese analyzed here. As mentioned in Chapter 2, unstressed high vowels in Brazilian Portuguese are subject to reduction so that unstressed /i/ may occur as [ɪ ~ ɪ̥ ~ ^{j} ~ ø] and /u/ as [ʊ ~ ʊ̥ ~ ^{w} ~ ø]. All Portuguese stimulus words had the shape /CVˈCV.CV/.

3.2.2 Experimental Conditions and Design

In order to assess how the different levels of prosodic constituents impact segmental information at the domain-initial boundary, two different sets of sentences containing the same test words were designed. The experimental conditions manipulated the position of the test word within carrier sentences. Test words were embedded in two different positions, either at the beginning of an Intonational Phrase (IP-initial condition) or in the middle of the Intonational Phrase (IP-medial condition).

As mentioned in Section 2.3, in English, Spanish, and Portuguese, the IP is a higher-level prosodic domain (Beckman et al. 2005, Hualde & Prieto 2015, Frota et al. 2015). However, the comparisons drawn here make no reference to a specific lower level domain in the IP-medial condition, since the three languages differ in the sizes and types of midlevel domains. Rather, test words at an IP-initial edge are compared against those occurring in the middle of the IP, which could possibly correspond to a Prosodic Word, to a Phonological Phrase, or to an intermediate phrase (in English).

A total of 12 meaningful carrier sentences (2 conditions x 6 words) were designed per language. Every sentence was unique and semantically consistent and formed a coherent phrase with regards to the test word. All carrier sentences in the study had a total number of 25 canonical syllables regardless of language and experimental condition. The position of the target syllable within carrier sentences was kept constant for each condition across languages. This precaution was taken in light of the influence of the length of an utterance on speech rate and thus segment duration (Fónagy & Magdics 1960, Lehiste 1974, among others).

A series of measures were undertaken to guarantee that test words were did not receive the nuclear pitch accent (phrasal accent). This is because in each of the three languages, phrasal accent has been found to increase duration in words/syllables that are accented (e.g. Cantoni 2003 for Brazilian Portuguese, Hualde & Prieto 2015 for Spanish). On the other hand, no specific controls were undertaken to avoid the placement of pre-nuclear pitch accents in test words.

In order to minimize the possibility of lengthening in target syllables, contrastive or corrective narrow focus was elicited elsewhere in the Intonational Phrase in the IP-initial condition. A focused word is defined as a salient unit in comparison to other related words or noun phrases either explicitly or implicitly evoked in the context (see Rooth 1992). All stimuli were piloted with different speakers of the individual languages.

3.2.2.1 IP-initial condition

For the IP-initial condition, the test words were inserted in syntactically complex carrier sentences consisting of two-parts: a background clause and a test clause (Table 3.4). The background clause provides context for the content of the test clause, and served to encourage speakers to produce the intended prosodic pattern. In order to elicit the production of a prosodic boundary before the test clause, punctuation marks (i.e. colons, semicolons, or commas) were used (cf. Turk & Sawusch 1997, Keating et al. 2003). Additionally, so as to minimize the possibility of test words receiving the phrasal accent, which might lengthen the whole word, background clauses in each carrier sentence in the IP-initial condition were designed to elicit contrastive focus (see Turk, Nakai, & Sugahara 2006 for a discussion of this strategy). In addition to contextual information, words that were to receive focus were capitalized and participants were instructed to emphasize them. Tables 3.4-6 below illustrate how sentences in the IP-initial condition were organized for the English, Spanish, and Portuguese stimuli, respectively.

Table 3.4 Sample of an English carrier sentence (IP-initial condition)

Example of a sentence containing /kə/ *in the IP-initial condition for English, the IP boundary is represented by <||>; test word underlined, target syllable shown in bold.*

Background clause(s)	Test IP
It doesn't refer to ability! You can check for yourself	**ca**pacious *means ROOMY or full of space*
||	**kʰə**ˈpʰeɪʃəz

Table 3.5 Sample of a Spanish carrier sentence (IP-initial cond.)

Example of a sentence containing /pi/ *in the IP-initial condition for Spanish, the IP boundary is represented by <||>; test word underlined, target syllable shown in bold.*

Background clause	Test IP
Estás confundido,	**pi**tada quiere decir SOPLADO más que sonido o pitido
||	**pi**ˈtaða
You're mistaken,	*whistling is a BLOWING SOUND more than a noise or a beep*

Table 3.6 Sample of a Portuguese carrier sentence (IP-initial cond.)

Example of a sentence containing /pi/ *in the IP-initial condition for Portuguese, the IP boundary is represented by <||>; test word underlined, target syllable shown in bold.*

Background clause	Test IP
Tem muito sal aqui;	**pi**tada quer dizer só UM POUQUINHO do ingrediente na receita
||	**pɪ**ˈtadə
This has too much salt,	*a pinch means just A LITTLE of the ingredient from the recipe*

The length of the background clause was kept constant at 15 syllables for English, but at 6 syllables for both Spanish and Portuguese. A distinct number of syllables in the precursor IPs proved necessary due to syntactic and word-length differences among the languages. Spanish and Portuguese words tend to be longer than English words, but the higher number of bound morphemes per word (i.e. morphological complexity) in the Romance languages means that there were generally fewer words per sentence in the Spanish and Portuguese stimuli overall.

3.2.2.2 IP-medial condition

The IP-medial condition was designed so that it would establish a baseline against which to compare words at an IP-initial boundary in the experimental condition described in the previous section. In the IP-medial condition, words containing target syllables occurred in the middle of an Intonational Phrase. That is, each test word was grouped together with the preceding and following words in the same prosodic domain (see the full set of stimuli in Appendix A). Carrier sentences in the IP-medial condition contained the same words that were used in the IP-initial condition (see Tables 3.1-3 above). The total syllable count for each sentence was once again 25 for all three languages.

In order to maintain a parallel structure between the two experimental conditions, background clauses were also used in the IP-medial condition. The total number of canonical syllables preceding the test words was also held constant within each language, but the number of syllables in the background clauses varied between 15, 17, or 18 depending on the language (see below). Since no major prosodic break was expected before test words in the IP-medial condition, the words immediately preceding target syllables were controlled for stress placement in this condition. Most often, the word preceding the target CV syllable ended in an unstressed syllable (e.g. /ˈsi.li/ in ‘si<u>lly</u> <u>**pe**</u>titions’ for English, or /ka.ʃoˈɦĩ.<u>ɲə</u> / in *cachorri<u>nha</u>* <u>**pa**</u>*tola* ‘stocky puppy’ in the

Portuguese stimuli). In some of the carrier sentences in the Spanish and Portuguese stimuli, an unstressed function word (cf. Hualde 2007) preceded the target syllable (e.g. *la* ***pi****tada* 'the whistle blow' in the Spanish stimuli, or /ˈu.mə/ in *uma* ***pi****tada* 'a pinch' for Portuguese).

The carrier sentences in the IP-medial condition were also controlled for phrasal accent placement. Because the phrasal accent tends to fall on the last content word in all three languages (see Sections 1.3 and 2.3 above), there was always at least one lexical word between the test word and the IP-final boundary (e.g. [... silly **pe**titions make no difference**]IP**, in which the word 'difference' was expected to receive the main phrasal accent). This strategy also had the advantage of minimizing the possibility of test words in the IP-medial condition undergoing phrase-final lengthening. The stimuli in all IP-medial carrier sentences was designed to elicit the intonational pattern of a neutral declarative statement. Examples of carrier sentences in the IP-medial condition in the three languages follow.

Table 3.7 Sample of an English carrier sentence (IP-medial condition)

Example of a sentence containing unstressed word-initial /pə/ *in the IP-medial condition in English, the lower-level domain boundary is represented by <#>; test word shown in bold. Putative IP boundaries represented by brackets.*

		Test word	
It is very sad there's not too much they can do at this point: the city's ***capacious*** *museum closed*			
	[	ˈsɪɾiz # k**ʰə**ˈpʰeɪʃəz	**]IP**

Table 3.8 Sample of a Spanish carrier sentence (IP-medial cond.)

Example of a sentence containing unstressed word-initial /pi/ *in the IP-medial condition in Spanish, the lower-level domain boundary is represented by <#>; test word shown in bold. Putative IP boundaries represented by brackets.*

Test word
A causa de la lluvia, el árbitro Federico dió la **pitada** a las tres horas
[la # **pi**ˈtaða **]$_{IP}$**
Because of the rain Federico the referee blew the whistle to end the match at 3 o'clock

Table 3.9 Sample of a Portuguese carrier sentence (IP-medial cond.)

Example of a sentence containing unstressed word-initial /pɪ/ *in the IP-medial condition in Portuguese, the lower-level domain boundary is represented by <#>; test word in bold. Putative IP boundaries represented by brackets.*

Test word
Pimenta caiena é mais forte do que do reino, só uma **pitada** tá mais que bom
[ˈumə # **pɪ**ˈtadə]$_{IP}$
Cayenne pepper is much stronger than black pepper, just one pinch is more than enough

For the English stimuli, the target syllable always occupied the 19th slot in the carrier sentence, and all but one test word was preceded by a disyllabic adjective ending in [i]. For Spanish, the target syllable always occupied the 18th slot in the sentence. Test words in the IP-medial condition were preceded by a verb or function word ending in a vowel or [l]. For the Portuguese stimuli, the target syllable always occupied the 19th slot in the sentence, and all test words were preceded by a noun or function word ending in a vowel.

Once again, morphosyntactic and word-length differences between English, Spanish, and Portuguese did not allow for an exact match between the stimuli in the languages in the study. Since the cross-linguistic goal of this dissertation is to provide first and foremost a qualitative assessment of differences between the three languages, the differences among the stimuli used in the three languages are small enough that it will be assumed they cannot be responsible for qualitatively different results.

3.2.3 Distractor and Filler Items

A variety of strategies were employed to guarantee a more natural rendering of the stimuli designed for this study (cf. Xu 2010). These included presenting distractor items with different kinds of intonation patterns, and using corpora of spontaneous language to obtain filler sentences. In addition to the experimental materials described in this section participants read sentences consisting of questions (yes-no as well as wh-items), lists, exclamations, and contrastive focus sentences. Sentences of various sizes and levels of vocabulary were selected. All filler sentences were obtained from the Brigham Young University (BYU) corpora of the specific varieties of the languages investigated: the Corpus of Contemporary American English (Davies 2008-) for English, *Corpus del español* (Davies 2016-) for Spanish, and *Corpus do português* (Davies 2016-) for Portuguese.

3.3 Recording Procedures

The same experimental procedure was used for the three languages. Acoustic data were acquired at a sampling rate of 16 kHz through an Audio-Technica USB microphone plugged directly into a laptop. The sound editing software Audacity (2012) was used to record all participants. English and Portuguese speakers were recorded in quiet rooms in Phonetics labs at the University of New Mexico and the Universidade Federal de Minas Gerais in Brazil, respectively, in 2016-2017. Spanish speakers were recorded in 2017-

2018 in a sound-attenuated booth at the University of New Mexico that had not been available at the time of the English recordings. Variability in the experimental setting yielded recordings of different qualities, although all were deemed fit for acoustic analysis.

Stimuli were presented on sheets of paper with six to eight sentences per page in large fonts, one sentence per line. Participants read each carrier sentence three times in pseudo-randomized order, with the carrier sentences interspersed among filler items in two (for English) or three blocks (for Spanish and Portuguese). Speakers were encouraged to read the sentences at their own pace, as naturally as possible while attending to the specific nature of the sentences (e.g. question, statement, negation etc.). Before they started reading the material, it was emphasized that the interest of the study lay in the sentences as a whole, so that there was no need to articulate individual words very carefully. English speakers read 120 sentences in total whereas Spanish and Portuguese speakers read 180 each. These included sentences with test words beginning with /m n/ which were intended for future analysis.

Practice trials acquainted speakers with the general task design, as well as with less frequent test words in the stimuli (e.g. 'toccata' for English) so as to avoid hesitations. At this stage, corrections were made when needed, and speakers were encouraged to re-read the words in case of error. Unless prompted by participants themselves, the experimenter provided no feedback/corrections during recording sessions. However, whenever there was an error or disfluency, speakers could repeat a given sentence if they wished. All interactions with participants took place in their own languages.

3.4 Data Extraction

All acoustic measurements were made using the software Praat (Boersma & Weenink 2011). The FAVE-align automatic forced aligner (Rosenfelder et al. 2014) was used to generate segment intervals in TextGrids for the analysis of the English stimuli, which were then hand-corrected as needed. Syllable, word, and phrase intervals were created manually by the author based on the output for segments generated by FAVE. For the Spanish and Portuguese datasets, the automatic forced aligner EasyAlign (Goldman 2011) generated syllable, word, and phone intervals. Hand-corrections where made where needed. Subphonemic segmentation was done manually by the author based on the acoustic information available in the spectrogram and waveform. Prosodic annotations were also done manually. All annotated data were extracted automatically from the TextGrids using purpose-designed Praat scripts. The ways in which the annotated data were operationalized as individual variables are explained below.

3.5 Variables

This dissertation examines how domain-initial effects impact each of the two segments of an unstressed CV syllable. Several acoustic parameters identified in previous literature as correlates of prosodic boundary "strength" in various languages (see Section 1.3.3) provide the data used to test the hypotheses that guide the present investigation. This section details how the acoustic data were operationalized as variables, and how they were measured in the annotated TextGrids.

The acoustic effects of domain-initial position are evaluated separately for each segment, so that there are two broad types of dependent variables: consonant measures and vowel measures. These are explained separately in Sections 3.5.1 and 3.5.2 below, along with the specific predictions for each. Independent variables that pertain to either consonants or vowels alone are discussed within each of those sections.

However, many factors have been found to affect all segments alike, especially acoustic duration. Additional measures that may account for some differences in the acoustic properties of the target consonants and vowels are addressed in Section 3.5.3. It should be noted that only subsets of these additional variables were selected for each of the statistical models described in 3.7.

3.5.1 Consonant Measures

3.5.1.1 Dependent variables for /p t k/

Voice onset time (VOT). VOT is defined as the period of time immediately after the release of the stricture up to the onset of regular laryngeal voicing (Lisker & Abramson 1964). VOT was measured manually from first peak of the stop burst release up to the zero crossing nearest the onset of the second formant in the following vowel, as shown in the spectrogram. In case of multiple release bursts, the first burst was used. In the absence of clear burst releases, periods of visible aspiration in the spectrogram were also measured as VOT (cf. Abramson & Whalen 2017), in which case the beginning of the aspiration noise was taken as the acoustic delimiter for segmentation.

Voice onset time is primarily related to the magnitude of laryngeal articulation in that longer VOT values could derive from a larger or longer glottal opening (Cooper

1991). It has been suggested that larger VOT values correlate with a strengthening of the glottal abduction gesture (e.g. Pierrehumbert & Talkin 1992, Jun, Beckman, & Lee 1998, Cho & Keating 2001). Based on results of previous studies of stressed syllables (Cho & Keating 2009, Lavoie 2001, Parrell 2015) it is predicted that VOT values will be longer in word-initial unstressed consonants at IP-initial boundaries in the three languages. It should be noted that differences in VOT values have been reported as a correlate of domain-initial effects also in languages with short-lag VOT consonants, such as French (Fougeron 2001), or Japanese (Onaka et al. 2003).

Occurrence of a stop release burst. It is defined as a transient noise pulse at the release of the built-up air pressure during the voiceless stop closure noted through visual inspection of both waveform and spectrogram. The absence of a voiceless stop release burst indicates a weaker phonetic manifestation of a segment than when the release is clearly visible (cf. Stevens & Keyser 1989, Torreira & Ernestus 2011). Following Lavoie (2001) it is predicted that IP-initial stops will show fewer instances of absent bursts than their IP-medial counterparts in all three languages.

3.5.1.2 Independent variable pertaining to /p t k/

Place of articulation. Defined as the individual place of articulation of the consonant in the target unstressed syllable in the stimuli. Place of articulation has been shown to influence VOT values (Cho & Ladefoged 1999, for cross-linguistic data; Avelino 2018, for Mexican Spanish; and Ahn 2018, for Brazilian Portuguese), as well as stop burst release (Winitz, Scheib, & Reeds 1972). It is predicted that place of articulation differences will pattern similarly across different experimental conditions, so that VOT values for /k/, for instance, will be consistently longer than those for /p/ both phrase-initially and phrase-medially.

3.5.2 Vowel Measures

3.5.2.1 Dependent variables for all languages

Unstressed vowel duration. Vowel duration is defined as the acoustic duration of the vowel in the nucleus of the target unstressed CV syllable, measured in milliseconds. Vowel duration was measured from the onset of the vowel's F2 to its offset as seen in the spectrogram and waveforms. It is predicted that word-initial unstressed vowels will show no significant differences in duration based on their position within the IP, in accordance with results from studies of stressed syllables.

First formant (F1). The first formant is defined as the first resonance of the vowel, measured in Hz. F1 was extracted from the midpoint of the target vowel as labeled in the TextGrid. The measurements obtained were then normalized for each token based on the means and standard deviations calculated over all productions by the same speaker. First formant values serve as an indirect measure of jaw opening, which has been found to correlate with articulatory clarity under prosodic focus (e.g. Erickson 1998). Cho & Keating (2009) also found partial evidence that domain-initial effects increase F1 values in vowels in CV syllables at an IP-boundary.

Research on domain-initial effects indicate that they operate most consistently on the word-initial segment of prominent syllables. If previous findings hold in the present investigation, it is expected that F1 values will show no significant difference between experimental conditions. However, if in unstressed syllables the scope of the effect goes beyond the domain-initial consonant, the vowel that follows the IP-initial consonant will show (height-specific) differences in F1 values, suggestive of changes in the degree of jaw opening. In that case, it is predicted that /i u/ in the Spanish and Portuguese data will show lower F1 values, whereas /a/ and English /ə/ will show an increase in F1. These changes are consistent with an expansion of the vowel space in the IP-initial syllable.

3.5.2.2 Additional independent variable pertaining to Spanish and Portuguese

In the Spanish and Portuguese stimuli, target syllables contained three different vowel qualities: /i a u/. It is thus possible that the data may reflect these differences, depending on characteristics of the vowel. To account for these differences, vowel height was coded as an independent variable only in Spanish and Portuguese subsets of the data.

Vowel height. Vowel height is defined as the canonical height of the target vowels in the stimuli, either *high* or *low*. High vowels were /i u/ and the low vowel consisted of /a/ alone. Note that all possible phonetic renderings of Portuguese /i/ and /u/ were classified according to the citation form. It is predicted that high vowels will show shorter duration values overall, and lower F1 values compared to /a/.

3.5.3 Independent Control Variables Pertaining to All Segments

Several additional measures were undertaken to better isolate the effects of the two boundary conditions under scrutiny. Further acoustic factors expected to influence dependent variables included: length of pre-boundary silent interval, duration of stressed syllables in target words, and unigram frequency. Additional variables that relate to between- and within-speaker differences included: articulation rate, and order of repetition of the experimental stimuli in the reading task. These were operationalized as follows:

Silent interval. Silent interval is defined here as the interval without visible phonation in the waveform, in milliseconds. For sentences in the IP-initial condition, silent interval duration was measured from the end of the last segment of the last word in the background clause, up to the beginning of the first segment of the test word (as generated by the automatic forced aligner, see Figure 3-a). As a control, silent interval duration was measured in words in the IP-medial condition using the same criteria as in the IP-initial condition. It should be noted that the automatic forced aligners may include part of the closure of the voiceless stop in its measure of the pause that may occur before the test word[11].

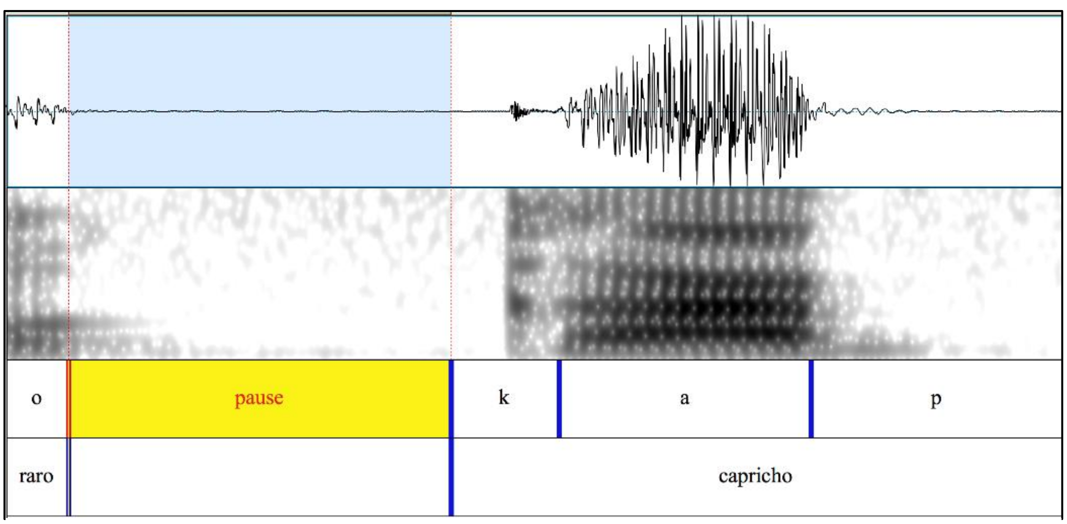

Figure 3-a. Measurement of a silent interval ("pause") in the IP-initial condition

The picture shows an annotated spectrogram and waveform taken from the Spanish dataset (Speaker MU02, test word capricho *'whim', second repetition). The boundary of the word-initial consonant in test words, as generated by the automatic forced aligner, was used as the parameter to mark the end of the silent interval*.

[11] Both the FAVE-align (Rosenfelder et al. 2014) used for English, and the EasyAlign (Goldman 2011) used for the Spanish and Portuguese data, estimate voiceless stop closure intervals using pre-trained acoustic models of clear speech built within the HTK Speech Recognition Toolkit.

Silent pauses are particularly relevant to the study of prosodic boundaries since they can serve as indications of boundary strength (see Krivakopić 2014 for a review). Specifically, there is evidence to suggest that the duration of a pre-boundary pause may be correlated with gestural magnitude of the first segment following the pause (e.g. Beňuš & Šimko 2014, see also Ramanarayanan et al. 2009). It is expected that the longer the silent interval, the more pronounced the domain-initial effects.

Duration of the stressed syllable in the test word. The stressed syllable is defined as the most prominent syllable in a word, as specified in the lexicon of each of the three languages. In order to distinguish boundary effects from effects of lexical prominence (see Section 2.2 above), the duration of the stressed syllable in test words was also measured as a control. In the Spanish and Portuguese data, stressed syllables were measured based on the output of the purpose-designed Praat script. In the English data, the stressed syllable was measured manually from the F2 offset of the unstressed vowel in the target syllable up to the offset of F2 in the vowel in stressed syllable for all but one test word. In the case of the word 'patrolmen', the only test word whose stressed syllable ended in a coda consonant, the syllable was measured from the F2 offset of the unstressed vowel /ə/ up to the beginning of the nasal murmur of the /m/ in the final syllable /mɪn/. Stressed syllable duration values were log-transformed for analysis because of differences in the number and types of segments in the stressed syllable across the different words used as stimuli (see 3.2.1).

It is assumed that the duration of the stressed syllable will be determined primarily by its prominence. Because stressed syllables occurred in the middle of test words in the stimuli (i.e. they are not word-initial), they are not expected to be affected by the presence or absence of an IP boundary before the test word.

Articulation rate. Defined as the number of syllables divided by phonation time, excluding silent intervals over 300 ms. Articulation rate was measured automatically through a Praat script (de Jong & Wemp 2009), which estimated the number of syllables based on acoustic information in the audio files containing individual carrier sentences. The script identifies syllable nuclei by detecting peaks in intensity (dB) that occur between two dips in the audio file, thus avoiding measuring segments other than vowels. It is assumed that the faster the articulation rate, the shorter the acoustic durations will be (cf. Fónagy & Mágics 1960, Crystal & House 1990, see also Kessinger & Blumstein 1998 specifically for VOT).

Repetition. Each speaker read the stimuli three times. This variable identifies the order of the individual productions of each target word in the reading task: first, second, or third, for each speaker. Previous results (e.g. Fowler & Housum 1987) suggest that segment duration in second or third productions will be shorter than the first occurrence in the stimuli. Similar results are predicted for all test words in the three languages in this study.

Word frequency. Word frequency was operationalized as the number of occurrences of target words per million in the Corpus of Contemporary American English (Davies 2008-), the *Corpus del español* (Davies 2016-a) for Spanish, and the *Corpus do português* (Davies 2016-b), for Portuguese. These values were log-transformed for the statistical analysis. Frequency of occurrence of a lexical item correlates with its overall duration (Bell et al. 2009), so that the higher the frequency, the shorter the duration.

3.5.3.1 Other independent variables: gender, age, speaker, and test item

Self-reported participant age and gender data obtained before recording sessions were also included as variables, based on vast evidence linking these predictors to phonetic variation and change (see Wagner 2012, and Simpson 2009 for recent reviews with a critical assessment). However, it is unclear whether the phenomena under investigation here show an influence of either factor, so that no specific predictions are made for age or gender.

Individual speaker variation, on the other hand, has been reported as a confounding factor in studies of boundary effects (e.g. Byrd & Riggs 2008), so that speaker was entered in the statistical models as a predictor (see 3.7 below). Recent studies have shown that talker-specific phonetic variation is also found in subphonemic features of segments such as VOT (e.g. Chodroff & Wilson 2007). Finally, since individual words may show idiosyncratic behavior, test item (i.e. individual test words) was also entered in the statistical models as a predictor.

3.6 Data Excluded Prior to Statistical Analysis

3.6.1 Unexpected Patterns, Disfluencies and Segmental Issues

Sentences uttered with unexpected intonation patterns were excluded from analysis, such as when speakers placed phrasal accent on test words (e.g. "*tequila is WEAKER than pure vodka*", in which 'tequila' is the test word). Sentences containing mispronunciations and/or disfluencies affecting test words or any words in the background clause were also discarded. On the other hand, sentences with errors affecting words more than one word

AFTER the test words were included in the final analysis so long as the overall intonation pattern was produced as expected.

Speaker-specific variation. One test word in the Spanish stimuli, *cuchara* /kuˈtʃaɾa/ 'trowel', was produced by a single speaker as [kuˈʃaɾa] in all occurrences of the stimulus. For that one speaker, all tokens of *cuchara* were excluded from analysis. On the other hand, one Portuguese test word, *cutelo* /kʊˈtɛlʊ/ 'cleaver', was produced by a few speakers with extremely short word-final vowel (e.g. [kʊˈtɛlʷ]), but these were not excluded from the analysis.

Vowel reduction in target syllables. Unstressed vowel reduction occurred in target syllables in both the English and Portuguese data, across speakers. A vowel was classified as reduced when it was shorter than 20 milliseconds and/or when no formant structure was visible in the spectrogram (see an example in Figure 3b)

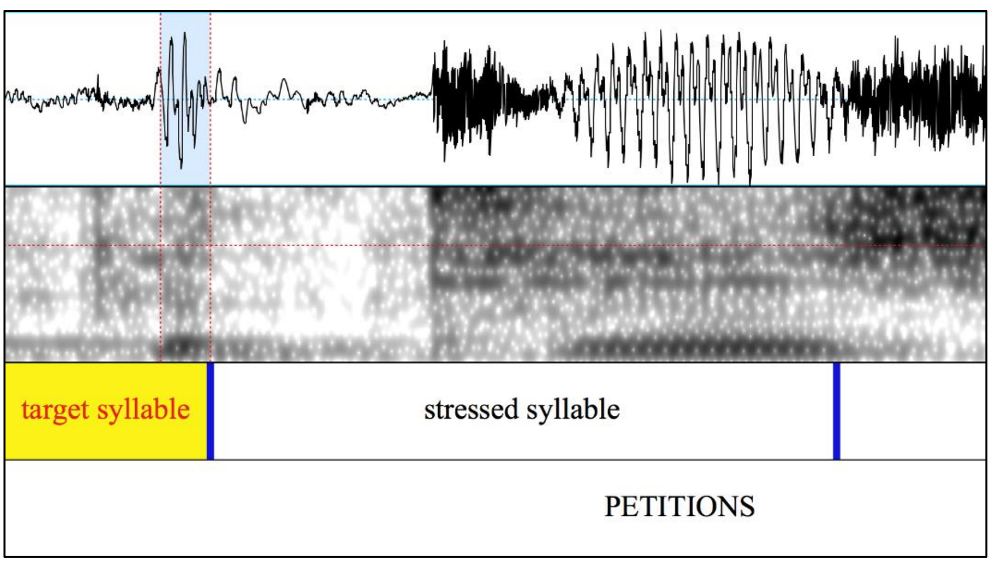

Figure 3-b. Example of a test word showing vowel reduction

This picture shows a word from the English dataset (Speaker FF07, test word 'petitions', IP-initial condition, third repetition). The yellow shading marks the target syllable. Also shown are the following stressed syllable and the beginning of the final syllable in the word 'petitions'. The interval marked in the spectrogram/waveform corresponds to the vowel /ə/, *which measured 12 milliseconds, in the syllable* [pʰə].

In total, 50 test words in the English data showed vowel reduction in target syllables, and 31 test words in the Portuguese data had their unstressed vowels reduced. Reductions occurred in target syllables containing any of the stops (i.e. /p t k/), both in the IP-initial and IP-medial conditions in the two datasets, However, all tokens of test words containing vowel reductions were excluded from the statistical analysis of the main variables (but see Section 5.4 in the Discussion).

3.6.2 Specific Criteria for Determining Domain-initial Boundaries

This study compares words produced at IP-initial boundary against those produced phrase-medially. Hence, it was important that the production of carrier sentences matched the prosodic context they were designed to elicit. The presence of a long silent interval (i.e. 200ms or more) between the background clause and the test IP was used as the primary criterion for determining the occurrence of a prosodic boundary. Whenever the silent interval between background clause and test IP was shorter than 200 milliseconds, two additional acoustic parameters were used as a confirmation that test words in the IP-initial condition were in fact produced at the left edge of the phrase: a declination in pitch, and/or the presence of creaky voice in the last word in the background clause (i.e. 'phrase-final creak', cf. Garellek 2015).

Pitch declination is defined as a lowering of the pitch range between the early part of the background clause and the end of that clause, without regard to the tonal description. Pitch declination has been described as a cue to IP boundaries in broad, declarative statements in all three languages in the sample (Pierrehumbert & Hirschberg

1990, for English; Frota et al. 2007, for Spanish and Portuguese). Figures 3-c through 3-e below illustrate pitch declination in the background clause for each of the languages in the study.

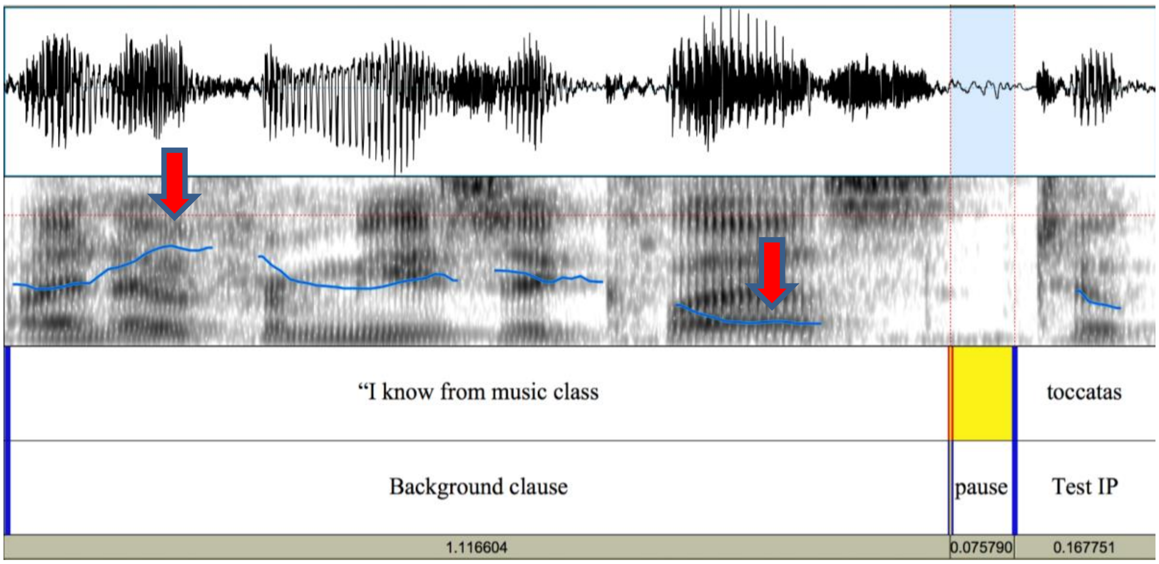

Figure 3-c. Pitch declination in an English background clause (IP-initial condition)

In this example, the speaker produced the carrier sentence with a short silent interval (76ms) before the test IP (Speaker MM02, test word 'toccatas', second repetition). The red arrows show the f0 declination.

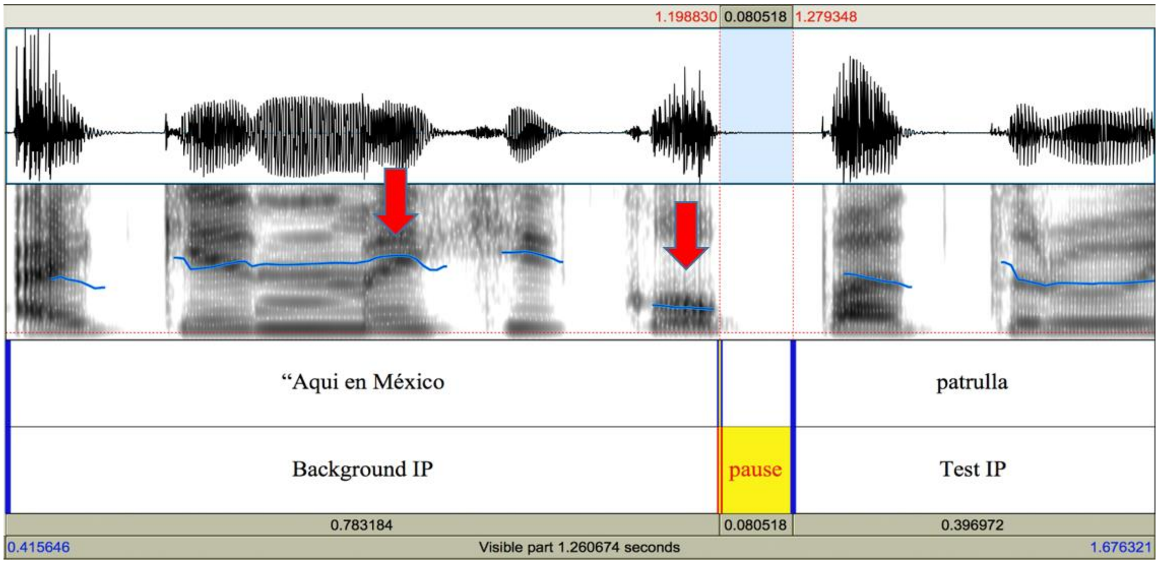

Figure 3-d. Pitch declination in a Spanish background clause (IP-initial cond.)

In this example, the speaker produced the carrier sentence with a short silent interval (81ms) before the test IP (Speaker MU07, test word patrulla *'patrol', third repetition). The red arrows show the f0 declination.*

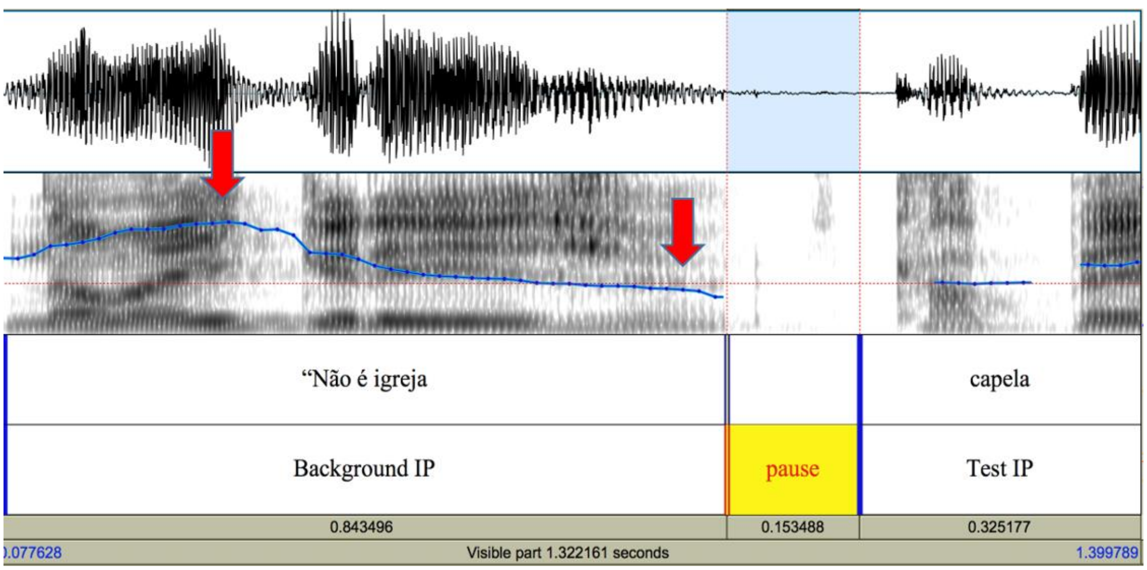

Figure 3-e. Pitch declination in a Portuguese background clause (IP-initial cond.)

In this example, the speaker produced the carrier sentence with a silent interval of 153 ms before the test IP (Speaker M07, test word capela *'chapel', first repetition). The red arrows show the f0 declination.*

Phrase-final creak is defined as a stretch of the speech signal characterized by irregular (e.g. less periodic) F0 and amplitude changes (Redi & Shattuck-Hufnagel 2001, Garellek 2015) that occurs at or near the end of a prosodic phrase. Phrase-final creak has been found to correlate with the end of larger prosodic domains in English (Redi & Shattuck-Hufnagel 2001), Spanish (de la Mota, Brutagueño & Prieto 2010), and Portuguese (Frota & Moraes 2016). Creaky voice was noted as phrase-final creak when it affected all voiced segments in the last word of the background sentence (Garellek 2015) for English, and the last syllable for Spanish and Portuguese. Figures 3-f through 3-h below illustrate phrase-final creak in the background clause for each of the languages in the study.

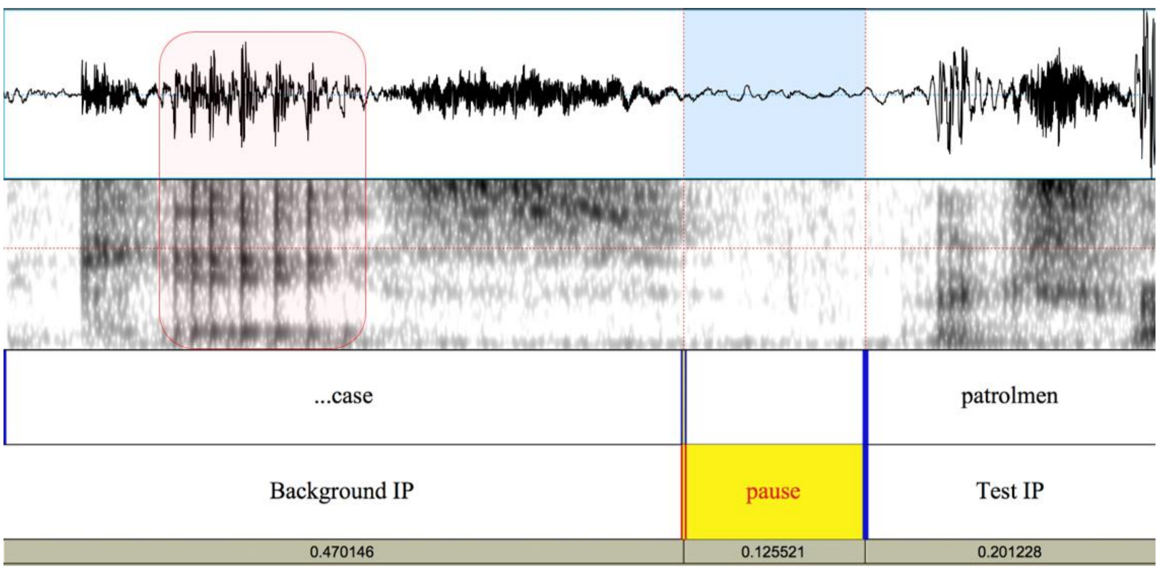

Figure 3-f. Phrase-final creak in an English background clause (IP-initial condition)

This picture shows phrase-final creak in the last word ('case', creaky voice phonation highlighted) in an English background clause in the IP-initial condition. In this example, the speaker produced the carrier sentence with a silent interval of 125 ms before the test IP (Speaker MM04, test word 'patrolmen', first repetition).

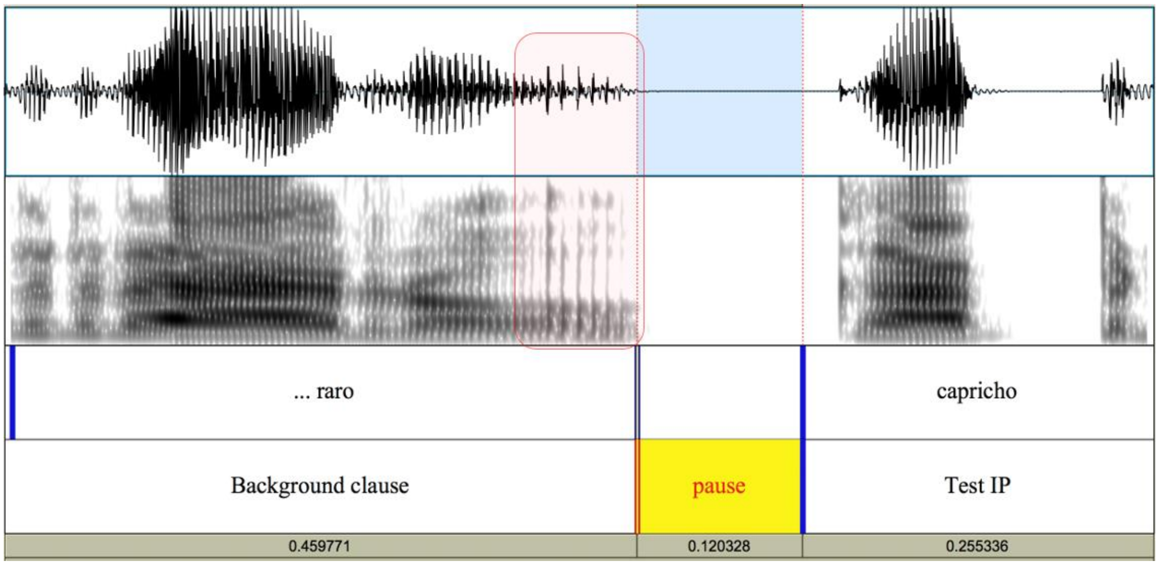

Figure 3-g. Phrase-final creak in a Spanish background clause (IP-initial cond.)

*This picture shows phrase-final creak in the last syllable of a word (*raro *'strange', creaky voice phonation highlighted) in a Spanish background clause in the IP-initial condition. In this example, the speaker produced the carrier sentence with a silent interval of 120 ms before the test IP (Speaker MU02, test word* capricho *'whim', third repetition).*

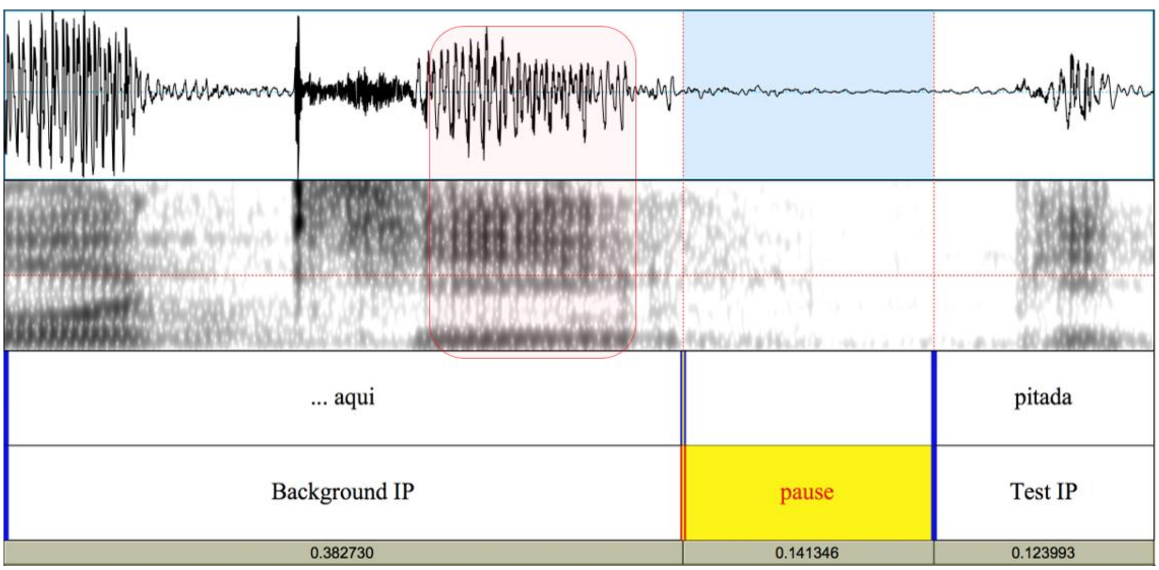

Figure 3-h. Phrase-final creak in a Portuguese background clause (IP-initial cond.)

*The picture shows hrase-final creak in the last syllable of a word (*aqui*, 'here', creaky voice phonation highlighted) in a Portuguese background clause in the IP-initial condition. In this example, the speaker produced the carrier sentence with a silent interval of 125 ms before the test IP (Speaker M04, test word* pitada *'a pinch', third repetition).*

3.6.3 Data Retained for Statistical Analyses

After the initial screening for issues described above, the remaining data were entered in spreadsheets and prepared for statistical analyses described in the next section. Table 3.10 below details the total number of tokens obtained in the recordings by language, experimental condition, and consonant.

Table 3.10 Total number of tokens analyzed by language

The table shows data points by consonant type, and by experimental condition (IP-i = IP-initial; IP-m = IP-medial; spkrs = speakers). Note that for Spanish and Portuguese, /i a u/ are collapsed under V.

Language & Condition/ Variable	**English** (14 spkrs)		**Spanish** (14 spkrs)		**Portuguese** (14 spkrs)	
	IP-i	**IP-m**	**IP-i**	**IP-m**	**IP-i**	**IP-m**
/p/ + V	75	69	71	65	73	52
/t/ + V	73	70	84	69	74	72
/k/ + V	74	71	66	58	71	58
Total by prosodic context	222	210	221	192	218	182
Total by language	432		413		400	

3.7 Statistical Analyses

Individual analyses were undertaken for each dependent variable for each of the three languages in the sample. That is, the analyses use different subsets of the full, language-specific datasets to address the hypotheses and predictions put forward in Sections 1.5 and 3.5, respectively. The general procedure for individual dependent variables consisted of the following six steps:

Step 1. Visual inspection of the data.

Step 2. Establishing the nature of the distribution of each dependent variable in the data via statistical tests of normality.

Step 3. Testing for significant differences between experimental conditions.

Step 4. Data transformation for the regression models, including exclusion of outliers.

Step 5. Running the mixed-effects models to evaluate which of the numeric variables and factor levels of categorical variables influence the mean value of a given dependent variable.

Step 6. Running an ANOVA to determine whether the set of specified independent variables entered in the model during Step 5 indeed explains the specific dependent variable.

All statistical analyses were conducted in R (R Core Team 2016). Visual inspection during Step 1 involved generating basic graphs that displayed broad distribution patterns of the dependent variables across experimental conditions. The Shapiro-Wilk normality test was then applied to variables in Step 2 using the generic function built in R as a way to assess whether values in numeric variables followed a normal distribution. For instance, the Shapiro-Wilk test confirmed that VOT, unstressed vowel duration, and F1 data failed to reach a normal distribution in all three languages. The Wilcox non-parametric statistical hypothesis test was then applied separately to the three continuous dependent variables in each language during Step 3, to determine whether prosodic context yielded statistically significant differences in the data.

Variables that showed no statistical difference between conditions were further excluded from further analyses of the individual languages' data (see Chapter 4). Only variables that showed statistically significant differences between experimental conditions were analyzed in Step 4.

All numeric variables, including dependent variables, were log-transformed during Step 4. Additionally, numeric predictors were z-scaled using the generic function scale() in R (cf. Gries 2013, Bell et al. 2008). At this point, any remaining outliers (i.e. figures that were three median absolute deviations away from the median) detected were further excluded from the subset. Linear mixed-effects models were then fit to each subset of the data using the mixed() function in the Afex package (Singmann et al. 2015) with all appropriate independent variables as predictors.

Variables in each model were introduced through a backward selection procedure to help guard against model overfitting. Following this procedure, the first model was fit with all individual predictors and theoretically relevant interactions. After each model was fit, it was compared to a set of models with one fewer predictor via the generic function anova() in R. The Akaike Information Criterion (AIC) was used a goodness-of-fit measure for model comparison. The predictor that contributed the least to model fit was then removed from the full model. The process was repeated until the final model was significantly better than all possible alternatives with one fewer predictor. The mixed() function was also used to obtain p-values for the likelihood ratio test. Further details on individual models are given in the Results chapter.

3.8 Chapter Summary

This chapter described how the study forming the basis of the dissertation. It detailed how the separate reading tasks were conducted with native speakers of English, Spanish, and Portuguese, and the experimental procedure and analysis methods utilized. Also introduced in Chapter 3 were the variables selected to test the hypotheses outlined in the Introduction, along with specific predictions for each variable. Criteria for data inclusion and trimming were outlined, and the subsequent statistical techniques used to confirm or refute the hypotheses were also described.

CHAPTER 4

RESULTS

4.0 Chapter Overview

This chapter presents a comparison of acoustic data belonging to words at two prosodic contexts in English, Spanish, and Portuguese. Section 4.1 describes the results from a cross-linguistic viewpoint while assessing some of the main hypotheses put forward in Chapter 1. Section 4.1 examines data referring to target unstressed consonants and vowels separately, followed by a consideration of the stressed syllables in the test words. The variables that contributed to the differences observed between experimental conditions are detailed in Section 4.2, 4.3, and 4.4 for English, Spanish, and Portuguese, respectively.

4.1 General Findings and Cross-Linguistic Overview

This study addresses how the marking of domain-initial boundaries affects acoustic properties of individual segments in fully unstressed syllables in English, Spanish, and Portuguese. The results suggest that domain-initial effects can indeed be observed in unstressed syllables in unaccented words in all three languages. Overall, these findings confirm the hypothesis that domain-initial effects manifest themselves in the acoustic signal, and provide additional data to support results obtained in articulatory studies.

In accordance with the literature, the present data indicate that boundary marking enhances acoustic properties of INDIVIDUAL segments within the syllable immediately following the prosodic boundary. However, in the current data, phonetic enhancements affect segment classes in the unstressed CV syllable differently depending on the language. For English, only the properties of CONSONANTS increase significantly at an IP-boundary (Fig. 4-a below). On the other hand, English vowels show no effect of prosodically induced temporal variation. For Spanish and Portuguese, the data reveal the opposite effect. In these two languages, only the VOWEL in the target CV syllable lengthens near an IP-boundary (Fig. 4b below), whereas consonantal properties show no difference in VOT values (Fig. 4-a). That is, in both Spanish and Portuguese, adjacency to a 'stronger' prosodic boundary exerts no effects on the acoustic properties of an unstressed segment immediately following the juncture.

One of the acoustic parameters tested here failed to show significant differences between prosodic contexts in any language: first formant (F1) values. This means that the lengthening observed in unstressed vowels as a function of proximity to stronger prosodic boundaries in both Spanish and Portuguese was not reflected in their magnitude of jaw opening as measured by F1. This result was observed for high and low vowels separately, as well as for English /ə/.

Finally, most voiceless stops in unstressed syllables in the current data were produced with an acoustically clear burst at the consonant release, the only exceptions being found in IP-medial position. However, due to the scarcity of burstless stops in the data as a whole, the occurrence of stop a burst at stop release may not constitute a robust variable to evaluate domain-initial effects. More detail is provided in the language-specific sections. The next two sections address the most consistent findings pertaining to consonants (4.1.1) and vowels (4.1.2) in the dataset as a whole.

4.1.1 *Stops in Unstressed CV Syllables (e.g. ENG 'petitions', SPA/POR 'tacada')*

Figure 4-a illustrates differences in VOT lag duration as a function of prosodic context in the three languages. A visual inspection of the box plots with VOT data for the three languages suggests Spanish and English showed greater variation than the Portuguese data, with English showing the overall highest voice onset time lags for /p t k/. The graph shows more variation in Spanish VOT data at an IP-initial boundary, as implied by the long tails. However, two-tailed Wilcoxon tests revealed that only in English were VOT values for /p t k/ significantly longer at IP-initial boundaries than at an IP-medial boundary (W= 26472, p =.015). As mentioned above, both the Spanish (SPA) and Portuguese (POR) data failed to show a statistically significant effect of prosodic context on VOT values for /p t k/ (SPA W= 19958, p=.299; POR W= 22193; p=.917).

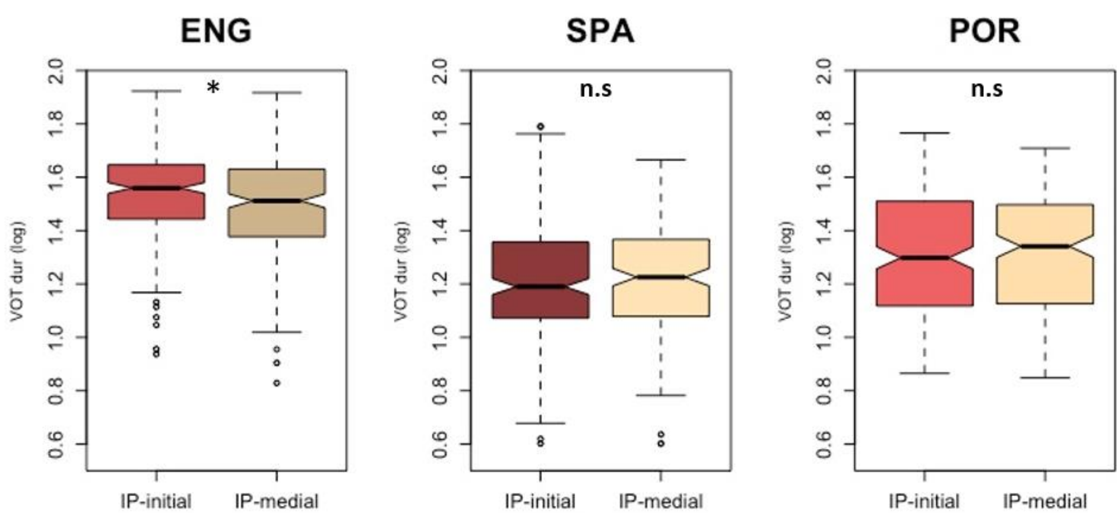

Figure 4-a. Durations of VOT lags in target syllables (all languages, log values)

*The box plots show VOT duration results measured in target syllables across the stimuli (e.g. ENG '**c**apacious', SPA/POR* **t**acada*), as a function of prosodic context. IP-initial values in left box, IP-medial data in right box; y-axis shows the same scale for the three languages.*

The results regarding VOT thus only partially confirm the predictions put forward in Section 1.4. Even though it was predicted that English consonants would show a larger effect of prosodic context than either Spanish or Portuguese voiceless stops, the finding that neither of the two showed an effect of proximity to domain edge goes against predictions. What's more, a lack of effect of prosodic context on VOT suggests Spanish and Portuguese domain-initial stops differ from consonants in similar conditions in other languages (see Ch. 5 for a discussion).

4.1.2 Vowels in Unstressed CV Syllables (e.g. ENG 'petitions', SPA/POR 'tacada')

Figure 4-b below illustrates differences in vowel duration as a function of prosodic context in the three languages. The box plots referring to both the Spanish and Portuguese unstressed vowels suggest a clear effect of prosodic context, with unstressed vowels being longer at the IP-initial boundary. The same observation cannot be made for English unstressed vowels.

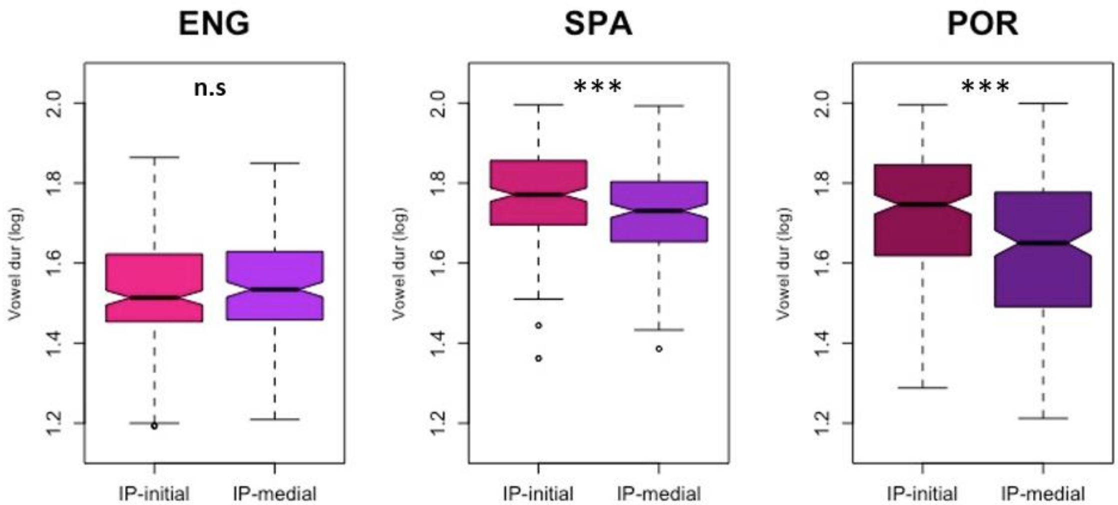

Figure 4-b. Durations of vowels in target syllables (all languages, log values)

*The box plots show vowel duration results in target syllables measured across the stimuli (e.g. ENG 'p**e**titions', SPA/POR* t**a**cada*), as a function of prosodic context. IP-initial values in left box, IP-medial data in right box; y-axis shows the same scale for the three languages.*

The comparison between vowel durations at IP-initial and IP-medial positions failed to reach significance for the vowel /ə/ in the target unstressed syllables in the English data ($W = 27261$, $p = 0.487$). In contrast, the two-tailed Wilcoxon test revealed that vowels in unstressed CV syllables following an IP boundary were significantly longer in Spanish ($W = 25630$, $p < 0.001$) and Portuguese ($W = 30646$, $p < 0.001$) than those that occurred IP-medially.

While the English results corroborate most previous articulatory findings that domain-initial effects impact segments rather locally, the Spanish and Portuguese data seem to weaken that claim. The hypothesis that vowels in a boundary-initial unstressed CV syllable are less prone to undergoing boundary effects thus only receives partial confirmation (i.e. only for English) in the present data.

4.1.3 Stressed Syllables (e.g. ENG 'ca<u>pa</u>cious', SPA/POR 'ta<u>ca</u>da')

The third set of results relates to the question of the scope of domain-initial effects. As explained in Section 3.5 above, the duration of the STRESSED SYLLABLE following target CV sequences was measured as an independent control variable. Although not targeted by the experiment design in this study, the possible role of lexical prominence in other types of prosodic prominence warrants a more detailed discussion of stressed syllables near a domain-initial boundary here.

Figure 4-c depicts variations in stressed syllable duration as a function of the position of the test words relative to the prosodic boundary. The box plots for all three languages suggest a large difference between the two experimental conditions, especially for Portuguese and English. It should be noted that stressed syllables were not as strictly controlled for size and segmental makeup as target syllables in the present study.

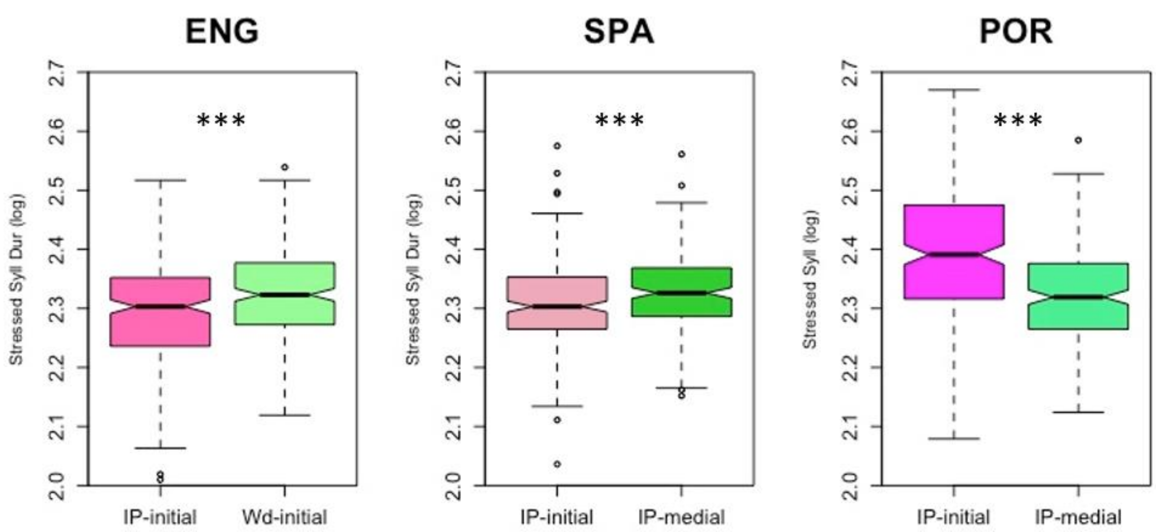

Figure 4-c. Durations of stressed syllables in test words (all languages, log values)

*The box ploys show duration results for the stressed syllable in test words (e.g. ENG 'ca**pa**cious', SPA/POR* ta**ca**da*) across the stimuli, as a function of prosodic context. Stressed syllables were acoustically shorter near IP boundaries in both English and Spanish, whereas Portuguese showed the opposite pattern. IP-initial values in left box, IP-medial data in right box; y-axis shows the same scale for the three languages.*

Notably, the direction of the difference in stressed syllable duration was different in different languages. As can be inferred from Figure 4-c, in English and Spanish stressed syllables near an IP-initial boundary were SHORTER than in the IP-medial context. On the other hand, in Portuguese, stressed syllables near an IP-initial boundary are LONGER than those in IP-medial position.

Indeed, the statistical analyses of these data revealed that non-boundary adjacent stressed syllables were a significant factor in the differences observed between experimental conditions in all three languages. Not only did the duration of the stressed syllable differ significantly between the two prosodic contexts when tested separately through a Wilcox test (ENG W= 23184, p <0.001; SPA W=18090, p <0.01; POR W= 30630, p <0.001), but it was also a contributing factor in all mixed-effects models (see Section 4.2). The findings related to the stressed syllables will be taken up again in the Discussion.

4.1.4 Cross-linguistic Summary

This section explored the general findings of the dissertation from a cross-linguistic perspective. Although morphosyntactic and phonological specificities did not allow for the building of a statistical model to compare the three languages directly, the similarity in experimental design offers enough elements for a general comparison. Table 4.1 summarizes the main results of the study.

Table 4.1 Summary of acoustic differences between prosodic contexts

Measures	**English**	**Spanish**	**Portuguese**
VOT	IP > Wd *	n.s.	n.s.
Unstressed vowel duration	n.s.	IP > Wd***	IP > Wd***
F1 of unstressed vowel	n.s.	n.s.	n.s.
Occurrence of burst at stop release	unclear	unclear	unclear
Duration of stressed syllable [a]	IP < Wd ***	IP < Wd ***	IP > Wd ***

***: p<.001; **: p<.01; *: p<.05; . : p= .07; ns: p> .1

[a] Control variable tested independently through a Wilcox-Test (see se also 4.2)

A broad generalization based on Table 4.1 could be formulated as follows: the languages in the present study show some similarities and quite a few differences in how boundary-initial marking affects the acoustic properties of trisyllabic words with penultimate stress. VOT is used to mark stops in unstressed syllables only in English, with Spanish and Portuguese stops failing to show significance in how VOT lag differs between prosodic contexts. Additionally, whereas English vowels in the target CV syllable are unaffected by boundary marking, the duration of Spanish and Portuguese vowels under similar conditions shows significant effects of prosodic context. What's more, while the non-boundary adjacent stressed syllable shows systematic variation in all three languages, the effect is opposite in different languages, with English and Spanish words patterning in one way, and the Portuguese data in another.

The next sections address the acoustic variables for each of the three languages in the study. More robust findings are addressed first, followed by brief discussions of the remaining dependent variables tested in this study.

4.2 English Results

The English data being discussed here come from the comparison of the acoustic properties of segments in test words presented in the two experimental conditions. The experimental conditions were elicited in a reading task using carrier sentences such as the ones in Table 4.2 below.

Table 4.2 Sample carrier sentences in the English stimuli

The sentences below show how unstressed CV syllables (e.g. /kə/ *in the English test word 'capacious'* [kʰəˈpʰeɪʃəz]*) were tested under the two experimental conditions in this study. The IP-initial boundary is represented by* <||>*; the lower-level domain boundary in the IP-medial condition is represented by* <#>*.*

Condition	Carrier sentence
IP-initial	It doesn't refer to ability! You can check for yourself **||** **capacious** means ROOMY or full of space
IP-medial	It is very sad there's not too much they can do at this point: the city's **#** **capacious** museum closed

A total of 432 tokens of English data were selected for analysis. The statistical summary for the main continuous variables is provided below. Words for which there were vowel reductions in target syllables are not included in the summary. A vowel was classified as reduced when it was shorter than 20 milliseconds and/or when no formant structure was visible in the spectrogram. It should be noted that F1 values were missing for 60 tokens due to formant tracking errors.

Table 4.3 Statistics summary for the English data

(ms = milliseconds; dur = duration; syll = syllable)

English	Prosodic context					
	IP-initial			IP-medial		
Variables	**Min**	**Max**	**Median (MAD)** [b]	**Min**	**Max**	**Median (MAD)**
VOT* /p t k/ *(ms)	8	84	36 (12)	7	83	32 (13)
Vowel duration (ms)	15	73	32 (12)	21	71	33 (12)
Vowel F1 (normalized) [c]	7.73	22.4	9.95 (1.33)	6.23	26.54	9.96 (1.81)
Dur. of silent interval (ms)	32	1187	101 (148)	0	48	1 (0)
Dur. of stressed syll. (ms)	102	329	201 (40)	131	346	210 (39)

[b] MAD = median absolute deviation. MAD is a more robust measure of variability in non-normal distributions than the standard deviation (Levshina 2015).
[c] Obtained for each token based on the means and standard deviations calculated over all productions by the same speaker. The number 10 was added to each score to facilitate interpretation.

At first glance, it would appear that VOT values for English /p t k/ were rather short compared to reports like in Ahn (2018), who found mean values of 94 milliseconds for the same consonant types. However, the values obtained in this study seem comparable to previous investigations of English VOT that controlled for prosodic context and/or prominence. Lisker and Abramson (1967), an early study of the influences of prosodic context in VOT, found that /p t k/ in unstressed syllables had VOT lags that varied between 23 and 50 milliseconds in phrase-medial position. More recently, VanDam (2003) reports that stops in unstressed syllables PRECEDING the primary stressed syllable in phrase-medial context averaged 32 milliseconds. Interestingly, VanDam also reports that, in phrase-medial position, even stops in stressed syllables had VOT values of around 60 milliseconds on average. A detailed discussion of VOT results is given in 4.2.1.

Table 4.1 allows for an assessment of other important factors in the present data. Additionally, the duration of silent intervals preceding test words was much longer for the IP-initial condition than those that occurred before test words in the IP-medial condition (*median = 101* ms for IP-initial, *median = 1* ms for IP-medial), and this difference was statistically significant ($W = 51859$, $p < 0.001$). Along with the other factors used to diagnose IP boundaries, namely pitch decline and/or creaky voice in the last word of the background clause (phrase-final creak), long silent intervals occurred consistently before test words in the IP-initial condition. This demonstrates that one of the most robust phonetic correlates associated with the IP domain did occur in the data. The next section explores the most consistent correlate of domain-initial effects found in the English data, namely VOT.

4.2.1 Voice Onset Time for **/p t k/** *in English (e.g.* **'**p*etition', '*t*equila', '*c*apacious')*

Voice onset time differed substantially in English voiceless stops as a function of proximity to the IP boundary. Figure 4-d depicts the differences in VOT in the English data according to prosodic context.

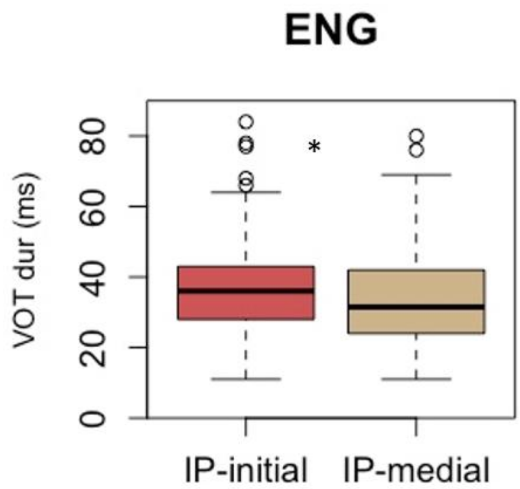

Figure 4-d. Distribution of durations of VOT lags in target stops in English

*The box plot depicts VOT values for target consonants (e.g. '**c**apacious'), as a function of prosodic context. IP-initial values in left box, right box contains IP-medial data (raw values in milliseconds).*

The next section describes the statistical models used to evaluate the differences in VOT values observed in the data.

4.2.1.1 Mixed-effects model for VOT in English

A total of 432 observations related to VOT in voiceless stops were entered in the English mixed-effects model. The model was fit through backward selection of variables, meaning that predictors that failed to improve model fit were excluded from the analysis, as explained in Section 3.7.

Table 4.4 Main effects for the English model with VOT as a response variable

Values refer to VOT lag (log-transformed) for /p t k/ *in unstressed word-initial CV syllables. The reference levels for categorical predictors are: 'IP-initial' for Prosodic context and '/k/' for Consonant.*

Estimate	β	SE	t	p (t)
Intercept	1.900	0.397	4.78	.004 **
Prosodic context = IP-medial	-1.831	0.588	-3.11	.002 **
Stressed syllable duration x IP-medial context	0.642	0.214	3.00	.009 **
***Consonant* = /p/**	-0.247	0.028	-8.80	.166 ns
***Consonant* = /t/**	-0.059	0.028	-2.11	.389 ns
Stressed syllable duration x IP-initial context	-0.127	0.172	-0.74	.492 ns

Table 4.5 Random effects for English VOT model

(SD = standard deviation)

Variable	Variance	SD
Speaker	0.0088	0.0941
Word	0.0002	0.0126
Residual	0.0445	0.2110

As summarized in Table 4.4, the results from the generalized linear model revealed significant main effects of **prosodic context**, with the duration of the VOT lag being shorter at an IP-medial boundary than an IP-initial one. The model also showed an effect of the interaction of **duration of the stressed syllable** and **prosodic context:** the longer the stressed syllable, the longer the VOT at an IP-medial boundary.

4.2.2 Bursts, Vowel Duration and F1 in target syllables in English

As mentioned in section 4.1, two of the acoustic variables targeted by the experimental design failed to show statistically significant differences in the English data, both of which related to the vowel in the target syllable: vowel duration, and first formant in unstressed vowels. A third variable, occurrence of a stop release burst, varied little between prosodic contexts, although burst absences were found exclusively in the IP-medial stops. Data corresponding to each of these variables are discussed briefly in this section.

*4.2.2.1 Occurrence of a stop release burst (e.g. '**p**etition', '**t**equila', '**c**apacious')*

The occurrence of a burst at the stop release is another acoustic measure of consonant strength that has been linked to domain-initial effects. Lavoie (2001) found that stops that occur at a phrase-initial position had a larger number of stop release bursts than those that occurred in the middle of the phrase. The number of occurrences of bursts at the release of /p t k/ was also inspected in the current data. Table 4.6 summarizes the findings for English consonants.

Table 4.6 Bursts at stop release in English

Proportion of occurrence of bursts at stop release for English /p t k/, by prosodic context

	IP-initial	**IP-medial**	***Total***
	Proportion (N)	**Proportion (N)**	**Proportion (N)**
Yes	1.0 (222)	.95 (200)	.98 (422)
No	0	.05 (10)	.02 (10)

English voiceless stops, Table 4.6 reveals, were produced with clear burst releases in the vast majority of occurrences in the current data, 98%. The few tokens of stops that did occur without a detectable release were found in words in the IP-medial condition, mirroring the findings in Lavoie (2001). As would be expected, Fisher's exact test indicates that the proportion of occurrences of stop release bursts significantly differed by prosodic context ($p < 0.01$). However, the small number of tokens that lacked bursts (only .02 of the total number of tokens) precluded further statistical analysis.

4.2.2.2 Vowel duration for /ə/ *(e.g. 'p**e**tition', 't**e**quila', 'c**a**pacious')*

The duration of vowels after stops /p t k/ was measured to determine the extent to which domain-initial position affects a totally unstressed segment close to the edges of two prosodic domains. Prosodic boundary strength showed no influence on the acoustic duration of fully unstressed vowels in word-initial CV syllables in English (e.g. the first /ə/ in tequila). The two-tailed independent-samples Wilcoxon test revealed that there was no significant difference between the duration of /ə/ at the IP-initial (*median* = 32 ms, *MAD* = 12 ms) and IP-medial (*median* = 33 ms, *MAD* = 11 ms) conditions; ($W = 22916$, $p = 0.7$).

4.2.2.3 First formant for /ə/ *(e.g. 'p**e**tition', 't**e**quila', 'c**a**pacious')*

First formant values were extracted from the midpoint of the target vowels in unstressed syllables in English. As mentioned above, F1 in English showed little variation with respect to prosodic context. The median values for both prosodic contexts were minimally different at the IP-initial (*median* = 9.95, *MAD* = 1.33) and IP-medial conditions (*median* = 9.96, MAD = *1.81*) for IP-initial and IP-medial conditions, respectively. The Wilcoxon test confirms that this minimal difference is not significant ($W = 22022$, $p = 0.917$).

The next section describes the results of the analysis of the Spanish data.

4.3 Spanish Results

The Spanish data analyzed in this study come from the acoustic measurements of segments in test words recorded in two experimental conditions. The experimental conditions were elicited in a reading task that used stimuli such the ones in Table 4.7 below.

Table 4.7 Sample carrier sentences in the Spanish stimuli

The sentences below show how unstressed CV syllables (e.g. /pi/ *in the Spanish test word* pitada [piˈtaða] *'a whistling') were tested under the two experimental conditions in this study. The IP-initial boundary is represented by* <||>*; the lower-level domain boundary in the IP-medial condition is represented by* <#>*.*

Condition	Carrier sentences
IP-initial	Estás confundido, **||** **pitada** quiere decir SOPLADO más que sonido o pitido
	You're mistaken, whistling is a BLOWING SOUND more than a noise or a beep
IP-medial	A causa de la lluvia, el árbitro Federico dió la **#** **pitada** a las tres horas
	Because of the rain Federico the referee blew the whistle to end the match at 3 o'clock

A total of 413 tokens of Spanish data were selected for analysis. Many observations were excluded due to disfluencies and unexpected intonation (see Section 3.6). The statistical summary for the main continuous variables is provided below, followed by a detailed discussion of the dependent variable that showed a statistically significant difference between prosodic contexts, namely vowel duration in unstressed syllables. The remaining dependent variables are briefly discussed in 4.3.2.

Table 4.8 Statistics summary for the Spanish data

(ms = milliseconds; dur = duration; syll = syllable; MAD = median absolute deviation)

Spanish	Prosodic context					
	IP-initial			IP-medial		
Variables	**Min**	**Max**	**Median (MAD)**	**Min**	**Max**	**Median (MAD)**
VOT **/p t k/ (ms)**	4	62	15 (6)	4	46	17 (7)
Vowel duration **(ms)**	23	99	59 (16)	24	98	54 (14)
Vowel F1 **(normalized)**[d]	8.14	13.87	9.86 (1.36)	8.36	13.15	9.56 (1.16)
Dur. of silent interval **(ms)**	59	1164	125 (131)	0	89	3 (0)
Dur. of stressed syll. **(ms)**	109	375	201 (31)	142	364	212 (30)

[d] Based on the means and standard deviations calculated over all productions by the same speaker + 10.

In addition to the dependent variables described in more detail in 4.3.1 and 4.3.2 below, Table 4.8 shows that the duration of silent intervals preceding test words was longer in carrier sentences in the IP-initial condition than in the IP-medial condition. Although silent intervals at the IP-initial boundaries were not as long in Spanish as in the English data, the difference observed in this subset of the data was also statistically significant (W= 40296, p< 0.001). Longer silent intervals occurred consistently before test words in the IP-initial condition, and were mostly absent from the productions under IP-medial condition, as can be deduced from Table 4.8. Once again, the data demonstrate that one of the most robust phonetic correlates associated with the IP domain did occur in the expected condition. The next section discusses the results related to vowel duration in the Spanish dataset.

4.3.1 Vowel Duration for /i a u/ *in Spanish (e.g. 'tipazo', 'patrulla', 'cuchara'*)

Vowel duration in the unstressed CV syllable showed a main effect of prosodic context in the data. Figure 4-e shows the differences found in data according to context.

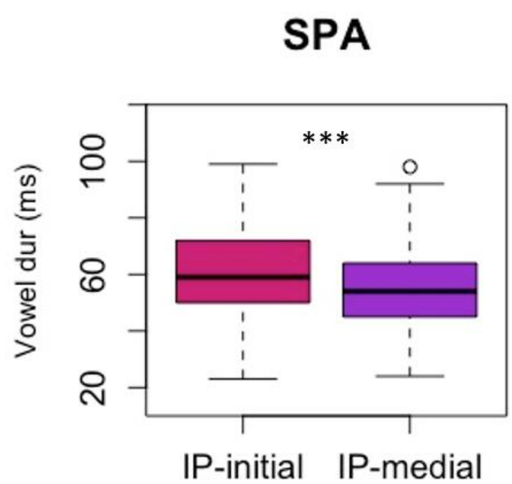

Figure 4-e. Distribution of vowel durations in Spanish

Durations of vowels /i a u/ in target syllables in Spanish (e.g. t**a**cada*), as a function of prosodic context. IP-initial values in left box, right box contains IP-medial data (raw values in milliseconds).*

4.3.1.1 Mixed-effects model for vowel duration in Spanish

A total of 413 observations related to unstressed vowels in the Spanish data were analyzed. The mixed-effects model for vowel duration in Spanish was fit through backward selection of pertinent variables, that is, excluding those related to consonants alone. Predictors that failed to improve model fit (i.e. $p > 0.05$) were excluded one at a time (Section 3.7). The predictors failed to improve model fit and were therefore excluded from the final model for Spanish vowels in target syllables were: **articulation rate, repetition, gender** and **age**.

The best model for Spanish vowel durations (log transformed) as the response variable included **speaker** and **word** as random effects, and the following variables as fixed effects: **duration of silent interval**, **word frequency, vowel height** (2 levels: *high* or *low*), and the **INTERACTION of duration of the stressed syllable and prosodic context** (two levels: *IP-initial* or *IP-medial*). The mixed() R function automatically calculated p-values. The final fixed and random effects estimates appear in Tables 4.9 and 4.10, respectively.

Table 4.9 Main effects for the Spanish model with vowel duration as the response variable

Values refer to vowel duration (log-transformed) for /i a u/ *in unstressed word-initial CV syllables. The reference level for the categorical predictor Vowel height is 'high'.*

Estimate	β	SE	t	p (t)
Intercept	1.388	0.018	10.89	<.001***
Duration of silent interval	0.020	0.008	4.71	<.001***
Vowel height = low	0.099	0.010	8.38	<.001***
Stressed syllable duration x IP-initial	0.172	0.072	2.39	.017*
Word frequency	-0.013	0.006	-2.22	.01*
Stressed syllable duration x IP-medial	-0.004	0.071	2.40	.659^{ns}

Table 4.10 Random effects for Spanish vowel duration model

(SD = standard deviation)

Variable	Variance	SD
Speaker	0.0088	0.0560
Word	0.0002	0.0050
Residual	0.0445	0.0853

As summarized in Table 4.9, results from the generalized linear model revealed significant main effects of **vowel height**, with the duration of the low vowel /a/ being overall longer than /i u/. The model also showed that a longer **silent interval** increases the duration of the vowel in the post-boundary CV syllable. Because silent pauses occurred most consistently before test words in the IP-initial condition, one can interpret the main effect of silent interval as an indirect correlation of domain boundary level with duration of unstressed vowels in the Spanish target syllables. There was also an effect of the **INTERACTION of duration of the stressed syllable** and **prosodic context:** the longer the stressed syllable, the longer the vowel in the unstressed syllable at a prosodic boundary. Finally, the **word frequency** of the test word also showed the expected influence on duration: the higher the frequency, the shorter the unstressed vowel.

The model for the Spanish data thus confirms that prosodic structure affects the duration of unstressed vowels following the initial segment after an IP boundary. In the Spanish data, these effects are attributable to boundary strength, in that both the duration of a silent pause before the test words, and the **interaction of stressed syllable with prosodic context** influenced duration of the vowel in the target CV syllable. It should be noted that the duration of the stressed syllable on its own failed to improve model fit.

4.3.2 VOT, Bursts, and F1 in target syllables in Spanish

As mentioned in 4.1, three of the acoustic variables targeted by the experimental design failed to show statistically significant differences in the Spanish data. These were VOT for unstressed word-initial stops, occurrence of a stop release burst, and first formant in unstressed vowels. Data corresponding to each of these variables are discussed briefly in this section.

4.3.2.1 VOT for unstressed /p t k/ *(e.g. '**p**atrulla', '**t**ipazo', '**c**uchara')*

Against predictions, prosodic boundary strength showed no influence on VOT in word-initial unstressed /p t k/ in Spanish. A two-tailed independent-samples Wilcoxon test was conducted to compare voice onset times in unstressed /p t k/ at IP-initial and IP-medial conditions. There was not a significant difference in the VOT values for IP-initial stops (*median* = 15 ms, *MAD* = 6 ms) and IP-medial (*median* = 17 ms, *MAD* = 7 ms) conditions (W = 19958, p = 0.265). These results suggest that VOT may not be a universal phonetic correlate of boundary strength. No further tests were undertaken on Spanish VOT.

*4.3.2.2 Occurrence of a stop release burst (e.g. '**p**atrulla', '**t**ipazo', '**c**uchara')*

The occurrence of a burst at the stop release is another acoustic measure of consonant strength that has been linked to domain-initial effects. Lavoie's (2001) study of Spanish and English consonants found that stops that occur in phrase-initial position have a larger percentage of stop burst releases than those that occur in the middle of the phrase. Inspection of the number of bursts at the release of Spanish /p t k/ in the current data confirms her findings. Table 4.11 summarizes these results.

Table 4.11 Bursts at stop release in Spanish

Proportion of occurrence of bursts at stop release for Spanish /p t k/ by prosodic context

	IP-initial	**IP-medial**	***Total***
	Proportion (N)	**Proportion (N)**	**Proportion (N)**
Yes	1.0 (221)	.94 (181)	.97 (402)
No	0	.06 (11)	.03 (11)

The proportion of voiceless stops that were produced with clear burst releases in the Spanish data corresponded to .97 of the data. Similar to the pattern for English /p t k/, the very few tokens that did occur without a detectable release were also found in test words in the IP-medial condition. Fisher's exact test also indicates that this proportion differed significantly by prosodic context ($p < 0.001$). However, the small number of stops that lacked bursts were deemed too few for further statistical analysis.

*4.3.2.3 First formant for unstressed /i a u/ (e.g. 'p**i**tada', 't**i**pazo', '**cu**chara')*

First formant values were extracted from the midpoint of the target vowels in unstressed syllables in Spanish. Similar to the results found in the English data, F1 values differed little between IP-initial (*median* = 9.86, *MAD* = 1.36) and IP-medial (*median* = 9.56. *MAD* = 1.16) contexts for Spanish vowels. The Wilcoxon test confirms that the difference between prosodic contexts failed to achieve significance (W= 22846, p = 0.178).

The next section presents the results for Portuguese.

4.4 Portuguese Results

The Portuguese data analyzed here come from measurements of the acoustic properties of segments in test words recorded in experimental conditions such as those in Table 4.12 below.

Table 4.12 Sample carrier sentences in the Portuguese stimuli

The sentences below show how unstressed CV syllables (e.g. /pi/ *in the Portuguese test word* pitada [pɪˈtadə] *'a pinch of something') were tested under the two experimental conditions in this study. The IP-initial boundary is represented by <||>; the lower-level domain boundary in the IP-medial condition is represented by <#>.*

Condition	Carrier sentence
IP-initial	Tem muito sal aqui, **|| <u>pitada</u>** quer dizer só UM POUQUINHO do ingrediente na receita
	This has too much salt, a pinch means just A LITTLE of the ingredient from the recipe
IP-medial	Pimenta caiena é mais forte do que do reino, só uma **# pitada** tá mais que bom
	Cayenne pepper is much stronger than black pepper, just one pinch is more than enough

In total, 400 tokens of Portuguese data were selected for analysis. The statistical summary for the main continuous variables is provided below. As described in Section 3.6.1, Table 4.13 does not include data from tokens in which vowel reduction occurred. A vowel was classified as reduced when it was shorter than 20 milliseconds and/or when no formant structure was visible in the spectrogram.

Table 4.13 Statistics summary for the Portuguese data

(ms = milliseconds; dur = duration; syll = syllable; MAD = median absolute deviation)

Portuguese	**Prosodic context**					
	IP-initial			**IP-medial**		
Variables	**Min**	**Max**	**Median (MAD)**	**Min**	**Max**	**Median (MAD)**
***VOT* /p t k/ (ms)**	7	58	20 (12)	1	51	22 (13)
***Vowel duration* (ms)**	19	117	56 (21)	16	100	45 (21)
***Vowel F1* (normalized)**	8.07	12.27	9.95 (1.02)	8.20	12.96	10.21 (1.26)
***Dur. of silent interval* (ms)**	47	724	185 (152)	0	33	0 (0)
***Dur. of stressed syll.* (ms)**	120	468	246 (71)	133	385	209 (37)

The duration of silent intervals preceding test words was longer in the IP-initial condition than in the IP-medial condition, in line with the English and Spanish results. This difference was significant in the Portuguese dataset as well (W= 42210, $p < 0.001$). Once again, this demonstrates that pauses may be one of the most robust phonetic correlates associated with the IP domain. The next section presents a detailed discussion of the dependent variable that showed a statistically significant difference between prosodic contexts, namely vowel duration in unstressed syllables.

4.4.1 Vowel Duration for **/i a u/** *in Portuguese (e.g.* **'pitada', 'tacada', 'cutelo')**

Vowels in the unstressed CV syllable showed a significant main effect of prosodic context in the data. Figure 4-f illustrates the differences found in vowel duration for the Portuguese data according to prosodic context.

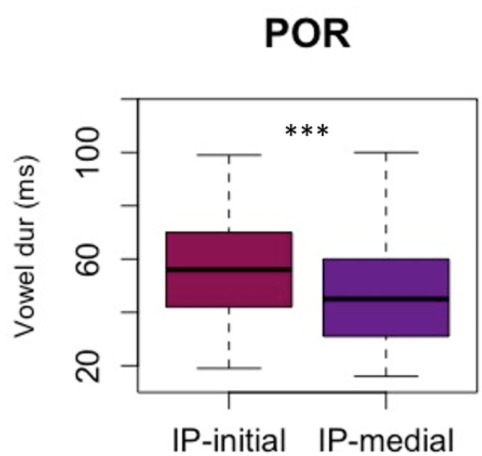

Figure 4-f. Distribution of vowel durations in Portuguese

The box plots show the distribution of durations of vowels /i a u/ *in target syllables in Portuguese (e.g.* c**a**pela*), as a function of prosodic context. IP-initial values in left box, right box contains IP-medial data (raw values in milliseconds).*

4.4.1.1 Mixed-effects model for vowel duration in Portuguese

A total of 400 observations of unstressed vowels in the Portuguese dataset were included in the mixed-effects model. The model was fit through backward selection using all the applicable variables. Once again, predictors that failed to improve model fit (i.e. $p > 0.05$) were excluded one at a time until the model described here was finalized. The predictors that failed to improve model fit for unstressed vowels in Portuguese were: **articulation rate, word frequency of test word, repetition** (3 levels: *first, second,* or *third repetition*).

The best model for vowel duration (log transformed) as the response variable in the Portuguese data included **speaker** and **test item** as random effects, and the following variables as fixed effects**: duration of silent interval, vowel height** (2 levels: *high* or *low*), and the **INTERACTION of duration of the stressed syllable and prosodic context** (two levels: *IP-initial* or *IP-medial*). The mixed() R function automatically calculated p-values. The final fixed and random effects estimates appear in Tables 4.14 and 4.15, respectively.

Table 4.14 Main effects for the Portuguese model with vowel duration as the response variable

Values refer to vowel duration (log-transformed) for /i a u/ *in unstressed word-initial CV syllables. The reference level for the categorical predictor Vowel height is 'high'*

Estimate	β	SE	t	p (t)
Intercept	2.464	0.419	17.88	<.001***
Vowel height = low	1.591	0.109	10.70	<.001***
Duration of silent interval	0.037	0.005	7.70	<.001***
Stressed syllable duration x IP-initial	0.025	0.008	3.29	.003**
Stressed syllable duration x IP-medial	0.018	0.010	1.83	.298 ns

Table 4.15 Random effects for Portuguese vowel duration model

(SD = standard deviation)

Variable	Variance	SD
Speaker	0.0018	0.0424
Word	0.0003	0.0164
Residual	0.0115	0.1071

Results from the generalized linear model shown in Table 4.14 revealed significant main effects of **vowel height**, with the duration of the low vowel /a/ being overall than /i u/, similarly to the findings for Spanish. The model also showed that a longer **silent interval duration** is associated with increased duration of the vowel in the post-boundary CV syllable. There was also an effect of **the interaction of duration of the stressed syllable** and **prosodic context**: the longer the stressed syllable, the longer the vowel in the unstressed syllable at a prosodic boundary, more so at an IP boundary than IP-medially.

The model for Portuguese vowels in unstressed CV syllables shows effects of boundary strength, in that both the duration of the silent interval before the test words, and the INTERACTION of stressed syllable with prosodic context influenced duration of the vowel in the target CV syllable. Once again it should be emphasized that the duration of the stressed syllable on its own failed to improve model fit.

4.4.1 VOT, Bursts, and F1 in target syllables in Portuguese

4.4.1.1 Voice onset time for /p t k/ (e.g. 'patola', 'tutela', 'capela')

As in the Spanish data and contra predictions, prosodic boundary strength showed no effect on VOT values in word-initial unstressed /p t k/ in Portuguese. A two-tailed independent-samples Wilcoxon test revealed no significant difference between the VOT scores for IP-initial stops (*median* = 20 ms, *MAD* = 12 ms) and IP-medial (*median* = 22 ms, *MAD* = 13 ms) conditions ($W = 23057$, $p = 0.92$). No further tests were undertaking with regards to Portuguese VOT.

4.4.1.2 Occurrence of a stop release burst in Portuguese target syllables

The number of occurrences of bursts at the stop was also tabulated in the Portuguese dataset. The proportion of bursts at the release of /p t k/ in Portuguese target syllables is summarized in Table 4.16.

Table 4.16 Bursts at stop release in Portuguese

Proportion of occurrence of bursts at stop release for Portuguese /p t k/ by prosodic context

	IP-initial	**IP-medial**	***Total***
	Proportion (N)	**Proportion (N)**	**Proportion (N)**
Yes	1.0 (218)	.97 (176)	.99 (394)
No	0	.03 (6)	.01 (6)

The largest proportion of voiceless stops were produced with clear burst releases in the Portuguese data, a total of .99 of the data. Once again, the very few tokens that did occur without a detectable release were also found in test words in the IP-medial condition. Fisher's exact test also indicates that this proportion differed highly significantly by prosodic context ($p < 0.01$). However, the small number of stops that lacked bursts were deemed too few to warrant conclusions about the status of stop burst releases as a correlate of domain-initial effects.

4.4.2.3 First formant for the vowels in Portuguese (e.g. 'pitada', 'tacada', 'cutelo')

First formant values were extracted from the midpoint of unstressed /i a u/ in unstressed syllables in Portuguese. Similar to the results found in the English data, F1 values varied little between IP-initial (*median* = 9.95, *MAD* = 1.02) and IP-medial (*median* = 10.21, *MAD* = 1.26) contexts for vowels in target syllables in the Portuguese data. The Wilcoxon test confirms that the difference between prosodic contexts failed to achieve significance (W = 20057, p = 0.098).

4.5 Chapter Summary

This chapter presented the results of the analyses used to evaluate how domain-initial effects impacts the acoustic properties of segments in unstressed syllables in English, Spanish, and Portuguese. It presented statistical evidence that confirms the hypothesis that domain-initial effects contribute to marking the IP boundary, as suggested by differences in the acoustic properties of unstressed syllables in the three languages. These differences were language-specific. In English, VOT for unstressed /p t k/ was longer at an IP-boundary than the VOT measured for stops occurring phrase-medially. In Spanish and Portuguese, VOT did not differ significantly between phrasal positions. On the other hand, vowel duration in unstressed CV in both Spanish and Portuguese showed a statistically significant increase at the IP-boundary, but no effects on VOT were detected in these languages. The results and statistical analysis also showed that not all acoustic variables showed significant differences between prosodic contexts. In particular, first formant values for vowels in unstressed syllables failed to show significant differences in any of the languages.

CHAPTER 5

DISCUSSION

5.0 Chapter Overview

This chapter discusses the findings presented in Chapter 4 in light of previous literature and the hypotheses put forward in the Introduction. Section 5.1 recapitulates the goals and reasoning behind the current study and its format. Section 5.2 evaluates the results obtained from this acoustic experiment in relation to previous findings, and discusses possible explanations for discrepancies between this study and others. In that section the specific hypotheses and predictions outlined for the dissertation are re-examined with reference to the results obtained. Sections 5.3 and 5.4 discuss the implications of the current results for research on the interplay of boundary marking and word prominence, and for research on sound change. A discussion of the broader function of domain-initial effects is presented in Section 5.5, followed by an acknowledgement of the study's limitations, and suggestions for future research in Section 5.6.

5.1 Domain-initial Effects in English, Spanish, and Portuguese

The different analyses and statistical models presented in Chapter 4 provide evidence that domain-initial effects operate on the phonetic properties of segments in word-initial unstressed syllables. The main results obtained from the current study can be summarized as follows:

- In trisyllabic words with penultimate stress, the acoustic correlates of domain-initial effects extend beyond the initial segment following a major prosodic boundary.
- The stressed syllable in trisyllabic words with penultimate stress shows effects associated with domain-initial position, despite being two segments away from the major boundary.
- Languages with lexical stress may differ as to how domain-initial effects influence the phonetic makeup of both the stressed syllable that is not adjacent to the domain boundary, and the unstressed syllable that immediately follows the domain boundary.
- Domain-initial effects operate consistently on the ACOUSTIC properties of segments, in addition to the articulatory modulations reported in most previous investigations.
- Domain-initial effects may not be sufficient to explain the novel onset clusters that emerge in word-initial unstressed syllables in languages like English or Portuguese.

Overall, the findings listed above corroborate the general hypothesis that domain-initial effects distinguish words occurring immediately after a major prosodic boundary from those that follow a more minor prosodic boundary (Fougeron 1999). The current data also strengthen the claim that prosodic structure modulates the phonetic expression of segments near a prosodic boundary, and that this modulation may be subject to language-specific patterns (Cho 2015).

However, results of the acoustic analysis of the English, Spanish, and Portuguese data provided only partial support for the specific hypotheses outlined in this dissertation (see section 1.4). Of the three languages, the English data corresponded most closely to what was expected given previous results. The Spanish and Portuguese results diverged substantially from predictions. As will be discussed below, the Spanish and Portuguese data nonetheless fit with proposals that integrate different levels of prosodic events, for instance in Turk and Shattuck-Hufnagel (2007) and Katsika (2016).

One additional novel finding from the current study is that the non-boundary-adjacent stressed syllable showed statistically significant durational differences between the two experimental conditions. Although no specific hypotheses were outlined for the behavior of the stressed syllable, it was assumed that the duration of stressed syllables would be determined primarily by lexical prominence (Section 3.5). It is thus noteworthy that syllables that were two segments away from the domain boundary (e.g. *petition*, SPA/POR *tacada*) appear to show domain-initial effects. The next sections evaluate the extent to which these results relate to the research questions and hypotheses outlined in the Introduction.

5.2 Hypotheses and Predictions versus Findings

5.2.1 Research questions

Convergent evidence accumulated in the literature on the prosody-phonetics interface suggests that domain-initial effects present the following characteristics: the initial boundary of a major domain (typically the IP) is phonetically marked on the segment level (cf. Fougeron 1999, Keating et al. 2003), and secondly, the effect is most consistently and systematically observed on the very first segment following the major boundary (Byrd, Krivokapić & Lee 2006, Cho & Keating 2009, Bombien et al. 2010, among others). That is, domain-initial effects are assumed to mark the beginning of a major prosodic domain, but its locus is the domain-initial SEGMENT. Lexical stress, on the other hand, is assumed to operate at the level of the word domain, but its scope is the SYLLABLE. Due to such differences in the locus size of these two types of effects, it is theoretically possible for the same word to show separate acoustic correlates of each of them. These two assumptions informed the first research question addressed by this dissertation, repeated below:

> **RQ 1:** *How does the marking of prosodic boundaries modify the phonetic expression of segments in fully unstressed syllables unaccented words occurring in domain-initial position?*

The study described in Chapter 3 was designed around the premise that domain-initial effects and lexical prominence operate independently of one another. Indeed, one of the main hypotheses addressed in this dissertation was that the unstressed syllable near the boundary would be more susceptible to domain-initial effects precisely because it lacked other types of prominence. Put differently, the interaction of the two effects was expected to manifest itself in a complementary rather than in an additive fashion.

For the CV syllables tested, it was predicted that a localized effect of boundary marking on the initial consonant would be apparent in the acoustic signal, whereas it was expected that the phonetic makeup of the vowel would be determined primarily by stress-related factors. As a result of the interaction of domain-initial effects and stress-related reductions, it was predicted that vowels following the phrase-initial consonant at an IP boundary would show more overlap with the preceding stop than in the middle of the IP.

The fact that the phonetic correlates of lexical stress are language-specific then led to the formulation of the second research question, which in turn relates to the third question this dissertation address. The second and third research questions are repeated below:

> **RQ 2:** *To what extent does language-specific phonology determine the phonetic makeup of segments in unstressed syllables occurring in domain-initial position adjacent to boundaries of different levels in the prosodic hierarchy?*

The phonetic makeup of unstressed syllables differs in the three languages investigated. In the word prosody systems of English and Portuguese, duration is a more robust correlate of stress than in Spanish (e.g. Vogel et al. 2018). Additionally, both English and Portuguese show phonological vowel reduction in unstressed syllables, a stress-related process that Spanish lacks (Nadeu 2014). The three languages also differ in VOT values for voiceless stops, according to recent research (cf. Rosner at al. 2000, Cristófaro-Silva et al. 2019, among others).

It was expected that the outcome of the interaction of boundary marking and lexical stress would be more apparent in the languages in which duration is a more robust correlate of stress, such as English or Portuguese. The correlates of domain-initial effects were expected to influence only the initial segment (the consonant) in unstressed syllables, whereas the vowel in unstressed syllables would be more likely to show influence from the preceding stop in English and/or Portuguese. This influence would have potentially resulted in voiceless vowels, for instance.

> **RQ 3:** *To what extent are the acoustic manifestations of domain-initial effects consistent with the results obtained in articulatory studies?*

With regards to RQ 3, it was hypothesized that articulatory enhancements linked to domain-initial boundaries would be apparent in the acoustic signal, and that these would be consistent with previous findings using articulatory data. That is, it was expected that acoustic enhancements (e.g. longer VOT values, longer vowel duration, more stop release bursts) would be found for segments near an IP boundary.

5.2.2 Expected Results vs. Findings Obtained in the Study

The diagrams in Figure 5-a below illustrate the expected versus the actual results of the acoustic marking of domain-initial boundaries on word-initial unstressed syllables in the three languages examined in the dissertation. While the English voiceless stops showed longer VOT values following the IP-initial boundary, for most words the vowels that followed showed no difference between prosodic contexts. Neither Spanish nor Portuguese showed increases in VOT, whereas the vowels that followed the respective voiceless stops were significantly longer rather than shorter at an IP boundary. As a result, target syllables as a whole were actually longer after an IP boundary than in the middle of the phrase in the three languages. In no language did F1 values show significant differences between the two prosodic contexts. In the figure, predictions are shown at the top, and findings are depicted at the bottom. Dashed lines represent syllable boundaries in the IP-medial condition as reference.

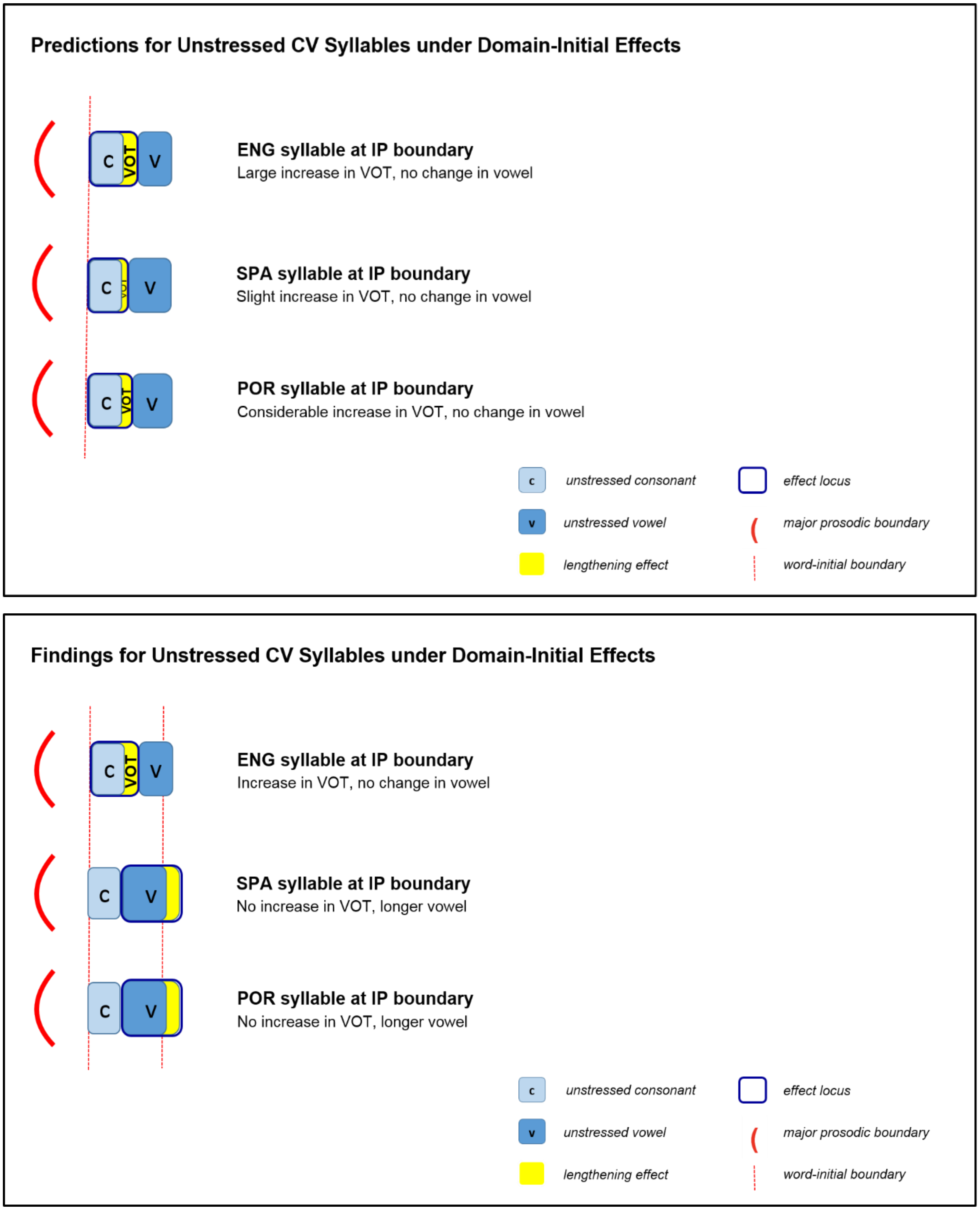

Figure 5-a. Effects of boundary marking on IP-initial target syllables

As stated in the Introduction, the specific goals of this project were: (i) to assess the extent to which domain-initial effects operate distinctly from lexical prominence; (ii) to establish the locus and scope of the temporal effect of domain-initial effects; (iii) to evaluate the role of language-specific phonology in how domain-initial boundaries are phonetically expressed; (iv) to provide an acoustic characterization of domain-initial effects that would complement the existing articulatory data; and (v) to provide an assessment of how domain-initial effects may relate to the emergence of onset clusters in lexical stress languages. Although results obtained in this project diverged from predictions, the current findings indirectly meet the goals established by virtue of the implications they carry. These are discussed below.

5.3 Implications: Locus, Prominence, and Phonology

5.3.1 Locality Condition Hypothesis

Domain-initial effects have been reported to operate most consistently on the initial segment of a prominent syllable immediately following the prosodic boundary (Cho 2015). Comparatively few studies have also found partial evidence for boundary-related articulatory enhancements in the vowels following a domain-initial consonant (e.g. Byrd 2000, Byrd, Krivokapić, & Lee, 2006, for English). Fewer still have reported on ACOUSTIC correlates in vowels in boundary-initial CV syllables (e.g. Cho & Keating 2009 for intensity; Cho, D. Kim & S. Kim 2017 for nasality; both in English).

Importantly, none of the studies above reported an absence of the effect on the consonant immediately following the boundary. That is, domain-initial effects observed for vowels in CV syllables occurred IN ADDITION TO effects on the consonant being tested. Although stop burst releases occurred less often in phrase-medial tokens of /p t k/ in the three languages, the number of burstless stop releases were too low to allow for a definite conclusion. The current results for Spanish and Portuguese, which showed vowel lengthening but no increase in VOT on the initial consonant, would thus pose a challenge to the locality hypothesis of domain-initial effects, which predicts that these effects begin at domain edge and spread from there.

One possible interpretation for the divergence between this study and previous research is that VOT may not be the best variable to test domain-initial effects in Spanish or Portuguese, since that these two languages are ‘true voicing’ languages (cf. Lisker & Abramson 1964, Cho, Whalen & Docherty 2019). In that sense, the lack of significance in the current data would not falsify the locality hypothesis, but rather suggest that a different choice of acoustic variable should be preferred for stops in languages that have short-lag VOT (see Hayashi, Hsu & Keating 1999 for a similar argument).

While it is certainly conceivable that acoustic variables other than VOT may be better fit to capture domain-initial effects in languages like Spanish or Portuguese, the fact that VOT has been found to correlate with domain-initial effects in both French (Fougeron 2001) and Japanese (Onaka et al. 2003) weakens the claim for rejecting it outright. This is particularly true given that French and Japanese are somewhat like Spanish and Portuguese in that both contrast voiceless unaspirated and fully voiced stops (e.g. [p t k] vs. [b d g]). Even though Fougeron’s (2001) and Onaka and colleagues’ (2003) results were admittedly based on few speakers and only applicable to /t/, those findings suggest VOT may play a universal role in the encoding of domain-initial effects. The importance of VOT as a reliable basis with which to characterize the voicing categories of stops across languages (Cho & Ladefoged 1999; Cho, Whalen & Docherty 2019) would constitute another argument for the selection of VOT as a variable in a wide range of languages. The presence of a boundary effect in French and Japanese VOT points to the possibility that there may be physiological phonetic underpinnings to domain-initial effects. Had a similar pattern been found in the current dataset for Spanish or Portuguese, the hypothesis of a biomechanical motivation for domain-initial effects would have gained some support.

An alternative interpretation of these results is that neither VOT nor vowel duration on their own may represent the full picture as far as the acoustic properties of unstressed CV syllables are concerned. There is some variability in what is considered the acoustic boundary between stop and vowel in a CV syllable (e.g. Thomas 2011), with some researchers suggesting that VOT be measured as part of the overall VOWEL duration. For instance, Turk, Nakai, and Sugahara (2006) explicitly recommend treating VOT as part of the vowel interval (p. 9):

> "It is our view that if segmentation of voiceless stop durations is to be comparable to that of fricatives and voiced stops, what we measure as voiceless stop durations should also correspond to their oral constriction durations, and should therefore end at oral release. On this view, vowels following voiceless stops should begin at consonantal release, rather than VOT."

If the segmentation criteria suggested by Turk and colleagues had been applied to the current data, the acoustic correlates of domain-initial effects would have yielded a different set of results. Using a single interval comprised of VOT and vowel duration as the main dependent variable, there would no longer be a difference in the acoustic results between Spanish and Portuguese, on the one hand, and English, on the other. In that analysis, the present findings would unambiguously indicate that domain-initial effects may operate on the acoustic properties of VOWELS in unstressed syllables of the CV type. It should also be noted that there are reports, albeit inconclusive, of domain-initial effects in segments not immediately adjacent to the boundary in English, as mentioned above. Figure 5b illustrates the durations if VOT and vowel duration are combined into one interval.

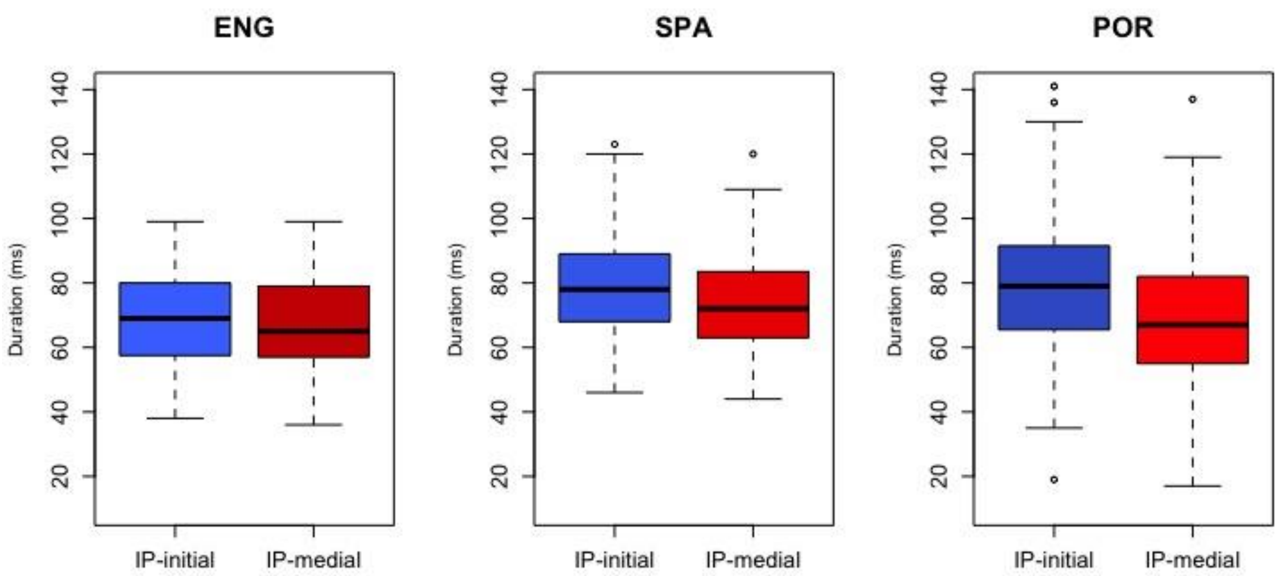

Figure 5-b. Results considering VOT and vowels as a single measurement interval

If unstressed vowels in a CV syllable are indeed the locus of the acoustic correlates of boundary-initial marking, the claim that domain-initial effects are strictly confined to the boundary-adjacent segment would be weakened in favor of the post-boundary SYLLABLE. The argument in favor of the syllable, and not just the vowel as results of the present study suggest, rests on the various investigations demonstrating that consonants at a major boundary show reinforced articulatory characteristics. Although more acoustic data is necessary to confirm this hypothesis, looking at a longer interval following a major boundary may allow for a more cohesive view of domain-initial effects. The current results regarding the VOT-vowel interval in English, Spanish, and Portuguese may be a case in point.

Additionally, it was mentioned in Chapter 2 that domain-initial effects manifest certain segment-specific idiosyncrasies in the way they are phonetically implemented. For instance, nasal consonants may show shorter nasal murmur at a major boundary (Gordon 1997, Fougeron & Keating 1997, Fougeron 2001, Cho & Keating 2001, 2009), while sibilants /s z/ may show no boundary effects at all (Fougeron 2001, Lavoie 2001). It is possible that the structure of the experimental design, with an emphasis on articulatory correlates of domain-initial effects, may have some bearing on the many differences found between segment types in the aforementioned studies. Recent evidence showing reduced coarticulation in vowels following nasals at prosodic boundaries (Cho, D. Kim, & S. Kim 2017), offers additional support for examining an extended scope of phonetic correlates of domain-initial effects. Cho and colleagues found that both the /n/ and the vowel in English syllables like /nɛt/ showed decreased nasality as a result of domain initial effects. That is, the acoustic effect was observed in two segments near a boundary.

In fact, the evidence gathered in this study suggests that domain-initial effects could extend even further away from the boundary, manifesting themselves in the domain-medial stressed syllable in all three languages. These findings present stronger evidence to refute the strict locality hypothesis, at least in terms of the acoustic correlates of domain-initial effects. The role of lexical prominence is discussed in further detail below.

5.3.2 Lexical Stress and Domain-initial Effects

As mentioned earlier, this study was designed to isolate the influence of lexical stress and phrasal prominence from domain-initial effects. While this investigation focused on the segments in the boundary-adjacent unstressed syllable, the following stressed syllable in test words was measured as a control variable. Individual statistical analyses for the three individual languages revealed that the stressed syllable had a significant main effect on the duration of VOT for English, and on vowel duration in both Spanish and Portuguese. The diagram in Figure 5-c depicts the findings of the study also showing the stressed syllable.

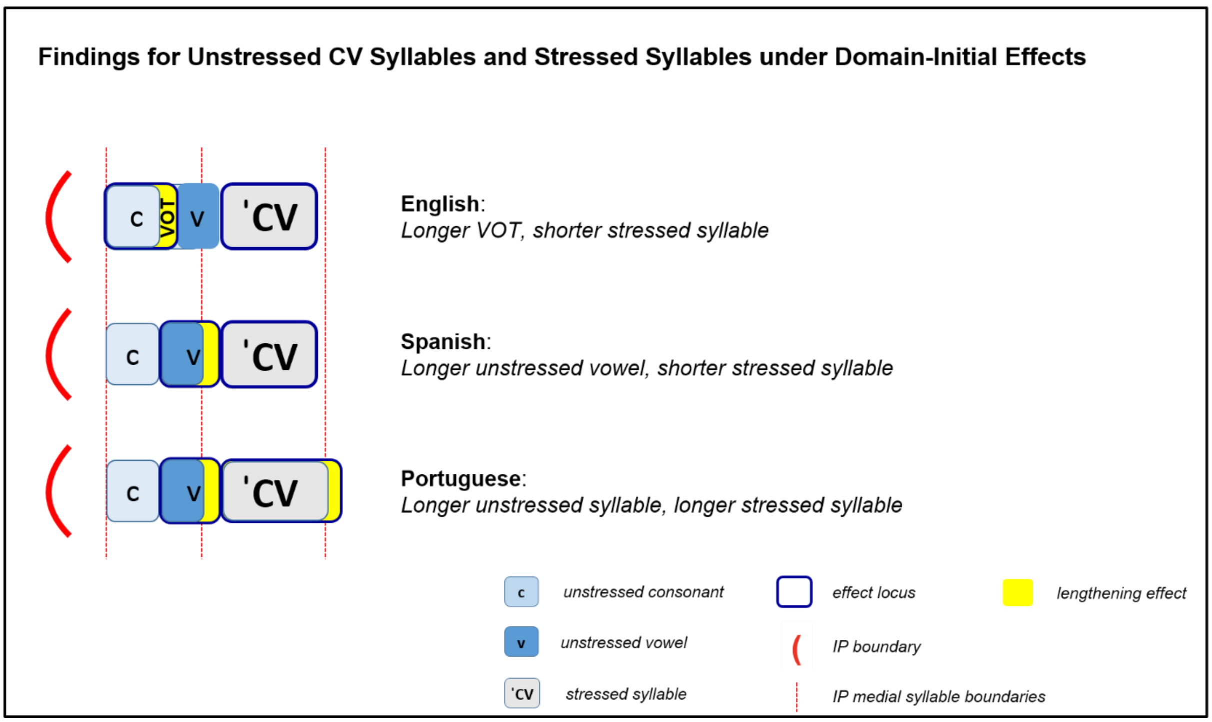

Figure 5-c. Domain-initial effects on first two syllables of IP-initial test words

In the diagram, dashed lines represent syllable boundaries in the IP-medial condition as reference.

While novel (to the best of my knowledge) in the domain-initial literature, these results have parallels in several studies of final lengthening that controlled for stress placement in phrase-final words. As detailed in Chapter 2, the position of the lexically stressed syllable was a decisive factor in determining the scope of boundary-related lengthening in English (S. Kim. J. Kim, & Cho 2018, S. Kim, Jang, & Cho 2017, Byrd & Riggs 2008, Turk & Shattuck-Hufnagel 2007, White 2002, Nakatani, O'Connor, & Aston 1981, Oller, 1973), Spanish (Rao 2010), and Portuguese (Frota 2000), but also in other stress languages such as Estonian (Krull 1997), Greek (Katsika 2016), Italian (Petrone at al. 2014), and Hebrew (Berkovits 1994). These studies and the current findings converge in that they all underscore the importance of lexical prominence in determining the scope of boundary-related effects.

The results presented here are compatible with the multiple target hypothesis outlined in Turk and Shattuck-Hufnagel (2007). The authors put forward a hypothesis that prosodic lengthening affects BOTH the boundary-adjacent syllable AND the stressed syllable that is not immediately adjacent to the boundary. On this view, the scope of boundary effects is determined by prosodic structure (i.e. the type of domain level) and the phonological properties of the word (i.e. where stress is located) simultaneously. Put differently, the multiple target hypothesis suggests boundary marking is phonetically expressed with reference to lexical prominence. Although formulated to account for final lengthening data, the multiple target hypothesis would explain the current findings of lengthening occurring both in the segments immediately following the IP boundary and in the stressed syllable.

Viewed this way, the results of the current study suggest that the lexically prominent syllable may serve as an anchoring point for boundary marking, perhaps in similar ways to how it encodes phrasal prominence. The idea that domain-initial effects and lexical stress are interdependent coheres with the existing body of literature showing an association between lexical stress and phrasal accent in terms of pitch movement. Having the stressed syllable as the anchoring point for the initiation of domain-initial effects also captures the fact that the post-burst interval (i.e. grouping VOT and vowel duration together) was longer near an IP boundary in all three languages in the current study. In this interpretation, domain-initial effects would begin in the stressed syllable, and move leftwards to the phrase-initial boundary (e.g. <u>**peti**</u>tions). Put differently, the locus of domain-initial effects would be best described as the stressed syllable, and the scope of the effect would potentially include segments between that syllable and the major prosodic boundary.

This account of the current data is also compatible with Katsika's (2016) proposal, which views prosodic boundaries and lexical prominence in an integrated fashion. According to her, prosodic events related to boundary marking (i.e. domain-edge lengthening, articulatory strengthening, phrasal accents, boundary tones, and pauses) are interdependent, with lexical prosody functioning as the interface between phrasal prosody and constriction gestures (Katsika 2016:169). While articulatory in nature[12], Katsika's hypothesis is compelling as it can account not only for the acoustic results in the current study, but also for data in studies of domain-final lengthening and phrasal accent.

[12]See also Byrd & Riggs (2008), and Saltzman et al. (2008) for an account of boundary-related spatiotemporal variation in articulatory parameters with regards to lexical prominence.

One possible interpretation of her proposal is that phrasal effects only affect segments in relation to a lexically prominent unit. This lexically prominent unit, for instance a stressed syllable in English, Spanish, or Portuguese, would then serve as a point of reference for the implementation of the effect. This approach would imply that prosodic structure is phonetically cued from the lower levels up, for instance from the Syllable to the IP. This bottom-up view of the prosodic hierarchy would suggest that smaller domains provide the framework upon which the whole structure is built. In light of the great deal of variability in prosodic phrasing, it may be useful to consider an approach that is more based on the concrete and more stable prosodic properties of lower-level domains such as the Word.

Further research into the interaction of different prosodic events is needed to support an integrated view of prosodic boundaries and prominence (see Section 5.5 below). However, the fact that the proposals in Turk and Shattuck-Hufnagel (2007) and Katsika (2016) stem from observations extracted from highly controlled experiments suggests that the examination of prosodic boundaries alongside prominence may provide important contributions to the study of prosodic structure. The current results provide some indication that that may be a fruitful avenue for future research.

The next section discusses the findings on the lexically prominent syllable in the English, Spanish, and Portuguese data.

5.3.3 Paradigmatic Contrast and Specificity

Although it was demonstrated in the acoustic analysis that the duration of the stressed syllable was a main effect in English, Spanish, and Portuguese, the languages differed as to how the stressed syllable patterned in different prosodic contexts. In English and Spanish, the stressed syllable was SHORTER near an IP boundary, whereas Portuguese showed LENGTHENING (see Figure 4.c). Despite the lack of experimental control for those syllables in the present study, as noted earlier, it may be relevant to discuss these findings given the aforementioned proposal of a link between prominence and prosodic boundaries.

A possible interpretation of the differences between the patterns of stressed syllables in the three languages follows what Cho (2011, 2015, 2016) proposes may be the linguistic function of domain-initial effects, namely enhancing linguistic contrast (see also Fougeron & Keating 1997). This hypothesis suggests that domain-initial effects mark prosodic boundaries most consistently by increasing the syntagmatic contrast between neighboring segments. In the current study, the longer VOT for voiceless stops in the English data would enhance the “consonantality” of the stop at the IP boundary, given that aspiration is a feature of consonants in English (see also Cho & McQueen 2005, S. Kim, Kim & Cho 2018, Cho, Whalen & Docherty 2019). However, Cho (2016) suggests that domain-initial effects may also enhance paradigmatic contrast, meaning that a given segment will have its contrastive features maximized in relation to all other segments. For example, the longer duration for vowels in the unstressed syllable in the Spanish and Portuguese data would enhance their phonetic clarity with linguistically relevant consequences, since the two Romance languages may contrast up to five vowel qualities /i e a o u/ in word-initial unstressed syllables. In the Brazilian Portuguese context of ongoing unstressed vowel reductions, this type of boundary-related lengthening might be especially informative (see Section 2.3 above).

In terms of enhancing contrasts in the stressed syllables, it could be argued, rather speculatively, that English and Spanish maximize the syntagmatic contrast between stressed and unstressed syllables near an IP boundary. Portuguese, on the other hand, might increase the paradigmatic contrast of both syllables near IP boundaries. Studies with tighter experimental control of non-boundary-adjacent stressed syllables are needed to verify these distinctions.

5.4 Implications for Sound Change

5.4.1 Vowel Reductions

The final set of implications relates to findings in the current study that could be relevant for investigations of sound change. As mentioned in 5.2, one of the questions raised in this dissertation was whether domain-initial effects would increase the influence of voiceless stops in English and/or Portuguese. One of the possible outcomes of that influence was hypothesized to be the occurrence of highly reduced voiceless vowels. The hypothesis was based on the observation that voiceless vowels tend to occur in the vicinity of voiceless segments, especially in non-prominent syllables (Gordon 1998).

Because long-lag VOT is often associated with consonants within the voiceless category of stops (Lisker & Abramson 1964, Cho, Whalen & Docherty 2019), it was speculated that domain-initial effects would entail more occurrences of voiceless vowels at the IP-boundary as a result of longer VOT. Although the small number of reduced vowels in both the English and Portuguese datasets (50 tokens in English, 31 in Portuguese) do not allow for drawing any robust statistical conclusions, a few observations may be in place. The English data are discussed first, followed by observations regarding Portuguese.

In terms of boundary strength, vowel reductions such as in the word shown in Figure 5-d occurred in both the IP-initial and IP-medial conditions (see also Figure 3-b in Section 3.6 above). Of the 50 tokens of vowel reduction in the English set, half (25) occurred in IP-medial words. This would imply that proximity to an IP-boundary is not a factor favoring vowel reduction.

However, many voiceless vowels like the one in Figure 5-d were observed in the English data. While the hypotheses regarding voiceless vowels and boundary strength did not receive support in the current study, the vowel reduction data may be relevant in studies of syllable structure. The presence of a voiceless vowel would suggest that the syllable is still present, whereas if aspiration is the only remaining trace of the vowel, it may be that re-syllabification has taken place[13]. The current results appear to support the view that the syllable remains, despite massive reduction in the properties of the unstressed vowel. More data is needed to better establish the role of domain-initial effects in preserving the consonant in highly reduced word-initial unstressed syllables.

[13] As noted in Section 3.5, intervals in which aspiration was visible in the spectrogram were coded and measured as VOT (cf. Abramson & Whalen 2017).

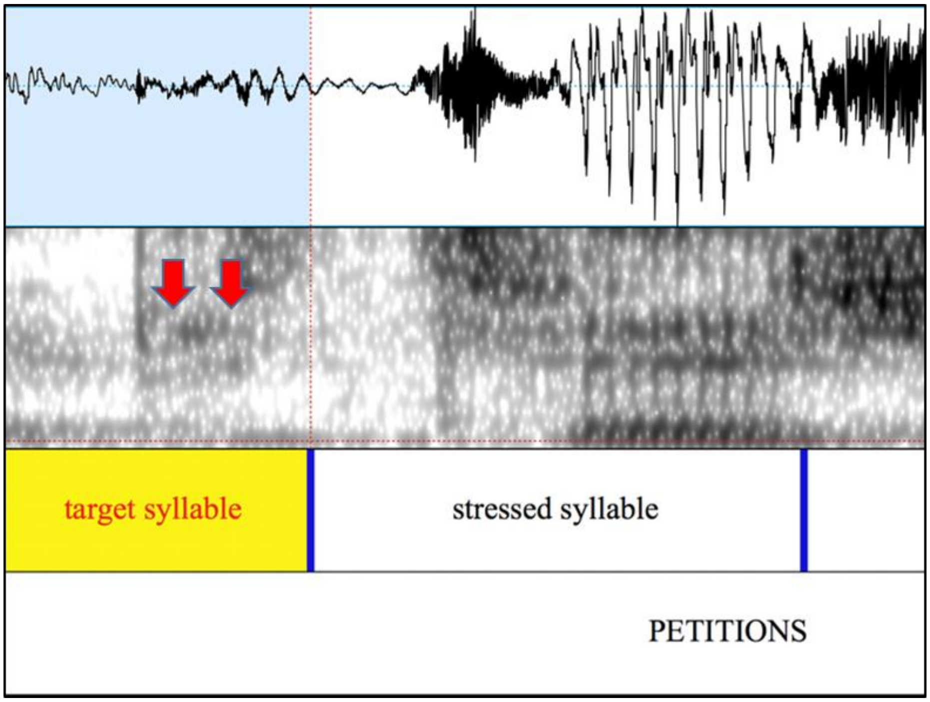

Figure 5-d. Example of a test word showing vowel reduction in the English dataset

The picture shows the target syllable, the following stressed syllable and the beginning of the final syllable in the word 'petitions' (Speaker FF03, IP-medial condition, second repetition). Red arrows show traces of formant structure where the /ə/ vowel in /pʰə/ was expected to occur.

A very different set of observations applies to the vowel reduction data in the Portuguese dataset. Of the 31 cases of vowel reduction, 26 (.84) occurred in PHRASE-MEDIAL position. As would be expected, Fisher's exact test shows that this is a statistically significant difference (p <0.001). This observation is the opposite of what was predicted, and yet it is consistent with the general finding in the Portuguese dataset that domain-initial effects operate on the unstressed vowel in the word-initial CV syllable. One possible interpretation of these results is that domain-initial effects may be opposing unstressed vowel reduction in word-initial syllables in Portuguese, which could explain why pre-stressed syllables in Brazilian Portuguese show less phonological reduction than unstressed syllables occurring elsewhere in the word.

5.4.2 Domain-initial Effects and Asymmetries in the Portuguese Vowel Inventory

The data obtained here suggest that unstressed vowels are longer near an IP boundary in Portuguese, and that this boundary-related lengthening may prevent unstressed vowel reduction from taking place. These results combined may be useful to explain the asymmetry between pre-stressed and post-stressed vowels in the language.

As mentioned in the Introduction, Brazilian Portuguese shows a complex system of vowel qualities that relates simultaneously to lexical stress and syllable position within the word. There is a stark contrast between unstressed oral vowels occurring in word-initial as opposed to word-final position. Up to five oral vowels can occur in unstressed word-initial syllables (i.e. /i e a o u/,) whereas only /ɪ ə ʊ/ can occur in unstressed final syllables[14].

If duration is taken to be one the most important factors in the neutralization of contrasts in vowels, the fact that more vowel qualities are found in pre-stressed than post-stressed position may be a consequence of domain-initial effects: the longer duration that can occur in pre-stressed position facilitates the distinction among more vowel qualities.

5.5 The Linguistic Function of Boundary Effects

The evidence gathered in this study suggests that there is more to domain-initial effects than a purely biomechanical motivation. If the initial movement of articulators after relative rest, for instance during a prosodic break expressed as a silent interval, was the

[14] In the initial syllables of *c**i**lada* /s**i**ˈladə/ ‘a trick’, *s**e**lada* /s**e**ˈladə/ ‘sealed’, *s**a**lada* /s**a**ˈladə/ ‘salad’, *s**o**lada* /s**o**ˈladə/ ‘shodden’, *suada* /suˈadə/ ‘sweating’ versus the final syllables of *Cál**i*** /ˈka.lɪ/ ‘Cali, Colombia’, *cal**e*** /ˈka.l**ɪ**/ ‘that I shut up’, *cal**a*** /ˈka.l**ə**/ ‘s/he shuts up’, *cal**o*** /ˈka.l**ʊ**/ ‘callus’, *camp**us*** /ˈkɐ̃.p**ʊ**s/. The orthography reflects an earlier period of the language.

main driver of these effects, all domain-initial consonants would be expected to show some correlate of the marking of the prosodic boundary. What's more, if domain-initial effects derived only from the start-up of articulation, different languages would show consistent similarities in the way the prosodic effect operates on given segments. The current results, as well as the findings from multiple studies reviewed in Section 1.3.3, and in Chapter 2, indicate that that is likely not the case. In that sense, domain-initial effects differ in relevant ways from the marking of phrase edges before a prosodic boundary.

Preboundary, the slowing down of articulators towards the end of phrase suggest a physiological motivation behind domain-final effects such as phrase-final lengthening, or phrase-final creak. These phonetic effects can be interpreted as a reflection of the speaker's planning for the upcoming prosodic break, when most articulators will be at rest. This biomechanical process could then explain why phrase-final lengthening and/or phrase-final creak are cross-linguistically common (cf. Jun 2005a, 2014, see also references in Garellek 2015).

On the other hand, the observation that the locus of phrase-final lengthening may relate to a lexically prominent syllable introduces a linguistic foundation for the effect. It is noteworthy that pitch movements that encode phrase-final edges also tend to associate with a linguistically relevant unit, such as a lexically prominent syllable in languages with lexical stress. As mentioned in the above discussion, the results of this dissertation provide indication that prosodic boundary marking in English, Spanish, and Portuguese also makes reference to the lexical stress systems of these languages. The correlation of preboundary marking with word prosody thus suggests a possible parallel between the phonetic encoding of both edges of a prosodic domain.

The fact that the phonetic marking of the initial edge seems to relate to the segmental phonology of a language bespeaks a perhaps clearer linguistic motivation for domain-initial effects. Given the relevance of prosodic boundaries in speech recognition (Carlson 2009), an increase in phonemic contrast between neighboring segments at a phrase edge could possibility facilitate the parsing of speech. Because stressed syllables are prominent, it could be argued that they serve as a natural anchoring point for the marking of phrase edges – initial and final alike.

5.6 Limitations and Future Research

This study focused on the acoustic properties of voiceless stops and vowels immediately following prosodic domain boundaries, compared to sounds that are not adjacent to major boundaries. While some of the results discussed above may appear to contradict earlier articulatory studies, the findings in this dissertation are strictly limited to the acoustic realm, and no claims are made as to the locus, scope or anchor of domain-initial effects in terms of articulation. Future articulatory studies that manipulate lexical stress and accent using similar sample sizes are needed to reconcile the findings put forward in this dissertation with previous research on articulation. Furthermore, although it is suggested that the current findings may be applicable to other types of consonants, more studies are needed to support that claim regarding segments other than voiceless stops.

Due to the fact that the current project focused on word-initial unstressed syllables, there was much less experimental control for the stressed syllable in the trisyllabic words used in the reading task. A follow-up investigation with tighter experimental control on both the unstressed and stressed syllables could potentially increase the validity of the present findings. As explained above, this study was not explicitly designed to capture differences between stressed syllables, but in fact main effects on stressed syllables were found in all of the languages investigated. More research is hence necessary to confirm the associations found between prosodic context and the phonetic characteristics of stressed syllables not immediately following a major prosodic boundary.

Acoustic studies that manipulate the number of unstressed syllables between the boundary and the stressed syllable would also offer important contributions to our understanding of domain-initial effects. Additionally, although the test words measured in this study did not receive the main phrasal accent, no specific control was undertaken with regards to the presence and type of pre-nuclear pitch accents. Future studies that manipulate pitch accent type and placement would constitute a relevant refinement of the methods employed here.

Finally, this dissertation only considers data from English, Spanish, and Portuguese, all of which are languages with culminative lexical stress. It is possible that a similar acoustic study of languages with other types of word prosody systems, including languages with fixed lexical stress, may result in different associations between boundary marking and lexical prominence. What's more, the claims made here may not be applicable to varieties of these languages other than the ones investigated here, namely American English, Mexican Spanish, and Brazilian Portuguese, given the known prosodic differences between dialects of the same language (e.g. Clopper & Smiljanić

2011, for English; Prieto & Roseano 2010, for Spanish; Frota et al. 2015 for Portuguese). In the case of Spanish, it would be desirable to conduct a similar study using only monolingual speakers instead of the fully bilingual participants recorded for the current project.

5.7 Discussion Summary

This chapter discussed the findings obtained in the dissertation in light of previous literature as well as of the hypotheses put forward in the Introduction. This study has provided some additional data that can further our understanding of prosodic structure, by investigating the acoustic consequences of this structure in a novel way. Although the initial predictions were not supported in all cases, the study does support the importance of prosodic structure in organizing speech.

CHAPTER 6

CONCLUSION

This dissertation aimed to tackle four unresolved issues regarding domain-initial effects. The four issues were described as follows: (I) the relation between boundary-initial marking and other levels of prominence; (II) the locus and scope of the temporal effect of boundary-initial marking with regards to the prosodic boundary; (III) the role of language-specific phonology in the phonetic manifestation of domain-initial effects; and (IV) the ways in which domain-initial boundaries are expressed in the acoustic signal in comparison to articulatory accounts. By addressing these four issues, it also aimed to evaluate whether domain-initial effects may be implicated in the emergence of onset clusters in lexical stress languages.

While previous studies have focused primarily on the articulatory correlates of domain-initial effects on individual languages, this dissertation sought to shed light on some of the acoustic properties of this boundary-marking effect from a cross-linguistic perspective (Issues I and IV). In contrast to most investigations on the topic, the current project looked at unstressed segments occurring in words that did not bear the main (nuclear) phrasal accent (Issues II and III). The data obtained from 52 speakers of English, Spanish, and Portuguese revealed that the acoustic correlates of boundary marking extend beyond the initial segment in unstressed CV syllables, affecting the vowel in Spanish and Portuguese, and the stressed syllable in all three languages.

The results obtained in this dissertation suggest a close connection between the grouping and prominence functions of prosody, in which the stressed syllable may serve as the anchoring point for boundary marking. This proposal is in line with findings from studies of domain-final effects that controlled for stress placement in test words (Turk & Shattuck-Hufnagel 2007, Cho et al. 2013, Katsika 2016). These investigations show that phrase-final lengthening is initiated farther away from the boundary in polysyllabic words that do not have stress on the final syllable. The combined evidence seems to suggest that lexically stressed syllables play a role in marking both domain-initial and domain-final boundaries of major phrases. This function of the stressed syllable would then add to its already established function in marking phrase-level prominence in some languages, and thus provide support to the view that prosodic structure manifests itself phonetically through the interaction of segmental and suprasegmental factors.

More broadly, the results of the current study reinforce the idea that speakers actively use language-specific phonological knowledge (e.g. VOT lag for English /p t k/, vowel duration for Spanish and Portuguese /i a u/) to implement phonetic distinctions that are relevant to speech categories (Keating 1984, Kingston & Diehl 1994, Cho & Ladefoged 1999). The present findings corroborate the hypothesis that speakers indicate the grouping of their speech units by manipulating phonetic detail (Cho 2016), thereby highlighting the effects of prosody on segmental phonetics (i.e. the prosody-phonetics interface). Finally, this dissertation presents further evidence that phonetic information relates to multiple levels of prosodic structure simultaneously.

APPENDICES

Appendix A - English Stimuli

/p/
petitions
You're talking about ordinary polls but it's not the same **||** **<u>petitions</u>** must be SIGNED to be valid
Very often students do get to voice their concerns but these silly # **petitions** make no difference

patrolmen
Policemen can certainly arrest you but that's not the case **||** **<u>patrolmen</u>** only REINFORCE order
I'm used to being stopped by the police but I have to say: those angry **#** **<u>patrolmen</u>** really scared me

/t/
tequila
I've checked labels plus I've tried both drinks, so I'm pretty certain **||** **<u>tequila</u>** is WEAKER than pure vodka
I'm used to drinking strong liquor because I don't like beer but that nasty **#** **<u>tequila</u>** made me so sick

toccata(s)
No, they're not something you eat at all! I know from music class **||** **<u>toccatas</u>** are just long MUSIC pieces
I did enjoy it; she's an excellent musician, no doubt: that classy **#** **<u>toccata</u>** was fantastic

/k/
katrina
A lot of hurricanes do hit those parts but this time you are wrong **||** **<u>Katrina</u>** hit NEW ORLEANS, not Texas
I've lived through many horrible storms that caused much damage but that deadly **#** **<u>Katrina</u>** destroyed the land

capacious
It doesn't refer to ability! You can check for yourself **||** **<u>capacious</u>** means ROOMY or full of space
It is very sad there's not too much they can do at this point: the city's **#** **<u>capacious</u>** museum closed

Appendix B - Spanish Stimuli

/p/
***pitada* [piˈta.ða]**
Estás confundido **||** **<u>pitada</u>** quiere decir SOPLADO más que sonido o pitido
You're mistaken, whistling is a BLOWING SOUND more than a noise or a beep
A causa de la lluvia, el árbitro Federico dio la # **<u>pitada</u>** a las tres horas
Because of the rain Federico the referee blew the whistle to end the match at 3 o'clock

***patrulla* [paˈtruja]**
Aqui en México **|| patrulla** quiere decir un CARRO de vigilancia en la ciudad
Here in Mexico, a patrol is a CAR used by city police
A pesar de las protestas, el gobierno va a mantener la **#** **<u>patrulla</u>** policial diaria
Despite the demonstrations, the government is keeping the daily police patrols

/t/
***tipazo* [tiˈpa.so]**
No te confundas **||** **<u>tipazo</u>** quiere decir AMABLE más que un cuerpo atractivo
Don't mix the two up, a stud is more like a NICE guy than a hot one
Es un tanto vulgar, aquí en esta zona no se dice **#** **<u>tipazo</u>** a las personas
That's a little vulgar; around here we don't call anyone a stud

***tacada* [taˈka.ða]**
Según sus abuelos **|| tacada** tiene que ver con ARMAS de fuego y no con el billar
According to his grandparents, a strike is something to do with GUNS, not with playing pool
Ganó el partido porque su papá le enseñó una **# tacada** spectacular
S/he won the match because her/his dad taught him a great move

/k/
cuchara [kuˈtʃaɾa]
Aprendí con ellos **||** **<u>cuchara</u>** se refiere TAMBIÉN a la herramienta del albañil
I learned this from them 'cuchara' ALSO means a trowel that you use to build stuff
Los albañiles estuvieron varias horas buscando la **#** **<u>cuchara</u>** para el muro
The contractors spent several hours looking for a trowel to build the wall

capricho [kaˈpritʃo]
Me parece raro **||** **<u>capricho</u>** significa un DESEO irracional muy intense
That sounds strange, a whim means an irrational DESIRE that is very intense

Los abuelos prepararon recetas para cumplirle su **# <u>capricho</u>** gastronómico
Her/His grandparents cook recipes just to satisfy his food whims

Appendix C - Portuguese Stimuli

/p/

***pitada* [pɪˈta.də]**

Tem muito sal aqui **||** **pitada** quer dizer só UM POUQUINHO do ingrediente na receita

You put too much salt in this; a pinch means JUST A LITTLE of the ingredient

Pimenta caiena é mais forte do que do reino; só uma **#** **pitada** tá mais que bom

Cayenne pepper is much stronger than black pepper; just a pinch is more than enough

***patola* [paˈtɔ.lə]**

Não é um pato não **||** **patola** tem a ver com TAMANHO ou peso duma pessoa

It doesn't mean full of stock, stocky has to do with someone's SIZE or weight'

Elas venderam todos os filhotes, mas essa cachorrinha **# patola** ninguém levou

They sold most of the puppies but no one really wanted to take the stocky one.'

/t/

***tutela* [tʊˈtɛ.lə]**

Isso é outra coisa **||** **tutela** garante a AUTORIDADE sobre uma criança

That's something else entirely; guardianship means having LEGAL AUTHORITY over a child

Meu pai ficou sabendo outro dia que o Gilberto perdeu a **#** **tutela** dos três filhos

My father heard the other day that Gilberto lost custody of his three children'

***tacada* [taˈka.də]**

Esquece de taco **||** **tacada** quer dizer uma IDEIA inteligente que deu certo

Forget about the word taco; tacada means a clever IDEA that panned out

Mesmo sem conhecer o gerente, não dá pra negar que aquela **#** **tacada** foi de mestre

You don't have to know the manager to acknowledge that his clever move was exceptional

/k/

***cutelo* [kʊˈtɛ.lʊ]**

Não é de açougue || **<u>cutelo</u>** é meio que um facão PEQUENO de uso diário

It's not a butcher knife, a cleaver is a kind of SMALL hatchet for daily use in the kitchen

Dependendo do tipo de carne é melhor usar aquele **#** **<u>cutelo</u>** maiorzinho

I guess it depends on the kind of meat but you should probably use that large-ish cleaver over there

***capela* [kaˈpɛ.lə]**

Não é igrejinha **||** **<u>capela</u>** é um nicho PEQUENO dedicado a algum santo

It's not a small church, a chapel is a small area dedicated to a given Catholic saint

De todas as partes da igreja a que eu mais gosto é aquela **#** **<u>capela</u>** dourada lá

Of all the areas of the church, my favorite spot is that golden chapel over there

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