A Typology of Stress- and Foot-Sensitive Consonantal Phenomena[1]

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Abstract

This article investigates consonantal alternations that are conditioned by stress and/or foot-structure. A survey of 78 languages from 37 language families reveals three types of consonantal phenomena: (i) those strictly motivated by stress (as in Senoufo lengthening), (ii) those exclusively conditioned by foot structure (as in /h/ epenthesis in Huariapano), and (iii) those motivated both by stress and foot structure (as in flapping in American English). The fact that stress-only and foot-only consonantal phenomena are attested alongside stress/foot structure conditioned phenomena leads to the proposal that stress and foot structure can work independently, contradicting the traditional view of foot structure organization as signaled by stress-based prominence. It is proposed that four main factors are at play in the consonantal phenomena under investigation: perception, duration, aerodynamics, and prominence. Duration, aerodynamics and perceptual ambiguity are primarily phonetic, while prominence and other perceptual factors are primarily phonological. It is shown that the mechanism of Prominence Alignment in Optimality Theory captures not only consonantal alternations based on prominence, but can also be extended to those with durational and aerodynamic bases. This article also makes predictions regarding unattested stress/foot sensitive alternations connected to the four factors mentioned above.

Keywords: *stress; foot structure; consonantal alternations; phonological typology; perception; duration; aerodynamics; prominence; Prominence Alignment; Optimality Theory.*

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1. Introduction

The influence of stress and foot structure has been well studied for a few consonantal phenomena. For instance, stress influences the length and strength of aspiration in onset voiceless stops in English (Turk 1993), and flapping of /t, d/ occurs in unstressed syllables in American and Canadian English (Kahn 1980, Turk 1992). In Norton Sound Yupik, fortition appears to be foot-sensitive rather than stress-sensitive (Van de Vijver 1998), as is the epenthesis of /h/ in Huariapano (Parker 1994, 1998). Nevertheless, the influence of stress and foot structure on consonantal phenomena has not been studied in broad-based terms, and there is no exhaustive survey or classification of the types of consonantal alternations that are conditioned by these metrical considerations.

This investigation aims to fill this gap. It presents an extensive survey of over 78 languages from 37 language families with stress- and foot-sensitive consonantal alternations.[2] It examines the types of consonantal phenomena that are influenced by stress and foot structure and explores the possible factors that underlie them. It also makes a number of generalizations concerning these processes, including the specific stress and footing environments in which consonantal phenomena are conditioned cross-linguistically, the types of segments and syllabic positions that are preferentially targeted (laryngeal consonants and onsets), and the relevance of positional factors. Thus, this study contributes to the understanding of the possible manners in which stress and footing interact with segmental processes, and, more generally, to the relationship between stress and foot structure.

Additionally, this paper puts forward three main theoretical proposals concerning the factors behind the consonantal alternations surveyed, the nature of the relationship between stress and foot structure, and the analysis of stress- and foot-sensitive consonantal phenomena in Optimality Theoretic terms. It is proposed that four factors are at work in stress- and foot-sensitive consonantal phenomena: perception, duration, aerodynamics, and prominence. While aerodynamics, duration and perceptual ambiguity are primarily phonetic (but can be phonologized in some cases), prominence and other perceptual factors are primarily phonological. In some cases, various factors can be at work in a single consonantal phenomenon; in others, a consonant alternation might be ambiguous as to the factors that condition it.

The second theoretical proposal is that stress and foot structure are separately needed to characterize the range of conditioning contexts for the consonantal phenomena surveyed. The survey evidences three different types of consonantal phenomena: stress-only cases (as in frication in Noth-Central Peninsular Spanish), stress/foot structure cases (as in flapping in American English), and foot-only cases (as in deletion in Capanahua). The finding that consonantal processes can be influenced strictly by stress and strictly by footing leads to the proposal that stress and foot structure are separate. Even if stress and footing might coincide, they are independent, as suggested by cases where foot structure is independent of stress (as in Panoan languages) and where stress is independent of footing (as in Senoufo). This contradicts the traditional

[2] This paper reports four additional languages not included in González (2003): Cashinawa (Panoan), Chacobo (Panoan), Guajajára (Tupí-Guaraní), and Urarina (Isolate).

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view of foot structure organization as signaled necessarily by stress-based prominence. While stress can be one of the possible ways in which languages organize syllables into groups, there are other ways which are available in order to achieve this aim, including vowel alternations, tonal phenomena, and consonantal alternations.

A third proposal concerns the analysis of stress- and foot-sensitive consonantal phenomena. This paper proposes that Prominence Alignment can be successfully deployed to capture prominence reduction and augmentation for consonantal phenomena in both stress- and foot-sensitive contexts. Additionally, it is proposed that Prominence Alignment can be extended to account for phonological consonantal phenomena with durational and aerodynamic bases; while it is generally recognized that durational and aerodynamic constraints play a role in phonological analyses, these constraints have often been left unformulated.

The organization of this paper is as follows. Section 2 lays out the theoretical framework of this study, briefly discussing Optimality Theory, the metrical theory of stress, and the separation between phonetics and phonology. Section 3 reports on an extensive cross-linguistic survey of consonantal processes where stress and/or foot structure are influential. This section is divided in three parts. Section 3.1 discusses the sources of the survey; section 3.2 is an overview; and sections 3.3-3.9 comprise the survey, organized according to the type of consonantal phenomena influenced by stress and/or footing. Section 4 discusses the typological generalizations that arise from this survey, including the specific stress and footing environments in which consonantal phenomena are conditioned cross-linguistically, the types of segments and syllabic positions that are preferentially targeted in these consonantal phenomena, and the relevance of positional factors. This section also discusses the three proposals previewed above, concerning the factors at work in stress- and foot-sensitive consonantal processes, the independence of stress and foot structure, and the extension of Prominence Alignment to account for prominence, durational and aerodynamic consonantal phenomena. Section 5 presents some conclusions and section 6 directions for further research.

2. Theoretical framework

This section briefly discusses the theoretical framework of this investigation: Optimality Theory (2.1), the metrical theory of stress (2.2), and the separation between phonetics and phonology (2.3).

2.1. Optimality Theory

This investigation is couched within Optimality Theory (OT) (Prince and Smolensky 1993). One of its central tenets is that phonological processes are not obtained by rules, but by universal constraints that operate over output forms in languages. Constraints are potentially opposing forces that may stand in tension with each other; cross-linguistic differences between languages are due to different ways of resolving these tensions. In OT this is expressed by different rankings of these constraints in a hierarchy. A claim of classic OT is that there are just two levels: input (roughly corresponding to the underlying form) and output (surface form); there are no intermediate forms or serial derivations. From the input form, a set of possible outputs or candidates are evaluated in parallel with respect to the constraint hierarchy in a language. The output that best satisfies the particular ranking in a language is chosen as the optimal form.

The two basic types of constraints within OT are faithfulness and markedness (Prince and Smolensky 1993). Faithfulness constraints conspire to 'pronounce everything as it is' in the input (Hammond 1997). In the Correspondence Theory of Faithfulness (McCarthy and Prince 1995), the input and the output are in a correspondence relation with each other. Examples of faithfulness constraints are MAX-IO, DEP-IO and IDENT-IO [voice].

(1) Examples of faithfulness constraints (McCarthy & Prince 1995)

MAX-IO	Every element of the input has a correspondent in the output (Phonological deletion is not permitted).
DEP-IO	Every element of the output has a correspondent in the input (Phonological epenthesis is not permitted).
IDENT-IO [voice]	Correspondent segments in the input and output have identical values for the feature [voice]. If x is a segment in the input, and y is a segment in the output, and if x*R*y and x is [γvoice], then y is [γvoice].

Markedness constraints ('phono-constraints') capture preferences in phonological well-formedness and in segment inventories. The interaction between faithfulness and markedness captures phonemic and allophonic distributions (Prince and Smolensky 1993, Kager 1999). Examples of markedness constraints are given in (2).

(2) Examples of markedness constraints

NOCODA	Avoid codas (Prince and Smolensky 1993)
*VOICED FRICATIVE	Voiced fricatives are prohibited.

2.2. The Metrical Theory of Stress

Stress can be defined as prominence produced by means of respiratory effort (Lehiste 1970: 119). Differences in stress are caused by differences in physical effort, which have a direct reflection in the activity of the respiratory muscles. The force exerted by the muscles involved in respiration is transmitted to the air in the lungs and is then reflected in subglottal pressure (Lehiste 1970 and references therein).

While there is no one-to-one correspondence between stress and any phonetic feature, stressed syllables are typically louder, have pitch extrema, and last longer than unstressed syllables (Hayes 1995). They are also perceptually and articulatorily prominent (Beckman 1998 and references therein).

Across languages, stress has an organizing function; it divides speech into units (Lehiste 1970: 147). The smallest unit carrying stress is the syllable, and the minimal unit of contrastive stress placement is a sequence of two syllables (Lehiste 1970: 147). This idea is behind the Metrical Theory of Stress (Liberman 1975, Prince 1976, Liberman and Prince 1977, Hayes 1980, 1995, Halle and Vergnaud 1987). The main assumption of this theory is that stress is a rhythmic phenomenon, encoded by strong-weak relations between syllables. Another important assumption is that constituents are grouped into higher units as in the prosodic hierarchy (3).

(3) Prosodic hierarchy (Selkirk 1980, McCarthy & Prince 1986)

PrWd	Prosodic Word
|	
Ft	Foot
|	
σ	Syllable
|	
μ	Mora

At the bottom of the hierarchy is the mora (represented with 'μ'), a weight-bearing unit in a syllable. According to Moraic Theory (Hulst 1984, Hyman 1985, Hayes 1989), the quantity of a syllable depends on its number of moras. In most languages, vowels are always moraic; short vowels have one mora and long vowels two. Diphthongs and coda consonants can be moraic or not depending on the language. Light syllables have one mora; heavy syllables, two.

Moras are grouped into syllables, which minimally consist of a mora. Syllables are grouped into feet. A foot is formed minimally by a stressed syllable, but it typically has both a stressed and an unstressed syllable. Two basic types of feet exist: iambic (right-headed), and trochaic (left-headed) (Hayes 1995). An iambic foot can be formed of a stressed syllable, or of an unstressed syllable followed by a stressed syllable. Typically, in the second case the stressed syllable is heavy. A trochaic foot can be moraic (quantity-sensitive) or syllabic (quantity-insensitive). Moraic trochees are formed of a heavy stressed syllable. Syllabic trochees are formed of a stressed syllable followed by an unstressed syllable (Hayes 1995). Examples of trochaic and iambic footing are shown in (4).

(4) Examples of trochaic and iambic feet

(a) *Trochaic feet: Huariapano* (from Parker 1998: 2-10; IPA)

Moraic	('H)	[ja.('wiʃ)]	'opossum'
	('L.L)	[('hi.wi)]	'branch, stick'
Syllabic	('σσ)	[('ha.βom.) ('βi.βi)]	'they'
		[mi.('βom.βi.) ('ra.ma)]	'you (plural)'

(b) *Iambic feet: Central Siberian Yupik* (from Van de Viver 1998: 116, 174; IPA)

Canonical	(L.'H)	[(qa.'jaa.) ni]	'his own kayak'
	(L.'L)	[(a.'tə.) pik]	'real name'
	('H)	[su.'ɣuu.) ('jaa).ni]	'in his (another's) drum'

The canonical iamb has an unstressed syllable followed by a heavy stressed syllable; the two syllables in an iamb contrast in duration. The canonical trochee is syllabic; syllables in a trochee contrast in intensity (Hayes 1995). This is stated in the Iambic/Trochaic Law (Hayes 1995) (5).

(5) Iambic/Trochaic Law (Hayes 1995: 80)

1. Elements contrasting in intensity naturally form groupings with initial prominence.
2. Elements contrasting in duration naturally form groupings with final prominence.

At the top of the prosodic hierarchy is the prosodic word. Typically, prosodic words have a single strongest syllable bearing the main stress. This is the *culminativity* property. Other cross-linguistic properties are the *demarcative* property (stress tends to occur at or close to constituent edges), *quantity-sensitivity* (stress is attracted to long vowels, diphthongs, and closed syllables), and the *rhythmic* property (stressed and unstressed syllables alternate, and stress clashes or lapses are avoided) (Kager 1999; see also Hayes 1995).[3] These properties are often in conflict; in OT, this conflict is solved by the language-particular ranking of universal constraints. Some metrical constraints are included in (6). Additional metrical constraints are discussed in section 4.

(6) Metrical constraints

Culminativity	
GrWd=PrWd	A grammatical word must be a prosodic word (Prince and Smolensky 1993)
Quantity-sensitivity	
Weight-by-Position	Coda consonants are moraic (Hayes 1989, Sherer 1994)
Stress-to-Weight	If stressed, then heavy (Myers 1987, Riad 1992)
Demarcative property	
Leftmost/Rightmost	Align (Hd-Ft, Left/Right, PrWd, Left/Right) 'The head foot is leftmost/rightmost in PrWd' (Prince and Smolensky 1993)
Rhythmic property	
Ft-Bin	Feet are binary under moraic or syllabic analysis (Prince and Smolensky 1993)

A proposal of this paper is that footing can be persistent even if not all feet in the prosodic word have stress. Persistent footing can be realized not only through stress, but also through consonantal and vocalic alternations, and possibly by tonal alternations too.

[3] Note that the *rhythmic property* and *rhythmicity* refer to different concepts; the first refers to an alternation between stressed and unstressed syllables, and the second to a prominence contrast in foot structure.

2.3. The relationship between phonetics and phonology

Phonetic realization is mostly subject to language-specific variation (Keating 1985). For example, while both English and Spanish have coronal stops, their phonetic realization varies; coronal stops are alveolar in English, but dental in Spanish. There are two options if we want to represent this fine-grained detail of realization. One is to include fine phonetic detail in the phonological representation; this will be referred to as the 'integrated' approach (see Byrd 1996, Kirchner 1997, Steriade 1997, and Flemming 2001). Alternatively, if fine detail is excluded from the phonological representation, then a phonetic component should be added to the grammar. This will be referred to as the 'modular' approach; advocates include Keating 1984, 1990, Archangeli and Pulleyblank 1994, and Howe and Pulleyblank 2001.

One argument for the separation of the phonological and the phonetic modules or components is given by Howe and Pulleyblank (2001), who investigate the patterning and timing of consonant glottalization. Howe and Pulleyblank find that there is a mismatch between the phonetic predictions of glottalization timing and the attested patterns of glottalization. The phonetic prediction is that the cues of glottalization will be optimal in vocalic environments; thus, consonant pre-glottalization will tend to occur post-vocalically, and post-glottalization pre-vocalically (Sapir 1938, Kingston 1985, Silverman 1997, Steriade 1997, among others). However, in many languages glottal timing correlates with syllabic position—which is a purely phonological construct in many languages. For example, consonants in coda positions are post-glottalized rather than pre-glottalized in Yowlumne and Kashaya, and consonants in onsets are pre-glottalized rather than post-glottalized in Nuu-chah-nulth and Yowlumne. Howe and Pulleyblank (2001) conclude that the phonetic factors of timing and perception of glottalization have no direct effect on the phonological component of the grammar; therefore, the phonetic and the phonological components are separate.

This paper assumes a strict separation between phonetics and phonology, as in the modular approach. The grammar will have both a phonological and a phonetic component. The phonological component will comprise phenomena which are category-neutralizing, categorical, or obligatory, while the phonetic component will comprise partial, variable, or gradient phenomena. For example, vowel reduction in Italian, which is category-neutralizing, will be a part of the phonological component; in contrast, non category-neutralizing vowel reduction will be a part of the phonetic component (see discussion in Flemming 2001). No claims are made as to the nature of the phonetic component. The phonological component will be represented in OT terms.

Although the classification of phenomena as 'phonological' or 'phonetic' might be straightforward, some cases might not clearly belong to each category. For example, there could be cases of phenomena which are category-neutralizing but variable, or obligatory but partial. Further investigation might elucidate the extent to which such processes belong to the phonetic or the phonological component.

The separation between the phonetic and phonological modules does not make any assumptions about the types of explanations that can influence phonological processes. As is well known, many phonological processes have phonetic bases; articulatory and perceptual factors in many cases condition phonological phenomena

(Browman and Goldstein 1990, 1992, Hayes 1997, Steriade 1997, among others). In OT, this is captured through phonetic grounding: a constraint can be motivated if it has a phonetic basis, that is, if it expresses a principle of ease of articulation or of maximizing perceptibility (Archangeli and Pulleyblank 1994). It is assumed here that phonetic explanations or motivations can be encoded in the phonology, provided the process is category-neutralizing, categorical or obligatory.

Variation in a process will be allowed in the phonological component provided that it occurs in at least half of the speaker population, or half of the time for a set of speakers. Phonological variation will be expressed as the free ranking or crucial unranking of relevant constraints. As a contrast, phonetic variation will be noted, but it will not be encoded in the grammar.

3. A survey of stress- and foot-sensitive consonantal phenomena

This section presents a survey of 78 languages from 37 language families with stress- and foot-sensitive consonantal phenomena. 3.1 discusses the sources and 3.2 presents an overview of the survey. Sections 3.3-3.9 report the types of consonantal alternations influenced by stress or foot structure found in the literature.

3.1. Survey sources

Some recent cross-linguistic studies of consonantal phenomena report that stress and/or foot structure are conditioning factors for some of these processes; see Lavoie (1996, 2001) and Kirchner (1998) on lenition and fortition; Blevins and Garrett (1998) and Hume (2000) on metathesis; Kehrein (2001) on laryngeal phenomena, and Smith (2002) on stress-attraction processes. These are briefly discussed in 3.1.1 Section 3.1.2 discusses the sources consulted for the present cross-linguistic survey of stress- and foot-sensitive consonantal phenomena.

3.1.1. Previous cross-linguistic studies

Lenition and fortition

Lavoie (1996, 2001) presents an extensive survey of languages with lenition and fortition in syllable onsets, focusing on the interaction between word position and stress on the one hand and lenition/fortition on the other. Lavoie finds that there are many reported instances of word position conditioning lenition and fortition, but very few reported cases where stress conditions consonant alternations. Languages with stress-sensitive lenition include West Tarangan and Somali (approximantization), Old English and Senoufo (voicing), Senoufo (fricativization), and American and Canadian English (flapping). Reported stress-sensitive alternations involving fortition include Yuman (occlusivization and devoicing), Guayabero (fricativization), Urubu-Kaapor (onset lengthening) and Maori (affrication). In two phonetic studies of American English and Mexican Spanish, Lavoie (2001) finds that stress correlates with differences in consonantal realization (such as length or lenition) more often than word position. She concludes that stress affects the realization of consonants phonetically, and that this effect is not reported in descriptions of languages because it is not usually phonologized.

Kirchner (1998) builds his lenition survey from Lavoie (1996). He identifies Djabugai (flapping), Farsi and Middle Italian (voicing), Gojri (gemination), Kupia (flapping and lenition), Pattani (pre-aspiration) and Southern Tati (deletion) as further cases of stress-sensitive lenition/fortition.

Metathesis

Cross-linguistic studies of metathesis report the influence of stress/foot structure for some cases. Blevins and Garrett (1998) distinguish between compensatory and perceptual metathesis. Compensatory metathesis affects vowels especially and consists of the weakening of vowel quality or duration with compensation via transfer of the vowel quality or duration to the stressed position. Perceptual metathesis involves the change in the linear order of a consonant due to perceptual ambiguity about its position; ambiguity occurs especially in unstressed syllables. Blevins and Garrett (1998) identify Cayuga, Mohawk, Oneida, Thompson River Salish, Colville, Shuswap, and Twana as languages with stress-conditioned perceptual metathesis. Additionally, Hume's (2000) metathesis website (www.ling.ohio-state.edu/~ehume/ metathesis) identifies Faroese as a case of stress-sensitive consonantal metathesis (Faroese has also stress-sensitive consonantal deletion).

Laryngeal phenomena

Kehrein's (2001) survey of laryngeal phenomena identifies several examples of laryngeal processes where stress/foot structure is relevant. These include Icelandic, Faroese, Scots Gaelic, Ingush, Ojibwa (pre-aspiration); Shuswap, Twana, Thompson River Salish, Squamish (laryngeal attraction); and Gitksan and Coast Tsimshian (pre/post glottalization). Smith (2002) provides examples of stress attraction by specific consonantal properties—including onsetful syllables or syllables with low sonority onsets, as in Alyawarra, Arandic and Pirahã.

3.1.2. This survey

The present survey includes stress- and foot-sensitive consonantal phenomena identified in the cross-linguistic surveys described above. In addition, it includes further examples gathered from independent grammars and theoretical studies. Any mention of stress or foot structure as conditioning a process was checked in the original source where possible. If the original source did not clearly mention stress or foot-structure as conditioning factors the language was not included. In some cases, checking the original sources brought in additional examples unreported in previous studies.

The resulting survey includes all languages that were found to reportedly and clearly possess consonantal phenomena influenced to some extent by stress and foot structure. The result is 78 languages belonging to 37 different language families. In this survey, languages and dialects have been entered as separate entries in order to be clear in regard to exactly what the process is and in which dialect it occurs (e.g.

Cardiff English vs. London English). In a few cases, languages with properties not directly relevant to this survey have been included for comparison; for instance, cases where stressed nuclei attract a glottal feature from a consonant. These cases are included because at least the original position of this glottal feature is consonantal, and because this process is conditioned by stress.

Section 3.2 presents an overview of the survey. The abbreviations used in this paper are listed under (7).

(7) List of Abreviations

C	Coda; consonant	sg.	Singular
C.C	Gemination	V	Vowel
C	Lengthening	vd.	Voiced
C/O	From coda to onset	vless.	Voiceless
esp.	Especially	.	Syllable boundary
gen.	Genitive	_#	Word final(ly)
inf.	Infinitive	_##	Utterance-final(ly)
N	Nucleus	#_	Word initial(ly)
NM	Not mentioned	##_	Utterance-initial(ly)
nom.	Nominative	`	Low tone
O	Onset	´	High tone
O/C	From onset to coda	¯	Mid tone
opt.	Optional	σ	Syllable
PIE	Proto Indo European	σ̆	Unstressed syllable
pl.	Plural	'σ	Stressed syllable
R	Sonorant	*	diachronic process
S	Stop	§	Section

3.2. Survey overview

The survey presented here is the first step towards identifying how stress and foot structure condition consonantal processes. The languages included are identified according to the following parameters: type of process, prosodic position, and syllable position.

Type of process

(i) *Duration/Magnitude*: Duration and magnitude differences in a consonantal feature or segment that pattern by stress or foot structure. It includes:

(a) *Durational differences:* Consonant duration, Voice Onset Time (VOT) duration.

(b) *Magnitude differences:*

—Flapping (total closure replaced by a quick, sometimes incomplete, closure).

—Fortition (sonority decrease that makes a consonant more consonantal).

—Lenition (sonority increase that makes a consonant more vocalic).
—Secondary articulation (palatalization, velarization, labialization or pre-nasalization on the main consonant articulation).

(ii) *Featural timing:* Distributional variants of a phoneme patterning by stress or foot structure. It includes:

(a) *Pre-glottalization:* The onset of glottalization begins before the onset of the closure of the segment.
(b) *Post-glottalization:* The offset of glottalization begins after or is simultaneous with the release of the consonant. In many instances, stress-sensitive pre-glottalization and post-glottalization are allophonic.
(c) *Voicing:* Variation in the voicing specification of a consonant.

(iii) *Deletion and epenthesis.* Segmental content disappears or is introduced for stress or foot structure considerations.

(a) *Deletion:* Non-pronunciation of an underlying segment.
(b) *Epenthesis:* Pronunciation of a segment not present underlyingly.

(iv) *Attraction:* Movement of a segment or feature to a non-adjacent position.
(v) *Metathesis:* Reversal in the linear order of adjacent segments or features.
(vi) *Assimilation:* A segment becomes more similar to another segment in a specific domain.[4]
(vii) *Dissimilation:* A segment becomes less similar to another segment in a specific domain.

Prosodic position

(i) *Stress:* Stressed syllable or unstressed syllable.
(ii) *Foot structure:* Strong syllable within a foot or weak syllable within a foot.

Syllable position

Coda, onset, or both. Cases where the nucleus is relevant are also discussed.

'Transfer' and 'attraction' are grouped within 'attraction' because in both cases, a feature or segment moves from its original position to another position. 'Fortition', 'lenition' and 'flapping' are grouped within 'durational/magnitude effects' because they involve both durational and magnitude differences. Gemination processes, usually classified under 'fortition', are included under consonant duration processes, because duration seems to be the main correlate.

In some cases, only stress or foot structure are reported to condition a consonantal alternation. Cases where both stress and foot structure coincide are also mentioned in the survey.

[4] This process was not included in González (2003).

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This survey is organized by process type as outlined above. Each section presents an overview in table form of the languages that have that process. Each table has information on which languages undergo the process, the language family to which they belong, a brief description of the process, and the syllable position involved. Languages in the summary tables are organized thematically rather than alphabetically. Genetic language information, if not mentioned or clear in the source, is from the Ethnologue (Lewis et al. 2014). This study focuses on synchronic consonantal alternations and does not aim to provide an extensive relation of historical changes; however, the survey occasionally includes instances of stress- or foot-sensitive diachronic processes. These are marked with * in the summary tables.

Summary tables are followed by as much detail as possible on how each process operates in each language. The process descriptions for each language include cross-references to other sections where the same language is discussed. After the description of each language, each section closes with a brief summary on the processes discussed. All languages discussed are listed in an appendix at the end of this paper, which provides more detail genetic language information and a summary of all stress- and foot-sensitive consonantal phenomena for each language.

This survey includes both segmental and featural consonantal processes, as well as phonetic (variable) and phonological (categorical) instances of consonantal alternation. It excludes contrast-based processes whereby phonological contrasts are maintained in stressed syllables and neutralized in unstressed syllables. These cases have been examined in Beckman (1997, 1998) and analyzed as instances of positional faithfulness, e.g., feature identity to the underlying featural specification of strong positions for perceptual and psycholinguistic reasons. However, if a language showing consonantal variation additionally shows consonantal contrasts in stressed and unstressed syllables, this is noted in the language description in the survey.[5]

The survey is presented in § 3.3-3.10. The main sources for each process are identified, and relevant examples included where available.

3.3. Duration/magnitude differences

3.3.1. Durational differences

Stress-conditioned durational differences have been reported for consonants in onset and coda position and for voice onset time (VOT) in obstruents. Table 1 includes cases of consonant lengthening and VOT differences, as well as gemination. In this paper, *gemination* refers to cases of lengthening that make a consonant tautosyllabic, while *lengthening* refers to cases where the consonant is not tautosyllabic. Lengthening is indicated by [ː] after the relevant segment, and gemination by two timing slots [C.C].

[5] Beckman (1997, 1998) suggest that prominent positions keep segmental underlying specifications more often than non-prominent positions. This would explain the fact that prominent positions have a larger number of contrasts than non-prominent ones, and that they trigger and resist more phonological processes. In this approach, faithfulness to segmental specification is respected preferentially in prominent positions. This investigation focuses on consonantal alternations that are sensitive to stress and/or foot structure and cannot be explained through the notion of contrast.

Table 1

Durational differences[6]

Language	Syllable position	Description	Language family
Spanish	O, C	/C/ → [C:]/[+stress]	Romance
English	O	/C/ → [C:]/[+stress]; VOT longer in 'σ	Germanic
Senoufo	O	/C/ → [C:]/[+stress]	Niger-Congo
Maori	O	/r/, nasals longer in 'σ	Austronesian
Greek	O	/s/ longer #_ in 'σ	Greek
Turkish	O	Longer VOT in 'σ for vless. S	Altaic
Urubu-Kaapor	O	/C/ → [C:]/[+stress]	Tupí-Guaraní
Copala Trique	O	Fortis C, resonants → [C:]/[+stress]	Otomanguean
Guelavía Zapotec	O/C	Fortis C → [C:]/'_C and _#	Otomanguean
Popoloca	O/C	Gemination after stress	Otomanguean
Alutiik Yupik	O/C	Gemination in open initial σ	Yupik
Norton Sound Yupik	O/C	Gemination in open syllables with [ə] Gemination in stems to get stress	Yupik
Gundidj	O/C	Gemination of /m/ after stress	Victorian
Narinari	O/C	Gemination of /l/, /n/ after stress	Victorian
Wergaia	O/C	Gemination of /l/ after stress	Victorian
Italian	O/C C/O	Gemination in 'V#_'V context Gemination in '_#V context	Romance
Somali	O/C	Gemination of vd. S #_ after stress	Cushitic

Spanish: Borzone de Manrique and Signorini (1983) report longer duration of both onsets and codas in stressed syllables in Argentinian Spanish. Lavoie's (2001) study of onsets reports the same result for Mexican Spanish except for /ɾ/. For Peninsular Spanish, Quilis (1981: 276, 281) reports that /l, ʎ/ are longer in stressed syllables than in unstressed syllables. While /ɾ/ is also slightly longer in stressed syllables, /r/ is longer in unstressed syllables than in stressed syllables (Quilis 1981: 292). Quilis (1981) does not specify syllable positions for these results.

6 Kirchner (1998: 306) reports —citing Sharma (1979)— that Gojri (India; Indo-Iranian) has geminate stops and fortis singletons except in onset of stressed syllables. However, Sharma (1979, 2002) mention tone, not stress.

English: Most consonants in English are longer in onsets of stressed syllables than in unstressed syllables (Umeda 1977, Turk 1992, Lavoie 2001). Voiceless stops have longer VOT in stressed syllables (Lisker and Abramson 1967, Turk 1992, Crystal and House 1988, Lavoie 2001).

Senoufo: Onset consonants are longer in stressed syllables than in unstressed syllables (Mills 1984: 119). In contrast to English and Spanish, vowels in Senoufo are not lengthened under stress.

Maori: /r/ is reported to have longer contact, and nasals to lengthen in onsets of stressed syllables (Bauer 1993: 555). For related processes, see § 3.3.3 and 3.4.2.

Greek: Word-initial /s/ is reported to be longer when the syllable is stressed rather than unstressed (Botinis, Fourakis and Bannert 2001).

Turkish:[7] Aspiration is longer in stressed onsets in Turkish (Jonathan Barnes, p.c.).

Urubu-Kaapor: Oral stops /p, t, k, kʷ, ʔ/ lengthen in onsets of primary-stressed syllables (8a-c).[8] Lengthening does not occur in secondary-stressed syllables (8c) or in primary-stressed syllables for nasals, approximants or fricatives (8d-f).

(8) Urubu-Kaapor lengthening (from Kakumasu 1986: 399, 401; IPA)[9]

(a) /katu/	[ka.ˈtːu]	'it is a good'	(d) /uruma/	[u.ru.ˈmã]	'duck'
(b) /kaʔa/	[ka.ˈʔːa]	'forest'	(e) /waruwa/	[ˌwa.ru.ˈwa]	'glass'
(c) /nupãta/	[nu.ˌpã.ˈtːa]	'he will hit'	(f) /ixa/	[i.ˈʃa]	'it is a fact'

Urubu-Kaapor consonants are /p, t, k, kʷ, ʔ, m, n, ŋ, s, ʃ, h, r, w, j/. Codas are allowed (Kakumasu 1986: 399). Primary stress occurs in word-final syllables. Secondary stress is usually (but not always) assigned to every second syllable counting back (Kakumasu 1986: 401). For related processes, see § 3.4.1.

Copala Trique: Resonants and fortis (voiceless) consonants are reported to lengthen before a short, stressed vowel (Hollenbach 1977: 37). Copala Trique has final stress. The stressed syllable has more tonal, consonantal and vowel contrasts than unstressed syllables (Hollenbach 1977, Beckman 1998: 130). Fortis consonants and affricates occur only in stressed syllables. These syllables are also the only syllables that can have a coda (/ʔ/ or /h/). Long vowels are extra-long in this position, and short vowels shorter. If the vowel is short, a fortis or resonant onset of the stressed syllable is lengthened.

The consonant inventory of Copala Trique is /p, b, t, d, k, g, ʔ, s, z, ʃ, ʒ, ʂ, r, h, ts, tʃ, ʈʂ, m, n, l, j, w/ (Hollenbach 1977: 36). Stops and sibilants can be fortis (voiceless) or lenis (voiced). Fortis consonants are unaspirated and slightly lengthened. Lenis consonants can vary between voiced and voiceless in unstressed syllables (see section § 3.4.1). /r/ is grouped with the lenis fricatives, probably because it shares

[7] Thanks to Sharon Inkelas for bringing this case into my attention.

[8] Lavoie (2001: 45) mentions that this also occurs utterance-finally; cf. Kirchner (1998: 313).

[9] Lenghening in Kakumasu (1986) is represented by consonant doubling; here I use the symbol [ː].

some allophonic properties with them. Additionally, /ʂ/ has an allophonic retroflex trill. See § 3.3.3 and 3.4.1 for related processes.

Gualavía Zapotec: Gualavía Zapotec has a contrast between fortis and lenis consonants. Fortis consonants—/p, t, k, ts, ʧ, ʈʃ, s, ʂ, ɕ, m̠, n̠, l̠/—are generally longer and tenser than lenis consonants.[10] Lenis consonants —/b, d, g, dz, dʒ, z, ʑ, ʝ, m, n, l, ɾ/— make a preceding oral vowel lengthen and have a voiceless release before a pause—except for /m, n/. All consonants can occur in codas except for /ʈʃ/.

Guelavía Zapotec has both stress and tone. There is one stress per word, usually in the penultimate syllable. Stressed syllables usually have higher pitch. Fortis consonants are reported to 'lengthen' before a pause and intervocalically after stressed vowels. Fortis stops and nasals also 'lengthen' after stressed vowels before /j, w/ or before a voiced consonant (Jones and Knudson 1977: 166). 'Lengthening' does not occur word-initially or in onset of stressed syllables. The fact that the context for 'lengthening' in Guelavía Zapotec is after stress rather than in stressed syllables suggests that this is gemination, not lengthening. Thus, the examples in (9) show consonant gemination (relevant segments in bold; gemination in underline).

(9) Guelavía Zapotec (from Jones and Knudson 1977: 164-175)

	Gemination after stress		*No gemination in stressed syllables*	
(a)	[ˈɾa**p.p**aˀ]	'I have'	[ɕa.ˈ**p**in.naˀ]	'my pine tree'
(b)	[ˈɕi**t.t**jaˀ]	'my onion'	[w̝e.ˈ**t**íp.pô]	'wasp'
(c)	[ˈɕl̠a**m.m**aˀ]	'my boss'	[ˈdat.**m**ám]	'grandfather'
(d)	[ˈɕpa**k.k**aˀ]	'my tadpole'	[ˈ**k**aːldt]	'broth'
(e)	[ˈdɛ**t.ts**aˀ]	'my back'	[ˈ**ts**ɨːŋ]	'there are ten (objects)'
(f)	[ˈna**ɕ.ɕ**ɨŋ]	'it is sweet'	[ˈ**ɕ**a.gaˀ]	'my tree'
(g)	[ɕaˈpi**n.n**aˀ]	'my pine tree'	[ˈ**n**an.naˀ]	'I know'

Additional durational processes occur in stressed vowels. Stressed oral vowels lengthen before lenis consonants, as in /ˈra.goʔ/ [ˈɾ**a**ː.ɤoˀ] 'you bite'. Stressed laryngeal vowels become interrupted, as in /ˈtiˀ.sj/ [ˈtɨˀɨ.sj̥] 'body'. In the last case the fortis consonant is not lengthened in spite of being intervocalic and occurring after stress. All of these phenomena suggest that stressed syllables in Guelavía Zapotec are heavy: they either have a long vowel or a coda. Vowel lengthening occurs before lenis consonants while gemination occurs for fortis consonants immediately after stress.

Popoloca: In Los Reyes Metzontla Popoloca the main correlate of stress is duration, especially for consonants (Veerman-Leichsenring 1984: 21; cf. Stark and Machin 1977: 79). The consonant inventory of Popoloca is shown in (10). Stress generally falls on the penultimate syllable of the word. Stressed syllables have a coda or a long vowel or diphthong.

[10] Jones and Knudson (1977) do not discuss the exact nature of fortis /m̠, n̠, l̠/ vs. lenis /m, n, l/.

(10) Popoloca consonants (from Veerman-Leichsenring 1984: 34; IPA)[11]

Stops	*Affricates*	*Fricatives*	*Sonorants*
p b t d k g	t̪s tʃ ʈʂ	f s x	l r m n m̥ n̥ w j
t^{h} k^{h}	t̪s^{h} tʃ^{h} ʈʂ^{h}		
^{m}b ^{n}d ^{ɲ}ɟ ^{ŋ}g		^{n}z ^{ŋ}h	^{n}r

Onset fricatives, liquids, approximants and voiced nasals are geminated after a stressed syllable (Veerman-Leichsenring 1984). Consonantal clusters and complex consonants, such as pre-nasalized, aspirated, and voiceless nasal consonants are 'disintegrated'; they are decomposed into a coda and an onset element (11).[12] Unaspirated stops and affricates are pre-glottalized in the same position (§ 3.4.3). See also § 3.4.1 and 3.6.1.

(11) Popoloca durational processes[13]

Gemination	(from Veerman-Leichsenring 1984: 45-7; IPA)			
(a) Fricatives	['kɑ**f.f**é]	'coffee'	['^{n}zɛ̀**s.s**ɛ̀]	'sand'
(b) Liquids	[ku.'pá**l.l**o]	'butterfly'	['^{n}dà**r.r**à]	'thin'
(c) Approximants	['ti**j.j**é]	'night'	['^{ŋ}gí**w.w**à]	'popoloca'
(d) Voiced nasals	['tú**m.m**ɛ́]	'money'	['tù**n.n**ĩ]	'hail'

'Disintegration'	(from Veerman-Leichsenring 1984: 48-9, 54; IPA)			
(a) Pre-nasal stops	[tù'ru**m.b**à]	'spinning top'	['kà**n.d**à]	'nopal'
(b) Pre-nasal fricatives	[ku.'tɛ́**n.z**ò]	'goat'	['ì**ŋ.ɦ**ũ:]	'six'
(c) Pre-nasal liquids	['ì**n.r**í]	'young single woman'		
(d) Aspirated stops	['^{n}dà**t.h**o]	'weapon'	['tù**k.h**à]	'potato'
(e) Aspirated affricates	['kà**t̪s.h**à]	'green bean'	[nĩ**ʈʂ.h**ɛ̀]	'clothes'
(f) Vless. nasals	[ku.'tũʔ**h.n̥**ũ]	'turkey'		

Alutiiq Yupik: Stress-sensitive gemination occurs in Alutiiq Yupik, a left-to-right iambic system with main stress on the leftmost foot (Van de Vijver 1998: 145-6). Closed initial syllables are always stressed (as in ['an.ci.ˌqua] 'I'll go out'), unlike heavy syllables in the rest of the word (as in ['ap.qaɣ.ˌlaa.qa] 'I always ask her'). If the first syllable is light and the second heavy, the onset of the second syllable geminates. This closes the first syllable and allows it to be stressed (12). Related processes are discussed in § 3.3.3.

(12) Alutiiq Yupik (from Van de Vijver 1998: 145)

(a) atii [('a**t**.) (ˌ**t**ii)] 'his father'
(b) ataa [('a**t**.) (ˌ**t**aa)] 'he put it on'

Norton Sound Yupik: Norton Sound Yupik is also a left-to-right iambic system. Vowels in open stressed syllables are lengthened (13a). However, if the vowel

[11] /t̪s, ʈʂ/ are dental and lamino-palatal respectively. /b, d, g, f/ only occur in non-assimilated Spanish loans (Veerman-Leichsenring 1984: 34ff).

[12] For voiceless nasals, the coda element can be /h, ʔ, x/ (Veerman-Leichsenring 1984: 48).

[13] Here and throughout, middle tone on Popoloca vowels will not be marked.

is [ə], vowel lengthening does not occur; rather, the onset of the following syllable is geminated and thus the syllable is closed (13b).

(13) Norton Sound Yupik (I) (from Van de Vijver 1998: 133, 140)

(a)	qayapigkani	[(qa.'jaa.) (pix.ˌkaa.) ni]	'his own future authentic kayak'
(b)	at pik	[(a.'təp.) pik]	'real name'

In a number of Yupik languages, including Norton Sound Yupik, monosyllabic stems followed by suffixes are closed in order to be stressed. If the stem syllable is open, the onset of the following syllable is geminated (Van de Vijver 1998: 114-5, 130-1) (14). For related processes see § 3.3.3.

(14) Norton Sound Yupik (II) (Van de Vijver 1998: 130-1)

	Stem	*Stem plus suffix*	*Gloss*
(a)	kuvə	'kuv.vuq	'it spills'
(b)		'kuv.lu.ni	'(it) spilling'

Gundidj: Data about this extinct Victorian language is scanty, but /m/ is long and tense intervocalically after a stressed vowel. Hercus (1986: 159-160) interprets this as gemination since a syllabic break occurs in this context. Gemination does not occur after unstressed vowels. Examples are /dameri/ ['tam.me.rɪ] 'sheep'; cf. with /guremug/ ['ku.rə.mək] 'possum'. No indication is given about the regular location of stress, but in most Victorian languages it falls on the first syllable, and that might also be the case in Gundidj.

Narinari: As in Gundidj, there is not much data available for this extinct language. /l/, /n/ appear to geminate intervocalically after a stressed vowel (15) (Hercus 1986: 154). Narinari has initial stress (Hercus 1986: 155).[14]

(15) Gemination and lengthening in Narinari (Hercus 1986: 153-154)

(a)	/gali/	['gal.lɪ]	'dog'	/lajurg/	['lajurg]	'woman'
(b)	/dinaŋ/	['din.naŋ]	'foot'	/nari/	['na:rɪ]	'no'

No examples occur with intervocalic /l/, /n/ preceding a stressed vowel, but cf. the realization of intervocalic /l/, /n/ following unstressed vowels, where gemination occurs, with the realization of word-initial /l/, /n/, where gemination does not occur.

Wergaia: Intervocalic /l/ is long in Wergaia, and it geminates in this position after the main stressed vowel (16a, b). Stress is initial and vowels in main stressed syllables are long. Gemination of /l/ does not occur after /u/ (16c) (Hercus 1986: 77, 78). See also § 3.4.1.

(16) Gemination of /l/ in Wergaia (from Hercus 1986: 77; IPA)

(a)	/wile/	['wɪl.le]	'possum'
(b)	/gelalag/	['gel.lʌ.l·ak]	'Major Mitchell cockatoo'
(c)	/buledj/	['bu.letj]	'two'

[14] Gemination of /l/ and /n/ appears to have occurred in the same context in Wadiwadi and Ledjiledji. Evidence comes mainly through spelling, as Wadiwadi *chellingoo* 'tongue', *liannoo* 'teeth'; and Ledjiledji *nginna* 'you', and *jennagi*, *chinnangi* 'foot' (Hercus 1986: 158).

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Italian: Italian has a contrast between single and geminate consonants word-medially (17a). Single consonants geminate across word boundaries provided the last syllable of the first word is open and stressed (Nespor and Vogel 1979, Chierchia 1982, Salterelli 2003, among others).[15] This is known as *raddoppiamento (fono-)sintattico* (17b-d) (geminates underlined; relevant segments in bold).

(17) Italian (from Nespor and Vogel 1979 and Saltarelli 2003 and p.c.)

(a)	/pa**l.l**a/	'ball'	vs.	/pa.**l**a/	'shovel'
(b)	metá torta	[meˌta**t.** ˈ**t**orta]	'half a cake'		
(c)	sará cotto	[saˌra**k.** ˈ**k**otto]	'it will be cooked'		
(d)	cittá vecchia	[tʃitˌta**v.** **v**ekkja]	'old city'		
(e)	amor mio	[aˌmo**r** ˈ**m**io]	'my love'		
(f)	cittá sporca	[tʃit.ˌta**s.**ˈ**p**orka]	'dirty city'		
(g)	metá strada	[meˌta**s.**ˈ**t**rada]	'half way'		

If the previous word ends in a consonant, gemination does not occur since this consonant is a proper coda (17e). Gemination does not occur either when the second word begins with an /s/ + consonant cluster, since the /s/ resyllabifies as coda of the preceding syllable (17f, g).

Italian has a second type of gemination, known as 'backwards' or 'inverse' gemination. It occurs across word boundaries in loanwords, neologisms and acronysm that end in a consonant (Chierchia 1982; Saltarelli 1970, 2003). In inverse gemination, the coda of a stressed syllable doubles to provide an onset for an immediately following onsetless syllable (18) (geminates underlined; relevant segments in bold).

(18) Inverse gemination (from Saltarelli 2003; IPA)

(a)	tram elettrico	[ˌtra**m.m**e.ˈlet.tri.ko]	'electric tramway'
(b)	Hotel Este	[o.ˌte**l.ˈl**es.te]	*name of a hotel*
(c)	Milan-Inter	[ˌmiː.la.ˈ**n**in.ter]	*name of a football match*
(d)	Hotel Patria	[o.ˌte**l.**ˈ**p**a.trja]	*name of a hotel*
(e)	sport estivo	[ˌspo**r.t**es.ˈti.vo]	'summer sport'

Inverse gemination occurs after stressed syllables (18a, b). When an unstressed syllable has a coda and an onsetless syllable immediately follows, the coda resyllabifies as onset and no gemination occurs (18c). Gemination fails to occur in two more cases: when the following syllable has an onset (18d) and when the last syllable of the first word has a complex coda (18e). In this last case, the second consonant of the coda resyllabifies as onset of the following syllable.

Stress-sensitive gemination in Italian is related to vowel lengthening, which occurs in codaless stressed syllables: /kasa/ [ˈkaː.sa] 'house' vs. /kassa/ [ˈkas.sa] 'box' (Saltarelli 2003). Both gemination and vowel lengthening appear to be the result of a requirement for heavy stressed syllables in Italian (Chierchia 1986, Saltarelli 2003).

[15] Nespor and Vogel (1979) report a syntactic restriction for this process whereby the first word has to *m*-command the second word. This is empirically unconfirmed. For discussion, see Loporcaro (1999: 20-3) and Saltarelli (2003).

Somali: Somali also appears to have stress-sensitive gemination across words (Armstrong 1964). Somali has four main tones: high, mid, low, and falling. In words with more than one syllable, stress falls on the syllable with high or falling pitch. If syllables have the same tone, stress is similar in all syllables. The consonant inventory of Somali is given in (19). Somali has phonemic geminates (or double consonants) word-medially for /l, r, n, d, ɖ) and word-finally for /l, r, n/ (20a, b). In connected speech, a word-initial consonant (especially a voiced stop) geminates after a stressed syllable ending in a short vowel and pronounced usually with high tone (20).[16]

(19) Somali consonant inventory (from Armstrong 1964)[17]

Stops	*Fricatives*	*Sonorants*
b, t, d, ɖ, k, g, ɢ, ʔ, tʃ	f, s, ʃ, x, ħ, ʕ, h	m, n, l, r, j, w

(20) Somali (from Armstrong 1964; IPA)[18]

(a)	[kɛ.**l**i]	'single'	[kɛ**ll**i]	'kidney'
(b)	['báa.**ɖ**aj]	'I searched'	['báa**ɖɖ**aj]	'she searched'
(c)	['háawl baan	ʔú**ɖ.ɖ**í'má.najjaa]	'I am dying of hard work'	
(d)	['há**g.g**alo]	'Let him go in'		
(e)	['ká**ɢ.ɢ**àad]	'Take from'		

Somali also has lenition of voiced stops, especially after a stressed syllable (Armstrong 1964, Lavoie 2001: 36). See § 3.3.4 for more details.

Summary: This section discussed longer consonantal and VOT duration and gemination. VOT is longer in stressed syllables than in unstressed syllables. Consonants are longer in stressed syllables than in unstressed syllables. In most cases, this applies to onset consonants; but this might be because codas are restricted or missing in some languages (as in Copala Trique). Onsets immediately following stressed syllables geminate in order to provide a coda for the preceding stressed syllable. This occurs within words or across word boundaries. In the case of Italian, coda gemination across word boundaries is also attested in stressed syllables to provide an onset for the following syllable. No cases of durational processes affecting codas exclusively have been found; it is unclear that this is a significant gap. Most of the languages with consonant or VOT lengthening and gemination show additional stress-related durational effects, as shown in the following sections.

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[16] Additionally, /n/ and /l/ are reported to be weak to the point of almost eliding after long vowels—as in /saa<u>n</u>/ 'skin, hide (of camel, cow)' —and long and strong after short stressed vowels— as in /sa<u>n</u>/ 'leather'. It is unclear from the source that this phenomenon is related to stress. It is plausible that this pattern is related to moraicity instead: when the vowel is long, it counts as two moras, and the coda consonant is weak. If the vowel is shorter, the coda is moraic, thus being pronounced as strong and long. Armstrong (1964) also reports that after long vowels, /r/ has fewer taps (about three) than after short vowels (four or five taps). Stress is not mentioned in this case, but it is the same environment for alternations witnessed with /n/ or /l/.

[17] /t, d/ are dental. /ɖ/ is more palato-alveolar than retroflex (Armstrong 1964).

[18] Armstrong (1964) is not paginated, so the page numbers are not included here.

3.3.2. Flapping

Flapping involves the shortening of the occlusion of a segment and possibly voicing. It can occur without sensitivity to stress, as in Tagalog (Schachter and Otares 1972). Flapping occurs in various languages in unstressed syllables, as summarized in Table 2.

Table 2

Flapping[19]

American English	O	/t, d, n/ → [ɾ]/ˈV_V (obligatory); V_V (opt.)	Germanic
Canadian English	O	/t, d, n/ → [ɾ]/ˈV_V (opt.)	Germanic
Djabugai	O	/r/ → [ɾ]/ˈV_V	Pama-Nyungan
Senoufo	O	/d/ → [ɾ]/._V	Niger-Congo
Kupia	O	/ʈ/ → [ɽ]/V._V (opt.)	Indo-Iranian

American and Canadian English: Flapping affects /t/, /d/, and /n/ in onsets of medial unstressed syllables (Kiparsky 1979, Kahn 1980, Borowsky 1986, Hammond 1999, among others). Lavoie (2001) reports that flapping of /n/ is more ambiguous than flapping for /t, d/, since the tongue-tip gesture is reduced but not the velum gesture. Other segments are reported to be flapped; Turk (1992, 1993) and references therein report shortening of all oral stops except /g/ in flapping environments. Turk (1992: 128) interprets these results as probably meaning that flapping in English is caused by an 'underlying timing mechanism'.

Flapping typically occurs intervocalically, but it can also be found after a sonorant and before a vowel (*ˈforty, tenting*). It typically occurs word-medially between a stressed and an unstressed vowel (*ˈmetal, poˈtato, ˈrider, ˈwinter*).[20] Flapping is optional between two unstressed vowels (as in *proˈvocative, ˈparody*), and word-finally between two vowels regardless of stress (*ˌnot at ˈall, ˈprivate ˈairplane*). Flapping does not occur in stressed syllables (*aˈttack*), non-final codas (*ˈatkins, ˈatlas*), or word-initially (*ˈtake, toˈmorrow*) (Kahn 1980, Turk 1992).[21]

Flapping in English is not a categorical process; the probability of its occurrence depends both on stress and phonetic context. Zue and Laferriere (1979) found that flapping of /t/ in a ˈV_V context occurs 99% of the time. The probability of flapping

[19] Another possible instance of stress-sensitive flapping is Pattani (Sino-Tibetan), where /ɖ/ is realized as /ɽ/ in medial and final position. Sarma (1982) does not discuss stress in this process, although it generally falls on the first syllable. As with other languages in Table 2, Pattani shows stronger aspiration in stressed syllables (§ 3.4.2).

[20] The /t/ in winter deletes concomitant with the flapping of /n/.

[21] Flapping of /t/ is reported to occur in Cardiff English in medial position between voiced sounds, as in *better* [ˈbɛ.ɾə] and *hospital* [ˈɑs.pɪ.ɾl] (Collins and Mees 1990: 90). In this position /d/ lenites to fricative, as /b/ and /g/ It is possible that this pattern have the same stress or foot conditioning as flapping in American and Canadian English.

for /t/ between two unstressed or reduced vowels lowers to 33%; aspiration of /t/ is more common (66%) in this context. In a context like 'Vn._V, /t/ has a probability of flapping of 14%; this is the same probability that the /t/ deletes in this context. A realization with aspiration is far more common (67% with /n/, and 5% with nasalization of the preceding vowel and nasal deletion). Results for /d/ are less clear, since unstressed /d/ has longer closure than a flap but no release, or both a short duration and a strong release (see Zue and Laferriere 1979 for details).

Some authors suggest that flapping in English is foot-sensitive (Kiparsky 1979, among others). English is a trochaic language, and flapping would occur foot-medially since the second syllable of a binary trochaic foot is unstressed. Alternatively, flapping would be the compensatory shortening for the occurrence of a long stressed vowel occurring earlier in the foot (Turk 1992).

Flapping in Canadian English is similar to American English, but it is considered to be more optional (de Wolf and Hasebe-Ludt 1987).

Djabugai: /r/ is pronounced as [ɾ] between a stressed and unstressed vowel; the word /ɡaraj/ 'to come' is pronounced ['ɡa.ɾaj]. Patz (1991: 253) notes that reduction to [ɾ] is more obvious between two low /a/s, less obvious between identical high vowels (as in /biri/ 'near') and least obvious between different vowels (as in /dira/ 'teeth').[22] In this last position [r] and [ɾ] are in free variation. It is plausible that in Djabugai flapping actually consists in the reduction of number of taps in unstressed position, as in Mexican Spanish, where trills have fewer taps in unstressed positions than in stressed positions (Lavoie 2001: 143). See § 3.4.1 for related processes.

Senoufo: /d/ is flapped word-medially in the onset of unstressed syllables (Mills 1984). See also § 3.3.1, 3.3.4, and 3.4.1.

Kupia: The retroflex coronal /ʈ/ is optionally flapped intervocalically in onsets of unstressed syllables; e.g. /caːʈu/ 'leg' can be both ['tsaː.ʈu] or ['tsaː.ɽu]. In contrast, /ɖ/ is always flapped intervocalically (Christmas and Christmas 1975: 18).[23] See also § 3.3.4.

Summary: Stress-sensitive flapping occurs word-medially in onsets of unstressed syllables. In some languages the preceding vowel has to be stressed. In the case of English, where flapping has been best studied, flapping occurs more often between vowels, especially when the first vowel is stressed; but it is also possible in onset of unstressed syllables, after a coda sonorant in a stressed syllable. Languages with stress-sensitive flapping frequently have additional stress-related consonantal processes such as spirantization, longer duration of consonants or VOT, and voicing differences. Typical segments undergoing stress-sensitive flapping are /t/ (in English varieties), /d/ (in English and Senoufo), /n/ (in English), /r/ (in Djabugai), and /ʈ/ (in Kupia). All of these segments have a tongue-tip articulator in common.

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[22] Djabugai has a three-way vowel contrast /a, i, u/. For more details on its phonological system, see § 3.4.1.

[23] Kirchner (1998: 308) reports the environment of /ɖ/ as obligatory in onset of unstressed syllables, but Christmas and Christmas (1975: 18) do not mention stress as being relevant in this case.

3.3.3. Fortition

In this paper, the term *fortition* is used to refer to a decrease in consonant sonority, and *lenition* to an increase in consonant sonority. Fortition makes a consonant more consonantal and thus 'stronger', while lenition makes a consonant more vocalic and thus 'weaker' (Vennemann 1988). Usually the identification of a process as fortition or lenition is based on what the analysis posits as the basic or underlying form. If the basic form is more sonorous than the non-basic form, the process falls under 'fortition'. If the basic form is less sonorous than the non-basic form, then the process involves 'lenition'. Thus, which allophones are 'stronger' and 'weaker' is relative.

Fricativization of approximants, occlusivization of fricatives, affrication of stops, gemination of singletons, and devoicing of voiced segments are considered instances of fortition because they involve a decrease in sonority (Lavoie 2001, Kirchner 1998). In this survey, gemination is discussed in § 3.3.1 under durational differences, and devoicing is discussed in § 3.4 under featural timing.

Fortition may be morphologically conditioned, as in Irish. A number of fortition cases are reported to be conditioned by stress and foot structure, including fricativization, affrication occlusivization and strengthening. These are summarized in Table 3.

Table 3

Fortition

Norton Sound Yupik	O	/w, j, l/ → [v, z, l]/foot-initially	Yupik
Alutiiq Yupik	O	Consonants fortify #_ and foot-initially	Yupik
Guayabero	O	[w] fricativizes in 'σ	Guahiban
Maori	O	/p, t, k/ → affricate/'_V	Austronesian
West Tarangan	O	/w, j/ → [g, dʒ]/#_ , '_V	Austronesian
Cashinawa	O	/w/ strong articulation/'_V	Panoan
Farsi	O	/ʔ/ stronger plosion/'_V	Indo-Iranian
Squamish	O	/Rˀ/ stronger [ˀ] when stressed/post-stressed	Central Salish
* Yuman	O	/v/ → /p/, /j/ → /d/ in σ̆	Hokan

Norton Sound Yupik: This dialect of Central Alaskan Yupik shows foot-sensitive fortition of fricatives. Underlying /w, j, l/ are fortified to [v, z, ɮ] in light syllables after a stressed closed syllable (Jacobson 1985: 32, Van de Vijver 1998: 43). [v, z, ɮ] are 'fortis' fricatives and [w, j, l] 'lenis' fricatives; here they will be referred to as fricatives and approximants respectively.[24]

[24] According to Jacobson (1985), [v, z, ɮ] have a stronger fricative nature while [w, j, l] are more sonorant.

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Norton Sound Yupik is a left-to-right iambic system with main stress in the leftmost foot and no final stress (Van de Vijver 1998: 125-132). Closed syllables are light except word-initially; syllables with long vowels are heavy. The stress and foot pattern of Norton Sound is also discussed in Jacobson (1985), Leer (1985), Kager (1993), Hayes (1995), and Baković (1996). Van de Vijver (1998) analyzes the context for occurrence of the fricative variants as foot-initial position.[25] Some examples are given in (21).

(21) Norton Sound /w, l, j/ (from Van de Vijver 1998: 43-4, 132)

	Fricatives		*Approximants*	
(a)	(ma.'juɤ) (v̱ik)	(d)	('at.) (xaɤ. w̱ik)	'place to go up/ down'
(b)	(ma.'juɤ) (ẕux.tuq)	(e)	('at.) (xaɤ.ˌj̱ux.) tuq	'he wants to go up/down'
(c)	(ma.'juɤ) (ɮ̱u.ni)	(f)	('at.) (xaɤ.ˌḻu.) ni	'(he) going up/down'[26]

Since approximants can occur medially in onsets of unstressed syllables (21d), and fricatives can occur in unstressed syllables (21a-c), fortition is not stress-sensitive, but foot-sensitive. Fricative allophones occur foot-initially and approximant allophones foot-medially. Since Norton Sound is an iambic system, there is a mismatch in the distribution of fortition for stress and foot structure; fortition occurs in foot-initial position, which is always unstressed; fortition does not occur foot medially, which is usually —but not always— a stressed position. This mismatch is expected in iambic systems, since foot boundaries and stress do not correspond for processes involving onsets; there are two competing strong positions: stressed syllables, and foot-initial syllables. In trochaic systems there is no mismatch, since stress falls on foot-initial syllables. This is exemplified schematically in Figure 1. Norton Sound Yupik is also discussed in more detail in section 4. For related processes, see § 3.3.1.

Trochaic		**Iambic**	
Foot-initial	Foot-medial	Foot-initial	Foot-medial
('σ . σ)		(σ . 'σ)	
Stressed	Unstressed	Unstressed	Stressed

Figure 1

Stress and footing in onsets of trochaic and iambic systems

Alutiiq Yupik: Foot-initial fortition is also found in the Alutiiq dialects of Yupik (Koniag and Chugach). Alutiiq Yupik is a left-to-right iambic system with main stress in the leftmost foot. As in Norton Sound, closed syllables are heavy only when

[25] But cf. Van de Vijver (1998: 132), where it is reported that lenis consonants occur foot medially and fortis consonants elsewhere [i.e., fortis can occur foot-finally in addition to foot-initially]. If this is so, this pattern would be an instance of foot-medial lenition rather than foot-initial fortition.

[26] According to Van de Vijver (1998: 126), the fact that the fricative in (21d) is lenis indicates that the final syllable is footed.

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word-initial (Cf. 22b, d). Syllables with long vowels or diphthongs are heavy and stressed (22b) (Van de Vijver 1998: 141-152).

Fortition occurs for all onset consonants and involves 'pre-closure' and complete lack of voicing for voiceless consonants. Fortition makes consonants 'more audible' (Van de Vijver 1998: 143, based on Leer 1985, 1989). According to Van de Vijver (1998) and references therein, fortition occurs both foot-initially and word-initially (22) (fortis consonants are in bold).

(22) Alutiiq Yupik (from Van de Vijver 1998: 143-4, 176; based on Leer 1985)

(a)	taqumaluni	(**t**a.'qu.) ma. (**l**u.ˌni)	'apparently getting it done'
(b)	anciqua	[('an.) ci.(ˌ**q**ua)]	'I'll go out'
(c)	akutaq	[(a.'ku.) taq]	*A food*
(d)	iqllunirtuq	[('iq).ĺ̥u.(**n**ix.'tuq)]	'He stopped lying'
(e)	apqarlaaqa	[('ap). qaɤ.(**l**áa).qa]	'I always ask her'
(f)	apqarlaanka	[(áp).qaɤ.(**l**án).ka]	'I always ask them'
(g)	tannərlirsuqutaquni	[(**t**án*)*.nəx.(**l**ix.sú.)	
		qu. (**t**a.qú.) ni]	'If he (refl.) is going to hunt bear'
(h)	kumlaciwilijaqutaquniki	'if he (refl.) is going to undertake constructing a freezer'	
	Koniag speakers	[('**k**um.) (**l**a.ˌci.) (**w**i.ˌli.) ja. (**q**u.ˌta.) qu. (**n**i.ˌki)]	
	Chugagh speakers	[('**k**um.) la.(**c**i.ˌwi).li.(**j**a. ˌqu). ta. (**q**u. ˌni.) ki]	

Fortition occurs foot-initially in disyllabic feet with light syllables (22a), in monosyllabic heavy feet (22b), in feet formed by two closed syllables (22d) and in monosyllabic (but bimoraic) feet even if the vowel is phonetically shortened (22f). Fortition does not occur in unfooted closed syllables (22c). Even if stress assignment and footing differ in Koniag and Chugag dialects (22h), fortis consonants correlate with foot-initial position in both. Fortition does not correlate with stress, since it can occur in stressed and unstressed syllables alike (22a, b).

For Van de Vijver (1998: 143), stressed heavy syllables (as in 22b) are not footed but form a stress unit where fortition can apply. It is assumed here that stressed heavy syllables are footed under a binary foot analysis and thus, fortition occurs in foot-initial position in all cases. Van de Vijver (1998) also assumes that word-initial closed syllables are footed with a catalectic syllable. This would make the heavy syllable foot-medial; fortition still applies in this case. Under a footing where this syllable forms its own foot 'word initial' fortition falls under 'foot initial' fortition.

Summarizing, fortition in Alutiik Yupik, as in Norton Sound Yupik, correlates with foot structure rather than stress. For related processes, see § 3.3.1.

Guayabero: Stress-sensitive fricativization of /w/ is reported in Guayabero (Keels 1985; see also Lavoie 2001, Kirchner 1998). The consonant inventory of this language includes /p, b, t, d, k, ʔ, ɸ, s, x, h, tʃ, m, n, r, l, w, j/ (Keels 1985: 58). All consonants except /b, j/ can occur word-finally and syllable-finally in clusters. Clusters occur in stressed syllables only. Stress is not predictable and falls on the last or penultimate syllable of the stem.

/w/ fricativizes to [β] before a stressed front vowel, and after a front or high central vowel (Keels 1985: 75). Keels (1985: 61, 64) reports that /w/ has a bilabial fricative allophone 'contiguous to stressed front vowels'. Additionally, /w/ is realized as a high back rounded offglide [ᵘ] 'in a syllable-final margin' after a back or low vowel (Keels 1985: 75). In other contexts, /w/ is pronounced as [w] (23).

(23) Fricativization of /w/ to [β] (from Keels 1985: 64, 73-5; IPA)

(a)	wíam	[ˈβ̠iᴧm]	'whip-worms'
(b)	nawél	[nʌ.ˈβ̠el]	'the Guaviare River'
(c)	wát	[ˈwat]	'older brother'
(d)	nehxaéhw-as	[nɛh.ˈxæh.wʌs]	'he is saddened'
(e)	babéh-tʃiw	[bʌ.ˈbeh.tʃɪβ̠]	'evil men'
(f)	puéwa	[ˈpʰ ᵘɛ.β̠ʌ]	'all'
(g)	sasíʔw-it	[sʌ.ˈtʃiʔ.β̠ɪt]	'a hummingbird'
(h)	nów-x	[ˈnʷo̠ᵘx]	'I cry'

These examples show that in onset preceding a front vowel /w/ is fricativized (23a, b); in onsets before a non-front vowel or onsets of unstressed vowels fricativization does not occur (23c, d). /w/ is also fricativized in coda and in onset after a front vowel (23e, f). In coda after a round vowel, /w/ is realized as [ᵘ] (23f, h). In (23g), fricativization occurs in onset of an unstressed syllable preceding a front vowel; however, there is a front vowel in the preceding syllable, which is probably causing fricativization. Unfortunately, no examples are provided of onset /w/ in unstressed syllables before a front vowel where a preceding front or central vowel does not influence the choice of allophone.

Guayabero has also stress-sensitive allophones of /ʔ, h/, which 'may be realized with voiced or voiceless partial rearticulation of the preceding vowel' in coda of stressed syllables (Keels 1985: 72, 74) (24).

(24) Guayabero: allophonic laryngeal consonants (Keels 1985: 72, 74)

(a)	biaʔ-t	[ˈbɨᵊʔ̠ᵊt], [ˈbɨᵊʔ̠t]	'a tooth'
(b)	cóʔ-t	[ˈtʃʷo̠ʔ̠ᵒt], [ˈtʃʷo̠ʔ̠t]	'an ear'
(c)	koʔtíya	[kʰɔʔ̠.ˈtʰi.jʌ]	'fingers'
(d)	paʔɨwlax	[pʰʌ.ˈʔ̠ɨ.βlʌx]	'jealousy'
(e)	móiht	[ˈmɔ.ᴵ͡ht], [ˈmɔ.ᴵ͡hᴵt]	'he sleeps'

Additionally, in unstressed syllables, /h/ is 'partially or completely coarticulated with the unstressed final vowel of a preceding vowel cluster if /h/ occurs syllable finally or when the vowel has the same quality as the ensuing vowel if /h/ occurs syllable initially' (Keels 1985: 74). In (25), coarticulation is indicated with a tiebar '͡'. Intervocalic /h/ can have light voicing (Keels 1985: 74).

(25) Guayabero: Coarticulation of /h/ (Keels 1985: 74).

(a)	bíaha	[ˈbi͡ʌ.hʌ], [ˈbi͡ʌ.ɦʌ]	'he swallows them'
(b)	bíahɪm	[ˈbiʌ.hɪm], [ˈbiʌ.ɦɪm]	'swallow them!'

Finally, before stressed high central vowels followed by [ʔ], /b/ freely varies with a bilabial implosive (26) (Keels 1985: 72). For related processes, see § 3.3.4.

(26) Guayabero: Allophonic variation of /b/ (Keels 1985: 72)

(a)	bɨa/a-t	[ˈbɨᵊ.ʔʌt], [ˈɓɨᵊ.ʔʌt]	'a shelter'
(b)	tabɨt	[tʰʌ.ˈbɨt]	'an egg'

Maori: Bauer (1993: 530) reports that /p, t, k/ in the onset of a stressed syllable may have stronger aspiration and even be affricated (27) (cf. Lavoie 2001: 45). Affrication is more common 'in the environment of a high front vowel' for /p, t/, and before /a/ for /k/ (Bauer 1993: 530). Affrication is also possible for /t/ before devoiced final /i/ and /u/, which are unstressed (Bauer 1993: 530).

(27) Maori: affrication in onset of stressed syllable (Bauer 1993: 531)

(a)	piu	['pç(i)u]	'swing'
(b)	karanga	['kxɐ.ɾɐ.nɐ]	'call'[27]
(c)	iti	['i.tsi], ['i.tçi]	'small'

Maori has ten consonants —/p, t, k, m, n, ŋ, f, h, ɾ, w/— and five vowels /i, e, a, u, o/.[28] Codas and consonant clusters are not permitted. For stress in mono-morphemic words syllables with long vowels take precedence over diphthongs, and these over short vowels. If there is a tie, the syllable to the left is stressed. For prefixed words, the prefix usually has main stress (Bauer 1993: 555 ff. and references therein). Maori has additional stress-related consonantal processes:

> The most constant correlates of primary word stress in Maori are pitch fall and length of vocalic element (the first element in a diphthong). These features are often accompanied by emphatic onset, which consists of a slight pause preceding the stressed syllable, and the appropriate one of the following: aspiration or affrication of stops; pre-glottalization of vowels; stronger friction for fricatives; longer contact for /r/; closer approximantion for /w/; lengthening for nasals. These features of stress may also be accompanied by increased loudness (Bauer 1993: 555-6).

West Tarangan: Word-initially and in medial stressed syllables /j/ affricates and /w/ occlusivizes (Nivens 1992) (28).[29] The consonantal inventory of this language is /b, t, d, k, ɸ, s, m, n, ŋ, r, l, j, w/.[30] West Tarangan has right-to-left moraic trochees.

(28) Fortition in West Tarangan (from Nivens 1992: 139-140; IPA)

(a)	/wɔwa/	['gɔ.wə]	'blossom'
(b)	/waymoj+na/	[gaj.'moj.nə]	'slow-3s'
(c)	/jabin/	['dʒa.bin]	'many'
(d)	/jirua/	[dʒi.'ruə]	'tree (sp)'
(e)	/suwakan/	[su.'ga.kən]	'elephant tusk'
(f)	/bijarum/	[bi.'dʒa.rum]	'whale'
(g)	/kawar/	['ka.wər]	'fish (sp)'
(h)	/rajan/	['ra.jan]	'boat shelter'
(i)	/i+jɔw/	[i'dzɔw]	'3s-see'
(j)	/rɔraw/	['rɔ.rəw]	'heat'

[27] 'The canonical realization of short /a/ is a slightly retracted low central unrounded vowel, i.e. [ɐ].' (Bauer 1993: 540).

[28] There is a controversy about whether vowel length is phonemic in Maori; see Bauer (1993: 429ff).

[29] Lavoie (2001: 36) reports this process as approximantization of /g, dz/. I follow Nivens' (1992) original classification of this process as fortition of underlying /j, w/.

[30] All coronal segments are alveolar except /t/ (dental) and /j/ (palatal).

In word-initial onsets /w, j/ are pronounced as [g, dʒ] regardless of stress (28a-d). /w, j/ are also pronounced as [g, dʒ] in onsets of medial stressed syllables (28e, f). Fortition does not occur in onsets of medial unstressed syllables and in coda position regardless of stress or word position (28g-j).[31]

Cashinawa: In this language, /w/ is reported to have a strong articulation in the onset of stressed syllables (Shell 1975: 38). /w/ is realized as a bilabial fricative or very lenis labiodental before /u/ or after all vowels except /u/, and it does not occur as onset of unstressed syllables after /u/.

On the other hand, /d/ has two possible allophones, [d] or [r]. These are in free variation except in three contexts: onsets of stressed syllables, onsets after stressed syllables, and onsets after a coda, where only [d] occurs (Kensinger 1963: 209). This suggests that fortition also applies for this phoneme. For related processes see § 3.3.5.

Farsi: /ʔ/ has 'emphatic and vigorous' plosion in onsets of initial stressed syllables (Samareh 1977: 17). /ʔ/ can also occur as coda. See also § 3.4.1 and 3.4.2.

Squamish: Glottalized resonants are reported to have stronger glottalization in stressed and post-stressed syllables than in pre-stressed syllables. Glottalization can involve post or pre-glottalization or a brief interruption of the resonant (Kuipers 1967: 25). See also § 3.6.1.

Yuman: Historically, Proto-Yuman /v/ became /p/ or /w/, and /j/ became /ɖ/ in stress-sensitive environments in a number of Yuman languages (Wares 1968; see also Lavoie 2001).[32] Consider the examples below for /v/:

(29) Fortition in Yuman (Wares 1968: 59)

	Dialect with no change		*Dialect with change*		*Gloss*
(a)	ʔa.'v̲a	(Mohave)	ʔu.'w̲a·	(Diegueño)	'house'
(b)	v̲i.'ce	(Paipai)	p̲i.'ci	(Kiliwá)	'daughter'
(c)	rá·.v̲i	(Ya)	ráp̲	(Taipai)	'to hurt (intr.)'

/v/ gave rise to /w/ 'immediately before the stressed vowel' in Cocopa, Diegueño, Taipai, Paipai, North Yuman and Kiliwa (29a). In Cocopa, Taipai, Diegueño and Kiliwa /v/ turned into /p/ 'before stressed vowel, but not immediately before' (29b) and 'immediately following stressed syllable' (29c). The relevant contrast seems to be that /v/ became /w/ in onset of stressed syllables, but /p/ in onset of unstressed syllables (and possibly in codas; but codas probably arose from the loss of unstressed final vowels (29c).

Proto-Yuman /j/ became /ɖ/ in onset of stressed syllables in Yuman, Mohave and Maricopa, and it remained /j/ in onset after stressed syllables. In Diegueno and Taipai /j/ gave rise to /ʔ/ in onset of stressed syllables, and in Kiliwa to /h/ (30).[33]

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[31] No examples of words with coda /w/ word-initially are reported in the source.

[32] It is unclear from the source what /ɖ/ stands for. Since /j/ is an approximant and this process involves fortition, it is plausible that /ɖ/ stands for a voiced fricative.

[33] Additionally, /t/ became a retroflex /ʈ/ in Yuma in onset after stressed syllables (Wares 1968: 54). One example is 'backbone', realized as [ax.táʈ] in Yuma but as [ax.tát] in Maricopa.

(30) Development of Proto-Yuman /j/ (Wares 1968: 67)

	Dialect with no change	*Dialect with change*	*Gloss*
(a)	i.'j̰a (Cocopa)	i˙.'d̶̠o˙ (Mohave)	'tooth'
(b)	'j̰a (Paipai)	'ʔ̠a (Taipai); 'h̠aʔ (Kiliwa)	'mouth'
(c)	ma.sa.'ha.j̰a (Yavapai)	ma.sa.'haj̰ (Mohave)	'girl, virgin'

Summary: Fortition includes fricativization of approximants, occlusivization and affrication of fricatives, and stronger articulation and plosion. In most cases, fortition occurs in onset of stressed syllables. However, the absence of coda fortition in some languages might be the result of the lack or restriction of codas. Fortition occurs in foot-initial position in some languages. In iambic languages, fortition occurs foot-initially in unstressed syllables to mark foot boundaries. Diachronic fortition in Yuman deserves more investigation.

3.3.4. Lenition

Lenition refers to an increase in consonant sonority which makes a consonant more vocalic and thus 'weaker' (Vennemann 1988). Phenomena considered under this rubric include spirantization, by which a stop is pronounced as a fricative or approximant; approximantization of fricatives, and debuccalization, by which supra-laryngeal features are lost. Voicing of underlying voiceless segments in weak positions is also considered to be lenition, since voicing increases the sonority of a consonant. In this study, voicing variation is discussed under featural timing because the examination of languages with stress-sensitive voicing in this survey shows that both voicing and devoicing might occur in weak positions (§ 3.4.1). A summary of stress- and foot-sensitive lenition processes discussed in this section is given in Table (4).

Table 4

Lenition

English	O	/t/ → [ʔ]/ 'V_V; /t/ → [h]/'V.CV_#	Germanic
Copala Trique	O	/d, g/ → [ð, ɣ]/V'_V	Otomanguean
Guayabero	C	/d/ → [θ]/'V_	Guahiban
Senoufo	O	Medial weakest vd. stops fricativize	Niger-Congo
Somali	O	/b, d, g, ɢ/ → [β, ð, ɣ, ʁ]/ V_V, (esp. 'V_V)	Cushitic
Spanish	O	/b, d, g/ → [β, ð, ɣ]/σ̆	Romance
Kupia	O	/p/ → ᵽ/ V._V in σ̆ (opt.)	Indo-Iranian
Nganasan	O	/h, t, k, s, ç/ → [b, d, g, ɟ, ɟ]/foot-initially	Uralic
Paamese	O	/p/ → [f], /t/ → [r]/_'CV; /f/ → [p]/ CV'_ (red.)	Austronesian
Silacayoapan Mixteco	O	/t/ → [d], /ʒ/ → [j] in weak σ	Otomanguean
Guajajára	O	All C lax articulation in unstressed syllable	Tupí-Guaraní

English: In some dialects of English /t/ is flapped intervocalically in the onset of an unstressed syllable (§ 3.3.2). In some other dialects, especially in Britain, /t/ is weakened to a glottal stop in the same context (Roca and Johnson 1999). One specific instance where this occurs is London English (31) (Carr 1999: 152).[34]

(31) English glottalization of /t/ (from Roca and Johnson 1999: 315-6)

(a)	'ten	ta'basco	'mastery	'after
(b)	'cutting	[kʌ.ʔɪŋ]	'waiting	['weɪ.ʔɪŋ]
(c)	a'ttain	re'tort		

Lenition to [ʔ] does not occur word-initially or immediately following a consonant (31a). Lenition to [ʔ] occurs intervocalically in unstressed syllables (cf. 31b, c). Some dialects of English have a related stress-sensitive process by which /p, t, k/ are pre-glottalized (§ 3.4.3).

In Liverpool English, where /t/ glottalizing is not common, /t/ is reported to be debuccalized to [h] utterance-finally. Debuccalization occurs most frequently in monosyllabic words, especially function words such as *it* [ɪh], or *that* [ðah]. In multi-syllabic words, debuccalization usually occurs in unstressed syllables (Honeybone and Watson 2002). Some examples are *climate* ['klaɪ.mɪh], *market* ['maː.kɪh], *permit* (noun) ['pɛˡ.mɪh], and *permit* (verb) [pə.'mɪt]. In the last case debuccalization does not occur because the last syllable is stressed.[35] In all cases of debuccalization, the preceding vowel must be 'short' (i.e., glottalization can occur in words like *it* [ɪh] or *get* [gɛt], but not in words like *wait* *[weɪh], *out* *[aTh] or *eat* *[iːh]) (Honeybone and Watson 2002).

Copala Trique: /d, g/ are reported to lenite to fricatives intervocalically in onsets of stressed syllables (Hollenbach 1977: 36). /b/ is never found intervocalically in this position. Initially in monosyllabic words /d, g/ are pronounced as voiced lenis stops. In other positions they can be voiced or voiceless (§ 3.4.1). See § 3.3.1 and 3.4.1 for related processes.

Guayabero: In coda of stressed syllables, /d/ is pronounced as [θ]. In onset of both stressed and unstressed syllables, /d/ is pronounced as [d] (32a-c); in coda of stressed syllable /d/ is fricativized (Keels 1985: 72).

(32) Guayabero: Fricativization of /d/ (from Keels 1985: 72; IPA)

(a)	dál	['dal]	'fat'
(b)	nehtʃadɨt	['neh.tʃa.'dɨt]	'he remembers'
(c)	nán-de	['nan.dɛ]	'stand up!'
(d)	núd	['nʷuθ]	'an ocelot, a jaguar'
(e)	bénd-hit	['benθ.hɪt]	'wax'

[34] Ladefoged (1993: 53) mentions that in Cockney English, words like *butter*, *kitty* and *fatter* are pronounced as ['bʌʔə, 'kɪʔɪ, 'fæʔə]. He does not refer specifically to stress, but in these words /t/ is realized as [ʔ] intervocalically in unstressed position. He also mentions that the realization of /t/ as [ʔ] is extended in both American and British dialects in words like *beaten*, *kitten*, *fatten* ['biʔn̩, 'kɪʔn̩, 'fæʔn̩]. These particular syllabic nasals are unstressed.

[35] Stress does not always block debuccalization; *forget* [fə.'gɛh], *forgot* [fə.'gɒt] (Honeybone and Watson 2002).

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Keels 1985 mentions that /d/ never surfaces in coda of unstressed syllables, and suggests that the distribution of [d/θ] is position-sensitive rather than stress-sensitive. This distribution might be similar to that frication of coda /b, d, ɡ/ in Basque Spanish, where most words with /b, d, ɡ/ in coda are stressed in the syllable containing /b, d, ɡ/; however, acoustic data shows that voiceless fricative realizations are more common in stressed syllables (González 2002).

Senoufo: Onset consonants are lenited in weak syllables. The consonant inventory is /p, b, t, d, k, ɡ, kp, ɡb, f, v, s, z, m, (n), (ɲ), (ŋ), l, j, w/ (Mills 1984: 92). Stress falls on the first syllable of the word and there are no secondary stresses. Stress is realized as long and fortis articulation of the onset, and as intense articulation of that syllable. Vowels are not lengthened because of word stress. Mills (1984) distinguishes among three degrees of length/strength for consonants: fortis, lenis and extra-lenis. Fortis consonants occur word-initially in stressed syllables. Lenis consonants occur initially after a pre-final semi-open juncture in unstressed syllables. Extra-lenis consonants occur in medial unstressed syllables in polysyllabic words. Extra-lenis consonants have the shortest duration and undergo different reduction processes. /b, d, ɡ/ are spirantized in medial unstressed syllables (cf. Lavoie 2001: 35). /d/ is flapped in this position (section 4.2), and nasals are 'slurred over' (Mills 1984: 131). Additionally, voiceless stops have voiced allophones in this position; see § 3.4.1.

Somali: Somali has the stop series /b, t, d, ɖ, k, ɡ, ɢ, ʔ/. Voiced and voiceless stops are mainly distinguished by aspiration rather than voicing, much as in English (Armstrong 1964). Voiced stops /b, d, ɖ, ɡ, ɢ/ frequently devoice word-finally; /b, d, ɡ/ have either not much voicing or none word-initially. Intervocalically, /b, d, ɡ, ɢ/ lenite to [β, ð, ɤ, ʁ] when single between vowels, especially after stressed syllables (/b, d, ɢ/ often; /ɡ/ sometimes) (Armstrong 1964). Thus, in a word like ['ɖá.b̠an] 'cheek', where /b/ occurs in an unstressed syllable, lenition is more common than in a word like /da.'b̠òol/ 'cover', where /b/ occurs in a stressed syllable. Although lenition is not restricted to unstressed syllables, it is more common there.[36] For related processes see § 3.3.1.

Spanish:[37] In Colombian Spanish /b, d, ɡ/ tend to be pronounced as voiced stops rather as approximants in onsets. This is especially the case in stressed syllables (33d-e) (Amastae 1986, Kim 2002). In unstressed syllables /b, d, ɡ/ tend to be pronounced as voiced approximants (33a-c) even after nasals, which typically block lenition in Spanish (33a).

(33) Colombian Spanish: lenition (from Kim 2002)

	Onset of unstressed syllables				*Onset of stressed syllables*		
(a)	dónde	['don.ð̱e]	'where'	(d)	andar	[an.'d̠ar]	'to walk-inf.'
(b)	habla	['a.β̱la]	'he talks'	(e)	hablar	[a.'b̠lar]	'to talk-inf.'
(c)	fiebre	['fje.β̱re]	'fever'	(f)	quebrar	[ke.'b̠rar]	'to break-inf.'

36 Lavoie (2001: 36) reports flapping of /ɖ/ in Somali in similar contexts as spirantization of /b, d, ɡ/. However, Armstrong (1964) does not mention stress-sensitivity for flapping of this phoneme; her examples include flapping in both stressed and unstressed syllables, as in /haɖ̠ímo/ 'dinner' and /tíɖ̠i/ 'she said', where the underlined segments can be realized as [ɽ] in both cases.

37 Thanks to Jose Ignacio Hualde and Khalil Iskarous for bringing to my attention and making available their work.

In a study investigating the effect of prosodic and segmental context for /ɡ/ in Castilian Spanish, Cole, Hualde and Iskarous (1998) found that intervocalic /ɡ/ had a more complete closure and was more resistant to spirantization in stressed syllables than in unstressed syllables, where /ɡ/ had more energy. For further discussion on lenition in Spanish see González (2003, 2007b).

Kupia: According to Christmas and Christmas (1975: 18), intervocalic consonants in Kupia are generally more lenis in non-prominent syllables than word-initial consonants. /p, ʈ, ɖ/ are singled out as having distinctive variants in this position. /p/ is optionally realized as lenis intervocalically in onset of unstressed syllables (34). This source does not mention if the preceding vowel has to be stressed or not. The consonantal inventory of Kupia includes /p, b, t, d, ʈ, ɖ, k, ɡ, m, n, ŋ, ɾ, l, j, w, s, ts, dz/ (Christmas and Christmas 1975: 5).

(34) Kupia: Optional lenition of /p/ (from Christmas and Christmas 1975: 18)

(a)	/kuːpija/	[ˈkuː.piʲa],	[ˈkuː.ᵽiʲa]	'Kupia'
(b)	/suːpu/	[ˈsuː.pu],	[ˈsuː.ᵽu]	'winnowing basket'

The realization of lenis /p/—which is represented with [ᵽ] in the source—is unclear. Kirchner (1998) represents this segment as [ɸ]. It is possible that the lenis allophone presents a change in voicing. Kupia also has optional flapping in this very context for /ʈ/; see § 3.3.2 for more details.

Nganasan:[38] Nganasan rhythmic consonantal gradation appears to be foot-sensitive. Rhythmic consonantal gradation consists in the alternation of specific consonants word-medially. It is clearly seen in suffixes, but historically it is also attested in roots (Helimsky 1998).

The consonant inventory of Nganasan is /b, t, d, c, ɟ, k, ɡ, ʔ, s, ç, x, m, n, ɲ, ŋ, l, ʎ, r/ (Helimsky 1998: 483; IPA).[39] /ɟ/ and /d/ have [j] and [ð] as allophones, respectively. [p] is an allophone of either /b/ or /h/ (in Nganasan, **p > h*). The consonants that undergo rhythmic gradation are given in (35). Note that strong grade consonants are voiceless, and weak grade consonants are voiced. This detail will be crucial in the discussion of Nganasan in section 3. Examples of rhythmic gradation for the suffixes {tɯ, ði} *3rd sg. possessive* and {rə.kɯ, rə.gɯ} *Similative* are given in (36).

(35) Consonant gradation in Nganasan (Helimsky 1998, Vaysman 2002)[40]

Strong grade	h	t	k	s	ç
Weak grade	b	d/ð	ɡ	ɟ	ɟ

[38] Thanks for Sharon Inkelas to bringing this language to my attention.
[39] /t, d, s, n, l, r/ are dental.
[40] Clusters of these consonants with nasals also undergo rhythmic gradation; see Helimsky (1998).

(36) Rhythmic gradation (from Helimsky 1998: 490; IPA)

	Strong grade		*Weak grade*	
(a)	'nɯ.-ṯɯ	'his wife'	bɯ.'nɯ.-ð̱i	'his rope'
(b)	hɯa.'ɟə.-ṯɯ	'his thumb'	kə.rɯ.gə.ʎi-ð̱i	'his march'
(c)	ˌbɯ.nɯ.-'rə.ḵɯ	'similar to a rope'	nɯ.'-rə.gɯ	'similar to a woman'
(d)	ˌkə.rɯ.ˌgə.ʎi.-'rə.ḵɯ	'his march'	hɯa.ɟə.-'rə.gɯ	'similar to a thumb'

The strong grade occurs after an odd number of vowels (first column in 36) and the weak grade after an even number of vowels (second column in 36) (Helimsky 1998).

In Nganasan, main stress falls 'on the penultimate vowel or on the vocalic sequence which includes the penultimate vowel' (Helimsky 1998: 486) (37, b). There is a strong preference for canonical trochaic words constructed with left-to-right syllabic trochees (37c-e). Words with five or more syllables are divided into rhythmic groups with two vowels each; the last group can have two or three syllables (Helimsky 1998: 487). Stems and suffixes tend to be disyllabic. The boundaries between rhythmic groups are very distinct, and sometimes 'the break in articulation creates the acoustic impression of a glottal stop' (Helimsky 1998: 487).

(37) Nganasan stress and foot structure (Helimsky 1998: 486-7; IPA, syllabification mine)[41]

(a)	['ko.ruʔ]	'house'	[ko.'ru.ðəʔ]	'houses'
(b)	[kʲy.'ma.a]	'knife'[42]		
(c)	(ˌkə.rɯ.) (ˌga.ʎi.) (ˌti.ni)		'in marches'	
(d)	(ˌkə.rɯ.) (ˌga.ʎi.) (ti. 'ni.nə)		'in my marches'	
(e)	(ˌkə.rɯ.) (ˌga.ʎi.) (ˌrɯ.a.) (ti. 'ni.nə)		'only in my marches'	

The description of the environment for rhythmic gradation coincides with the foot structure of the language: the strong grade occurs foot-medially, and the weak grade occurs foot-initially, in left-to-right syllabic trochees. For a more detailed discussion see § 4.[43]

Paamese:[44] A puzzling case of stress-sensitive lenition appears to take place in a form of reduplication in Paamese.[45] In one pattern of reduplication in this language, the initial consonant and vowel of a word are doubled, as shown below:

---

[41] Stress is optionally retracted from a high vowel or [ə] to the preceding syllable, which is usually an open syllable: [ba.'ru.sji]~['ba.ru.sji] 'devil' (Helimsky 1998: 486; see also de Lacy 2002).

[42] Helimsky (1998: 485ff) considers long vowels and dipththongs as vocalic sequences. The foot structure for (37e) suggests that two contiguous vowels are syllabified heterosyllabically; the syllabification in (37b) models this example. For a different approach in which long vowels are tautosyllabic in Nganasan, see (De Lacy 2002).

[43] Nganasan has also a process of syllabic gradation whereby the strong grade occurs word-medially in closed syllables and the weak grade word-medially in open syllables. For example, ['ku.**h**u] 'skin (nom. sing.)', but [ku.**b**uʔ] 'skin (nom. pl.)'. For details, see Helimsky (1998).

[44] Thanks to Caro Struijke for pointing out Paamese as a possible example of stress-sensitive lenition, and to Peter Alengra for providing me with information about reduplication in this language.

[45] Reduplication in Paamese derives verbal items from roots. For details, see Crowley 1982: 47-51.

(38) Paamese reduplication (from Crowley 1982: 47; IPA, syllabification mine)

	Root	*Reduplication*	*Gloss*		*Root*	*Reduplication*	*Gloss*
(a)	ˈsi.ta.li	si.ˈsi.ta.li	'emerge'	(d)	ˈka.a	ka.ˈka.a	'fly'
(b)	ˈme.sa.i	me.ˈme.sa.i	'sick'	(e)	ˈto.ko.li	to.ˈto.ko.li	'touch'
(c)	ˈta. ho.si	ta.ta.ˈho.si	'good'	(f)	ˈsu.a.i	su.ˈsu.a.i	'disappear'

The consonant inventory of Paamese includes /p, t, k, ^{m}b, ^{n}d, ^{ŋ}g, f, s, h, m, n, ŋ, l, r, j, w/ (Crowley 1982: 12; IPA).[46] /p, t, k/ have minimal aspiration, if any.[47] /^{n}d/ is sometimes pronounced with a 'slight r off-glide' [^{n}d^{r}] (Crowley 1982: 15). Paamese appears to have right-to-left moraic trochees (Hayes 1995: 178-179).

Lenition/fortition in reduplication applies to /p, ^{n}d, f/. When the root begins with /p/ or /^{n}d/ the reduplicated form has word-initial [f] or [r] respectively. When the root begins in /f/ the correspondent consonant in the root occlusivizes to [p] (39).

(39) Paamese lenition/fortition (Crowley 1982: 48; IPA, syllabification mine)

	Root	*Reduplication*	*Gloss*
(a)	ˈpi.li.tu	f̱i.ˈpi.li.tu	'stick'
(b)	ˈpu.si	f̱u.ˈpu.si	'kick'
(c)	ˈpo.le	f̱o.ˈpo.le	'burnt'
(d)	ˈfo.ra.a	f̱o.ˈpo.ra.a	'noisy'
(e)	ˈ^{n}de.mi	ṟe.ˈ^{n}de.mi	'think'

There is only one stress per word in Paamese. Stress is penultimate in two-syllable words, as in the roots in (39b, c, e). Stress falls on the antepenult of words with three or more syllables, as in the roots in (39a, d), unless this syllable is lexically unstressed or morpheme-final.[48] In this form of reduplication, the first syllable is morpheme-final, so the reduplicated form keeps the stress on the original syllable from the base. This means that the initial syllable of the reduplicated forms is unstressed, and the second syllable is stressed. Thus, lenition of /p, ^{n}d/ correlates with unstressed syllables, and fortition of /f/ with stressed syllables.[49] Note that /p, f/ neutralize syllable- and word-finally. Word-finally they are in free variation, and syllable-finally only [f] occurs. For related processes see § 3.4.1.

Silacayoapan Mixteco: /t/ and /ʒ/ lenite in weak positions (North and Shields 1977: 22, 23). The consonant inventory of Silacayoapan is /p, t, c, k, k^{w}, ʔ, ^{m}b, ^{n}d, ^{ɲ}ɟ, ^{ŋ}g, β, s, ʃ, ʒ, h, m, n, ɲ, l, r, j/ (North and Shields 1977: 21; IPA). North and Shields

[46] Crowley (1982) takes the labiodental fricative to be voiced, but I represent it as /f/ because in most cases it is pronounced as voiceless, and because all other fricatives are voiceless in the language (Crowley 1982: 14).

[47] Pre-nasalized voiced stops are represented as /b, d, g/ in Crowley (1982); here they are represented as /^{m}b, ^{n}d, ^{ŋ}g/.

[48] Hayes (1995: 178-9) analyzes this stress system as involving right-to-left moraic trochees, with final extrametrical syllables and some exceptional forms. See also Crowley (1982: 28-31).

[49] /fu.ˈe.li/, reduplicated to /f̱u.pu.ˈe.li/ 'lost' does not conform to the stress-based generalization proposed here. However, this is an exceptional form that has an 'unstressable' second syllable (Crowley 1982).

(1977: 21) report that the base of the phonological word is the 'couplet', a unit formed of two syllables which shows allophonic conditioning and restriction. The couplet is also the main unit of tone contrast. The first syllable of this unit carries the word stress, and can have a /ʔ/ coda. In foot terms, this corresponds to a syllabic trochee.

Voiceless stops are unaspirated (40a) except for foot-initial /t/, which has some aspiration. Lenition of /t/ occurs in onsets in unfooted syllables (40c). The nature of lenited /t/ is not clear; it is described as 'softened' and represented with [ɗ]. /ʒ/ alternates with [j] in onset position foot-medially in rapid speech (40d). It is considered here that this is an instance of optional lenition because [j] occurs in weak position. The distribution of /j/ is limited in Silacayoapan; it only occurs alone in two words, and it is more frequent as the second member of a cluster foot-initially (North and Shields 1977: 24). For related processes, see § 3.4.1, 3.4.2 and 3.6.2.

(40) Silacayoapan Mixteco lenition (from North and Shields 1977: 22, 23)

(a)	('tà.à)	'man'	(c)	kíʔvì-ta	[('kíʔ.vì).**ɗ**a]	'he is sick'
(b)	[('ʒá.ʔà)]	'chile'	(d)	[('ká.**ʒ**ì)],	[('ká.**j**ì)]	'cough'

Guajajára: Bender-Samuel reports a tendency for all consonants in this language to have a lax articulation in unstressed syllables, especially /ʔ, h/ (Bendor-Samuel 1972: 64). Especifically, /ʔ/ tends to have an incomplete closure in this position, and /h/ to show some voicing (Bendor-Samuel 1972: 62, 64). See also § 3.4.1 and 3.8.

Summary: Lenition correlates with unstressed syllables, weak footed syllables and unfooted syllables. It is found mainly in onsets, but in some languages this might be the case because no codas exist or they are restricted. Types of lenition include debuccalization, fricativization of stops, and approximantization of fricatives.

3.3.5. Secondary articulation

In some languages secondary articulation —as labialization or palatalization— occurs exclusively in stressed syllables. Some reported cases include Senoufo, Guayabero and Cashinawa (Table 5).

Table 5

Secondary articulation

Guayabero	O, C	C → C^w/'_/u, o/_	Guahiban
Senoufo	O	Secondary release in 'σ	Niger-Congo
Cashinawa	O	/b, d/ → ^{n}C/'σ /p, t, k/ → ^{n}C/'σ._	Panoan

Guayabero: Guayabero has a stress-sensitive process by which all onset and coda consonants are labialized in stressed syllables with /o, u/ (41).

(41) Guayabero labialization (from Keels 1985: 71,72; IPA)

(a)	púka	[ˈp̱ʷ̱ʰ̱ u.kʰʌ]	'a lagoon'
(b)	tʃapó-t	[tʃʌ.ˈp̱ʷ̱ʰ̱oṯʷ̱]	'a mirror'
(c)	taknúk	[tʰʌk.ˈṉʷ̱uḵʷ̱]	'he stands watching'
(d)	taka	[ˈṯʰa.kʰa]	'a shoulder'

(41a, b) show that labialization occurs in stressed syllables only. Codas as well as onsets are labialized (41b, c). (41d) shows that consonants in stressed syllables are not labialized with vowels other than /o, u/. Onset voiceless obstruents are aspirated in Guayabero (Keels 1985: 71, Lavoie 2001: 44). See also § 3.3.3.

Senoufo: Except for /n, ɲ, ɳ, l, j, w/, consonants in Senoufo are realized with secondary articulation —including palatalization and labialization— in stressed syllables. See also § 3.3.1, 3.3.2, 3.3.4, and 3.4.1.

Cashinawa: Voiced stops /b, d/ may become slightly pre-nasalized by a homorganic nasal, especially phrase-initially or in the onset of a main stressed syllable after an oral vowel (Kensinger 1963: 209, Shell 1975: 36). Kensinger 1963: 209 also notes that voiceless stops may be lightly pre-nasalized after a nasal vowel, especially after a stressed syllable.

Cashinawa has the following consonants: /p, t, k, b, d, s, ʃ, ʂ, ts, tʃ, m, n, w, j, h/[50] (Kensinger 1963: 209, Shell 1975: 35). Only spirants can be codas (Kensinger 1963: 212). Stress falls on the first syllable of the word and on alternate syllables thereafter (Kensinger 1995: 4). See also § 3.3.3.

Summary: Secondary articulation is found in codas or in onsets of stressed syllables. The nature of the immediately preceding or following vowels influences secondary articulation. For certain consonants in Cashinawa, secondary articulation occurs after stressed syllables; this case might be better analized as assimilation than secondary articulation.

3.4. Featural timing

This section considers languages with stress-sensitive variation in featural timing for aspiration, glottalization and voicing. Pre-aspiration is distinguished from post-aspiration, and pre-glottalization from post-glottalization. Pre-aspiration or pre-glottalization means that the onset of [spread glottis] or [constricted glottis] begins before the closure of the consonant. Post-aspiration or post-glottalization means that the offset of [spread glottis] or [constricted glottis] comes after the release of the consonant.

[50] Shell (1974: 36, 41) reports that /b/ cannot be the onset of a stressed syllable, and that /h/ is only found as the onset of stressed syllables in non-initial positions. Kensinger (1995: 4) does not include /h/ as a phoneme of Cashinawa.

3.4.1. Voicing alternations

Languages with stress-sensitive voicing alternations fall into four different patterns, indicated with numbers in Table 6. In pattern 1, underlyingly voiceless segments voice in unstressed syllables; in pattern 2, underlying voiced segments devoice in unstressed syllables. In pattern 3, underlyingly voiceless segments become voiced in stressed positions, and in pattern 4, the stress of the preceding syllable influences consonantal voicing. A language might have competing patterns for different segments, as Silacayoapan Mixteco. The pattern of voicing for 'x' in English is not clear.[51]

Table 6

Voicing variation

Senoufo (1)	O	/p, t, k/ → [b, d, g]/ V_V	Niger-Congo
Popoloca (1)	O	[vless.] obstruents → [voi]/[-stress]	Otomanguan
Chacobo (1)	O	/k/ → [g]/ [-stress]	Panoan
Guajajára (1)	O	/h/ → [ɦ]/[-stress]	Tupí-Guaraní
Djabugai (2)	O	/b, d, g/ → [p, t, k]/[-stress]	Pama-Nyungan
Wembawemba (2)	O	Oral stops devoice/[-stress]	Victorian
Wergaia (2)	O	Oral stops devoice/[-stress]	Victorian
Farsi (2)	O	Vd. obstruents devoice/[-stress] #_	Indo-Iranian
Copala Trique (2)	O	/d, g, z, ʒ, r/ devoice/[-stress] (opt.)	Otomanguean
Silacayoapan Mixteco (1, 2)	O	/k/ → [g]/unstressed syl. outside foot Pre-nasal stops devoice foot medially	Otomanguean
Wasco-Wisram (3)	O	Vd. stops devoice/[-stress]	Penutian
Urubu-Kaapor (3)	O	/p, t/ → [b, d]/[-stress] (optional)	Tupí-Guaraní
*Proto-Germanic (4)	O, C	Vless. fricatives vd./[-stress]_	Proto-Germanic
*Middle English (4)	O	/θ/ → /ð/ after weakly 'σ	Germanic
Paamese (4)	O	/nt/ → [ⁿd] medially, esp. after 'σ	Austronesian
English (?)	C/O	'x' → [k.s]/ 'V_._V; → [g.z]/V_.'_V	Germanic

Senoufo: /p, t, k/ are voiced in onsets of medial unstressed syllables (Mills 1984: 94). In other positions /p, t, k/ show light aspiration. Since Senoufo has durational

[51] Grammont (1933: 163-4) reports that in Central Italian /p, t, k/ became voiced in onsets of stressed syllables except word-initially; e.g. *coperta* > *coverta* 'covered', *betulla* > *bidolla* 'birch tree' and *securu* > *siguro* 'sure'. Since the data reported by Grammont is not consistent with any variety of Italian (Mario Saltarelli, p.c.) Central Italian is not included in this section.

differences for consonants in stressed and unstressed syllables (§ 3.4.1), it is possible that voicing of /p, t, k/ in unstressed syllables is perceptual. Voiceless segments are universally longer than voiced ones (Catford 1977). In unstressed syllables /p, t, k/ are shorter, which gives the percept of voicing (see Lavoie 2001). Under this hypothesis, no glottal (i.e., articulatory) voicing actually occurs in this position at least synchronically with the reinterpretation.

Popoloca: In Los Reyes Metzontla Popoloca, voiceless stops and affricates become voiced in onsets of 'reduced' syllables (Veerman-Leichsenring 1984: 43-5). Sibilants become voiced optionally in this position. Additionally, both affricates and sibilants might become voiced after a long vowel (42).

(42) Popoloca voicing (from Veerman-Leichsenring 1984: 43-5; IPA)

(a)	/jú + **k**à/	['ìj.jú.**g**à]	'two leaves'
(b)	/jú + **s**ùʔ/	['i j.júː.**z**õʔ]	'two beds'
(c)	/ᵑgu + **t**ù/	['ìŋ.gu.**d**ù]	'fruit pit'
(d)	/nˀáɑ.ʈʂ̩í/	['nˀáː.**ɖʐ̩í**] / ['nˀáː.**ʈʂ̩**í]	'old woman'

Stressed syllables in Popoloca have either long vowels or diphthongs, or —more commonly— coda consonants. Gemination occurs after stressed syllables (4.1). /i/ is epenthesized in monosyllabic words so that stressed syllables have a coda from the following onset. This occurs in /ju / 'two' and /ᵑgu/ 'fruit' in (36a-c) (Veerman-Leichsenring 1984: 22, 23). Stress is not realized in '/**k**à/ 'leaves', **/s**ũʔ/ 'beds', and **/t**ù/ 'pit' for morphological or syntactic reasons (42a-c) (Veerman-Leichsenring 1984: 22). This causes these words to be reduced phonetically; their onsets are voiced. In these cases, the 'reduced' syllables follow unstressed syllables. (42d) shows that affricates are optionally voiced in reduced position and after long vowels. See also § 3.3.1, 3.4.3, and 3.6.1.

Chacobo: Chacobo exemplifies voicing pattern 1. /k/ is reported to voice to /g/ in the onset of stressless syllables preceded by an oral or nasal /ɯ/ (Shell 1975: 36). Chacobo has four vowels, /a, i, o, ɯ/, and fifteen consonants /p, t, k, ʔ, β, s, ʃ, ʂ, h, ts, tʃ, ɾ, m, n, w/.

Guajajára: Guajajára exemplifies voicing pattern 1. /h/ is reported to have some voicing in onsets of unstressed syllables and in 'span-final'codas (Bendor-Samuel 1972: 64). In this case, voicing of /h/ seems to be an instance of general consonant weakening (see section 2.3.4). For related processes see § 3.3.4 and 3.8.

Djabugai: Djabugai exemplifies voicing pattern 2. Voiced stops are devoiced intervocalically or medially after /j, l, r/ (43). Devoicing occurs in allegro speech; no devoicing occurs in citation form (Patz 1991: 252-3).

(43) Djabugai: devoicing in unstressed positions (from Patz 1991: 252; IPA).

(a)	/wabar/	['wa.p̱ʌr]	'Hunt'	(c)	/bulbal/	['ḇul.p̱ʌl]	'To rub'
(b)	/wajgal/	['wai.ḵʌl]	'To search'	(d)	/murba/	['mur.p̱ʌl]	'Under water'

The consonantal inventory for this language is /b, d, ɟ, g, m, n, ɲ, ŋ, l, r, ɻ, j, w/. Only /m, n, ŋ, l, r, ɻ, j/ can be codas (Patz 1991: 250-1, 255). Stress is generally assigned to the first syllable of the word. One exception is three-syllable words with a long vowel in non-final position; in this case, main stress falls on the long vowel. Secondary stress falls on the penultimate syllable in words with more than three syllables (Patz 1991: 258-60). This suggests that devoicing occurs in unstressed syllables. However, no examples are provided of the realization of /b, d, ɡ/ in unstressed syllables outside the second syllable, or of the realization of /b, d, ɡ/ in stressed second syllables or in syllables with secondary stress. See also § 3.3.2.

Wembawemba: Wembawemba also exemplifies voicing pattern 2. It has only voiced consonants: /d̪, d, ɖ, ɟ, ɡ, m, n, ɳ, ɲ, ŋ, r, ɻ, l, w, j/. Main stress is initial; secondary stress occurs on the third syllable of the word. Oral stops are totally devoiced intervocalically and word-finally (44d, f), i.e. in syllables that do not receive main stress. Word-initially, devoicing is often partial and gradient; different speakers show different amounts of voicing. Initial voicing is facilitated by /u/ for /b, ɡ/ and by /i, e/ for /ɟ/ (44a-e). Oral stops are voiced after nasals (44a, b). Nasals can be devoiced syllable-finally, but never in monosyllabic accented words (Hercus 1986: 10).

(44) Wembawemba voicing (from Hercus 1986: 6; IPA)

(a)	bunda	['ḇTn.ḏʌ]	'to bite'	(d)	ɟilega	['ɟi.le.ḵʌ]	'sick'
(b)	gumba	['ɡu˙ m.ḇʌ]	'to sleep'	(e)	ɟuɽa	['c̱u.ɽʌ]	'to gossip'
(c)	bana	['p̱a.nʌ]	'ringtail possum'	(f)	wuɟub	['wu.c̱Tp̱˺]	'stomach'

Wergaia: Wergaia has a similar voicing pattern to Wembawemba. The consonant inventory is /b, d, ɖ, ɟ, ɡ, m, n, ɳ, ɲ, ŋ, r, ɻ, l, w, j/ (Hercus 1986: 73). Main stress occurs on the first syllable and secondary stress generally on the third syllable (for details see Hercus 1986: 81). Oral stops are devoiced except word-initially, where they are always voiced (45). This suggests devoicing is sensitive to stress. Intervocalically, there is a tendency towards voicing before certain vowels (45a, c) (Hercus 1986: 75). See § 3.3.1 for related processes.

(45) Wergaia devoicing (Hercus 1986: 75, 198)

(a)	bubug	['ḇu.ḇTk]	'baby'	(c)	miɟiin	['mɪ.ɟ̱ɪ.ʲɪn]	'moon'
(b)	babi	['ḇɑˡ.p̱ɪ]	'female'	(d)	miɟag	['mɪ.c̱ʌḵ]	'rain'

Farsi: Farsi also exemplifies pattern 2. 'Lenis' obstruents /b, d, ɡ, j, v, z, ʒ/ are fully voiced intervocalically and in stressed initial positions, but only partially voiced in unstressed initial syllables. Since there is no preceding voiced sound, it is possible that consonantal voicing is more difficult to maintain word-initially, especially if the syllable is unstressed. /b, d, ɡ, j, v, z, ʒ/ are totally or partially devoiced in codas (Samareh 1977: 24-5). /b, d, ɡ, ʒ/ are also reported to be devoiced in contact with voiceless sounds.

The consonantal inventory of Farsi is /p, t, k, b, d, ɡ, q, ʔ, tʃ, dʒ, f, s, ʃ, χ, h, v, z, ʒ, m, n, l, r, j/. All consonants can be codas (Samareh 1977: 8-9). See also § 3.3.3 and 3.4.2.

Copala Trique: Copala Trique distinguishes between 'fortis' and 'lenis' stops and sibilants. Fortis consonants are voiceless and lenis consonants are voiced (Hollenbach

1977: 36). Lenis consonants /d, g, z, ʒ, r/ optionally devoice in onset of unstressed syllables and in clusters (Hollenbach 1977: 37; only /ʔ, h/ can be codas). /ʒ/ is realized as [dʒ] word-initially in unstressed syllables, and /r/ is realized as [ɽ] intervocalically, in clusters with stops, and word-initially following a word final /ʔ/ and preceding a vowel; otherwise it is a sibilant.

Fortis consonants and affricates are restricted to stressed positions. It is plausible that devoicing occurs in unstressed positions since the voicing contrast is not relevant there. Cf. related San Andrés Chicahuaxtla Trique, where fortis (voiceless) and lenis (voiced) consonants have similar distributional restrictions; the phonemic inventory is slightly different (see Hollenbach 1977: 50 ff. for details). For more details on Copala Trique see § 3.3.3.

Silacayoapan Mixteco: Silacayoapan Mixteco shows two apparently opposed tendencies regarding voicing variation. Silacayoapan has both voiceless unaspirated stops /p, t, c, k, k^w, ʔ/ and pre-nasalized voiced stops /^{m}b, ^{n}d, ^{ɲ}ɟ, ^{ŋ}g/ (North and Shields 1977). Pre-nasalized stops are voiced foot-initially (46a) and optionally devoiced foot-medially (46b, c). Additionally, /k/ is optionally realized as [g] in unstressed unfooted syllables (46d).

(46) Silacayoapan Mixteco (from North and Shields 1977: 22-3; IPA)

(a)	[('^{m}̱ḇà.à)]	'compadre'	[('^{n}̱ḏé.é)]	'thick'
(b)	là^m̱ḇà	[('là.^{m}̱ḇà)], [('là.^{m}̱p̱à)]	'bladder'	
(c)	ú^ṉḏó	[('ʔú.^{n}̱ḏó)] ,[('ʔú.^{n}̱ṯó)]	'animal fat'	
(d)	ákʉ́ʃʉ-ka^{n}dì	[à.('kʉ́.ʃʉ.)g̱a.^{n}dì], [à.('kʉ́.ʃʉ.)ḵa.^{n}dì]	'we (excl.) won't eat more'	

/^{m}b, ^{ɲ}ɟ, ^{ŋ}g/ are rare; /^{ɲ}ɟ, ^{ŋ}g/ are found foot-medially only. There is no mention of optional devoicing of pre-nasalized voiced stops in onset of unfooted syllables; it is possible that these segments do not occur in this position. Silacayoapan Mixteco has syllabic trochees (§ 3.3.4). For related processes see also § 3.4.2 and 3.6.2.

Wasco-Wisram:[52] Wasco-Wisram (Upper Chinook) exemplifies voicing pattern 3. /p/ is realized as [b] in onsets of stressed syllables and as [p] in onsets of unstressed syllables. Coda /t/ has a voiced variant in final position before words beginning with stressed vowels (47).

(47) Wasco-Wisram (from Sapir 1925: 44)

(a)	inaṯ	'across'	ina'ḏV	'across'
(b)	'wa.p̱ul	'night'	wa.'ḇul.max	'nights'

Urubu-Kaapor: Kakumasu (1986: 399) reports optional voicing of /p, t/ in non-primary-stressed syllables, which would mean that Urubu-Kaapor exemplifies pattern 3. However, secondary stresses are not marked in the source (48). Aditionally, note that in (48b) onset /p, t/ can be voiced in any of the two last syllables in any combination. /k/ is optionally voiced at word boundaries, but this is not reported to

[52] I thank Joaquim Brandao de Carvalho for bringing to my attention Wasco-Wisram and Verner's Law.

be sensitive to stress (Kakumasu 1986: 399). Oral stops lengthen in primary-stressed syllables (section 3.3.1).[53]

(48) Urubu-Kaapor optional voicing of /p, t/ (from Kakumasu 1986: 399).

(a)	/arapuha/	[arap̱u'ha] ~ [araḇu'ha]	'deer'
(b)	/heta tipe/	[he'ta ṯiḇe] ~ [he'ta ḏiḇe]	'there are many, but in vain'
		[he'ta ṯip̱e] ~ [he'ta ḏip̱e]	

Proto-Germanic: In the development from PIE, /p, t, k, k^w/ changed to voiceless fricatives /f, θ, x, x^w/ (Grimm's Law). A subsequent change voiced these voiceless fricatives if they were surrounded by voiced sounds and the immediately preceding syllable did not have the main accent of the word (49) (Verner's Law). This change was obscured by a later change in the position of stress to the first syllable of the word (Wright 1957, Collinge 1985).

(49) Verner's Law [54]

		Grimm's Law	Verner's Law	Gloss
(a)	*pa'**t**er* (PIE)	*fa'**θ**er* (Early Germanic)	*fa'**ð**er*	'father'
(b)	*sap'**t**a* (Sanscrit)	*seo'**f**on* (Old English)	*si**β**un* (Old Saxon)	'seven'

Middle English: Kabell and Lauridsen (1984: 80) report that in the stage between Middle and Modern English, /θ/ among other consonants began to be voiced after a weakly stressed syllable, or initially, as in *the, thou, thee, that* and *though*. No examples are provided for the stress-sensitive change; it is not clear if only onsets are involved, and no other consonants are mentioned.[55] It is plausible that since this process occurred in function words, 'weakly stressed syllables' correspond to unstressed syllables and that this process takes place word-initially.

Around the 14th century the /f/ of weakly stressed *of* became /v/ in opposition to strongly stressed *off* (Kabell and Lauridsen 1984: 50). This seems to be an isolated case, but in Modern English, the /θ/ of *with* becomes voiced when followed by a voiced segment in the next word. A possibility is that in both of these cases the voicing of the following segment causes coda devoicing.

Paamese: Medial /nt/ sequences created by vowel deletion become [^{n}d] obligatorily when the preceding syllable is stressed (50a, b), and optionally if the preceding syllable is unstressed (50c) (Crowley 1982: 39). See also section 3.3.4.

(50) Paamese (from Crowley 1982: 39; IPA, syllabification mine)[56]

(a)	ma+'ani+tei	['ma^{l}.^{n}dej]	'I will eat some'
(b)	féni+tasi	['fe. ^{n}das]	'knowing the sea'
(c)	manu+táai	[ma.'^{n}daːj]	'perched flying fox'

[53] In (48b) the onset of the stressed syllable should be lengthened (see section 3.3.1). It is not clear if this is a typo in the source or if there is some other process going on.

[54] From Wright (1957) and http://homepage.mac.com/branscombcourses/HEL/Verner.html.

[55] Cf. Lavoie (2001: 32).

[56] Crowley's (1982: 20-1) distinction between 'loose' and 'tight' morpheme boundaries is ignored in this data.

English: In some varieties of English, voicing in the pronunciation of the grapheme ‘x’ correlates with stress. For instance, in British English ‘x’ is pronounced as [ɡz] when ‘x’ overlaps the coda of an unstressed syllable and the onset of a stressed syllable, as in *exists* [ɪɡ.ˈz̲ists], *exert* [ɪɡ̲.ˈzɛːt]. ‘x’ is pronounced as [ks] when it overlaps the coda of a stressed syllable and the onset of a stressed syllable, as in *exit* [ˈɛk̲.s̲ɪt] (Collinge 1985: 211).

For many speakers [ˈɛk̲.s̲ɪt] is in free variation with [ˈɛɡ.z̲ɪt]. In onset position, ‘x’ is pronounced as [z], as in *xylophone* [ˈz̲aɪ.lə.fəTn] and *xerox* [ˈz̲ɪə.ɾɑks].[57] Syllable-finally ‘x’ is pronounced as [ks], as in *hex* [hek̲s̲]. According to Collinge (1985) the same effect of stress is seen in pairs like *possess* [pə.ˈz̲es] and *possible* [ˈpɑ.s̲ə.bl]; in this case [z] occurs in stressed syllables and [s] in unstressed syllables. This suggests that the onset in [ɡ.z]/[k.s] is sensitive to stress.

Summary: Four consonantal voicing patterns are attested. In pattern 1, voiceless consonants are voiced in unstressed syllables. In pattern 2, voiced consonants are voiceless in unstressed syllables. In pattern 3, voiceless consonants are voiced in stressed syllables. In pattern 4 the stress or lack of stress of the preceding syllable conditions consonantal voicing. The voicing alternation in the pronunciation of ‘x’ is unclear. The fact that a pattern in which voiced consonants would become voiceless in stressed syllables is missing seems to be significant and is discussed in section 4.

3.4.2. Aspiration alternations

(a) Post-aspiration

This section discusses cases where stressed syllables correlate with stronger aspiration, friction or affrication from the release of a consonant. Stronger aspiration is distinguished from longer aspiration; the first refers to the amount of the aspiration, and the second to its duration. For cases of longer aspiration see § 3.3.1.

Table 7

Post-aspiration

English	O	/p, t, k, tʃ/ → [pʰ, tʰ, kʰ, tʃʰ]/#_/ˈ_V	Germanic
Maori	O	Stronger aspiration/friction/ˈ_V	Austronesian
German	O/C	Stronger #_/ˈ_V/ˈV_	Germanic
Pattani	NM	Stronger #_ /ˈ_V	Sino-Tibetan
Farsi	NM	Stronger #_ /ˈ_V	Indo-Iranian
Chali (Tati)	O	/r/ aspirated if geminated in ˈσ	Indo-Iranian
Silacayopan Mixteco	O	/t/ → [tʰ]/ˈ_V	Otomanguean
Squamish	O	Non-glottalic S aspirated/ˈ_V. (opt.)	Central Salish
Basque Spanish	C	/b, d, ɡ/ → [ɸ, θ, x]/ˈV_	Romance

[57] In all words beginning with ‘x’, ‘x’ is pronounced [z] in all cases except in the proper name *Xhosa* (Oxford Advanced Learner’s Encyclopedic Dictionary).

English: Aspiration of voiceless stops and /tʃ/ in American English is reported to be longer and stronger word-initially and in stressed syllables (Lisker and Abramson 1967, Kahn 1980, Crystal and House 1988, among others). It has been proposed that aspiration is stronger and longer foot-initially (Davis 2002, among others).

Stronger aspiration in stressed syllables is also reported for Cardiff English and London English (Collins and Mees 1990, Carr 1999). Affrication of voiceless stops —especially for /t/— rather than strong aspiration is reported for New York City English, Liverpool English, and London English (51).

(51) Affrication/strong aspiration (Carr 1999: 153, 156)

(a)	cup of tea	[ˌkʰʌʔpəˈtsʰɪi]	(London English)
(b)	tin	[ˈtsɪn]	(New York City English)

Maori: Aspiration of oral stops increases with loudness and stress. In onsets of stressed syllables either aspiration or affrication might occur (§ 3.3.1, 3.3.3). Fricatives also have stronger friction in this position (Bauer 1993: 530-1, 555).

German: Stronger aspiration for both onset and coda voiceless stops occurs in Standard German word-initially and in stressed syllables (Kohler 1977, Giegerich 1989, Iverson and Salmons 1995). Alber (2001) suggests that aspiration occurs foot-initially.

Pattani:[58] Sarma (1982) reports a tendency for stronger aspiration in initial and accented syllables and for reduction of aspiration in pre-accentual ('weak') syllables (Sarma 1982: 48, 67, cf. Kirchner 1998). Pattani has phonemic aspirated and unaspirated consonants and initial main stress.

Farsi: Aspiration of /p, t, k, tʃ/ is reported to be stronger word-initially and in stressed syllables than in other positions (Samareh 1977: 24). See also § 3.3.3 and 3.4.1.

Chali Tati: In the Chali dialect of Southern Tati, /r/, a 'voiceless or partially voiced weak alveolar trill', becomes 'somewhat' aspirated when geminated and followed by a stressed vowel (Yar-Shater 1969: 35). /r/ tends to become a flap in final position. Voiceless stops in Chali, which are slightly aspirated, are more strongly aspirated when the stops are geminated; the source does not mention stress in this context.

Silacayoapan Mixteco: /t/ is reported to be slightly aspirated 'couplet initially' i.e., foot-initially (section 4.4) (North and Shields 1977). Word stress in Silacayoapan Mixteco falls on the first syllable of the couplet, so /t/ is aspirated in stressed syllables. In other positions /t/ has no aspiration or is lenited (North and Shields 1977: 22). See also § 3.3.4, 3.4.1 and 3.6.2.

Squamish: Aspiration of non-glottalized plosives occurs optionally in onsets of stressed syllables (Kuipers 1967: 25).

[58] Pattani (West-India, Sino-Tibetan) is different from Pattani Malay (Thailand, Austronesian).

Basque Spanish: In Peninsular Spanish /b, d, ɡ/ are usually pronounced as approximants in most environments. In the dialect of Spanish spoken in the Basque Country coda /b, d, ɡ/ usually fricate and devoice, as in /pared/ [pa.ˈɾeθ] 'wall'. For some speakers, frication of coda /b, d, ɡ/ occurs mostly in stressed syllables, indirectly causing a loss of voicing (González 2002b, 2003, 2007b).

Summary: Unaspirated segments may be post-aspirated in stressed syllables or foot-initially. Aspirated segments might have stronger post-aspiration in stressed syllables and foot-initially. It is common for post-aspiration to occur both in stressed positions and word-initially. In most cases onsets are more prone to be post-aspirated, but lack of codas or restrictions thereon might play a part in this patterning. In some cases, strong aspiration might lead to affrication. In some other cases, strong friction occurs for fricatives in stressed syllables.

(b) Pre-aspiration

Pre-aspiration is reported to occur in onsets after stressed vowels in a range of languages (Kehrein 2001). In some cases pre-aspiration is restricted to preceding short or non-high stressed vowels. In all languages with stress-sensitive pre-aspiration oral stops are affected; in Ojibwa fricatives are affected as well.[59]

Table 8

Pre-aspiration

Icelandic	O	After short 'V	West Scandinavian
Standard Faroese	O	After short ' V	West Scandinavian
Northern Faroese	O	C (C) ^{h} → ^{h} C (C) /'V_ (-high)	West Scandinavian
Scots Gaelic	O	'V_	Celtic
Irish Gaelic		'V_	Celtic
Ingush	O	After short ' V	North-East Caucasian
Toreva Hopi	O	Stops/ ' V_V	Uto-Aztecan
Ojibwa	O	Stops, fricatives/ ' V_	Algonquian
Tarascan	O	'V_	Tarascan

[59] Pre-aspiration in Lule Sami (Uralic) might also be related to prosodic structure. According to Ladefoged and Maddieson (1996) it has similar pre-aspiration to Icelandic. Kehrein (2001) mentions the possible role of strengthening due to, among other factors, shortening of preceding stressed vowels. Engstrand's (1987) phonetic study does not mention any stress differences for pre-aspiration, but Lule Sami has lexical stress in the first syllable. It is possible that pre-aspiration occurs word-medially or in non-primary stressed syllables. Engstrand (1987) also mentions that pre-aspiration frequently takes the form of frication rather than aspiration, especially in palatal and velar contexts.

Icelandic: Icelandic has both contrastive and alternating pre-aspirated stops (Silverman 1997). Phonemically, pre-aspirated stops contrast with voiceless unaspirated, voiceless geminates and voiceless post-aspirated stops. Voiceless unaspirated and voiceless post-aspirated stops occur word-initially (52a, b). Word-medially and word-finally voiceless unaspirated, pre-aspirated and geminate stops occur (52a-c).[60]

(52) Icelandic stops (from Ringen 1999: 138 and references therein, and Ladefoged and Maddieson 1996: 71)[61]

	Initially		*Medially*		*Finally*	
(a)	['paːr]	'bar'	['k^{h}ɔː.pɑr]	'copper'	['kɑːp]	'zeal'
(b)	['p^{h}aːr]	'pair'	['k^{h}ɔh.pɑr]	'small pot (n. pl)'	['k^{h}ɑhp]	'zeal'
(c)			['k^{h}ɔp.pɑr]	'young seal (n. pl)'	['kɑpp]	'hoax'

In alternations, pre-aspirated stops are realized 'coordinated with a stressed syllable' and 'away from unstressed syllables' (53) (Silverman 1997: 78). Main stress in simplex words in Icelandic falls on the initial syllable. Icelandic has left-to-right syllabic trochees with secondary stress on alternate syllables (Hayes 1995: 188-198 and references therein).

(53) Icelandic alternations (Silverman 1997: 77-78, citing Thráinsson 1978)[62]

(a)	/k^{h}ak^h+a/	['k^{h}aː.**k^h**a]	'cake (nom. sg.)'	/k^{h}ak^h+na/	[k^{h}a**h.k**a]	'cake (gen. pl.)'
(b)	/nit^h+a/	['niː.**t^h**a]	'utilize (inf.)'	/nit^h+t^h+a/	['ni**h.t**a]	'utilize (past)'

Standard Faroese: Standard Faroese is reported to have the same stress-sensitive pre-aspiration pattern as Icelandic (Kehrein 2001). Faroese has initial stress (Hume and Seo 2001). Pre-aspirated stops occur medially and finally as realizations of geminate voiceless aspirated stops. Initially, there is a contrast between voiceless unaspirated and voiceless aspirated (Ladefoged and Maddieson 1996: 70).

Northern Faroese: Northern Faroese (including Vágar) contrasts among aspirated and non-aspirated singleton and geminate oral stops /t, tt, t^h, tt^h/. Aspirated single stops and geminates are pre-aspirated after non-high stressed vowels (54a-d). Post-aspirated stops are found in onsets of stressed initial syllables (54a, d) (Kehrein 2001, Petersen et alia 1998; cf. Ladefoged and Maddieson 1996).

(54) Northern Faroese (cited in Kehrein 2001; from Petersen et alia 1998: 126)

(a)	pápi	['p^{h}ɔa.^{h}pɪ]	'dad'	(c)	rekkja	['rɛ^{h}tʃ.tʃa]	'bed'
(b)	lappi	['la.^{h}ppɪ]	'rag'	(d)	takka	['t^{h}a.^{h}kka]	'thank'

Scots Gaelic: Scots Gaelic contrasts post-aspirated and non-aspirated stops initially. Post-aspirated stops are realized as pre-aspirated medially and finally after

[60] The same contrast exists for coronals and velars. See Ladefoged and Maddieson (1996: 71).

[61] Pre-aspiration is marked as /hC/ rather than /^{h}C/ to reflect the fact that pre-aspiration in Icelandic is longer than post-aspiration (Ladefoged and Maddieson 1996: 70 and references therein).

[62] Silverman (1997) assumes that pre-aspirated stops are phonological; cf. Thráinsson (1978), Ladefoged and Maddieson (1996), Kehrein (2001), among others, who consider they derive from underlying geminates.

a stressed vowel (Ni Chasáide and Dochartaigh 1984, Ladefoged and Maddieson 1996: 70). Pre-aspirated stops derive from voiceless geminate stops in this language; one example is Proto-Celtic **kattos* > ['kɑ^{h}t] 'cat' (Ni Chasáide and Dochartaigh 1984: 155). Pre-aspirated stops have the same origin in Icelandic and in Irish.

Ni Chasáide and Dochartaigh (1984) suggest that the contrast between voiced and voiceless geminate stops in previous stages of Scots Gaelic was lost due to the difficulty in maintaining voicing in a geminate stop. As voicing was reduced and less perceptible, leftward devoicing started to take place before the voiceless geminate, with glottal/cavity friction at the same time, and when it could be perceived it became the relevant contrast. Ni Chasáide and Dochartaigh (1984) suggest that pre-aspiration evolves in the following way: *kk* > *^{h}k* > *hk* > *xk*. The last stage would be pre-affrication. This would explain the variable realization of aspiration in languages like Tarascan (see below) or the differences in pre-aspiration duration in Icelandic, where pre-aspiration is very long.

Irish Gaelic: Irish has weak pre-aspiration, defined as 'no audible friction', 'silence' or 'weak glottal fricative' (Ni Chasáide and Dochartaigh 1984: 142; also Kehrein 2001). It is reported to occur after stressed vowels, but there is no mention of the absence of pre-aspiration in other contexts.

Ingush: Ingush has fixed initial stress (Nichols 1994). Single stops are post-aspirated initially (55a). Geminated stops are pre-aspirated after underlying long, stressed vowels (55b-d).

(55) Ingush (Kehrein 2001, citing Nichols 1994; IPA)

(a)	/tuxa/	['t^{h}u.xə]	'hit (infin.)'
(b)	/laːtta/	['la^{h}t.(t)(ə)]	'stand (infin., imp.)'
(c)	/beatstsara/	['bea ^{h}ts (ts) ər(ə)]	'green'
(d)	/doaqqa/	['doa^{h}q (q)(ə)]	'take(s)'

Toreva Hopi: Pre-aspirates in the Toreva dialect of Hopi occur intervocalically after stressed vowels (56a). Pre-aspirates contrast with /hC/ clusters (Whorf 1946: 160, cited in Steriade 1997: 73). A change in stress makes pre-aspiration disappear (56b).

(56) Toreva Hopi (from Whorf 1946: 182, cited in Steriade 1997: 73)

(a)	tál-wì^{h}pi	'a lightning flash' (approx.)
(b)	tál-wipì-ki	'a lightning-flash design' (approx.)

Steriade (1997: 73) suggests that the restriction to following a stressed vowel may be related to the vowel's longer duration: 'a longer vowel will reflect preaspiration without becoming completely aspirated itself (cf. Gordon 1996)'.

Ojibwa: Underlying unaspirated voiceless stops and fricatives are pre-aspirated after stressed vowels; elsewhere they are unaspirated (Kehrein 2001, based on Bloomfield 1956). Geminate consonants —/pp, tt, cc, kk/— are pre-aspirated word-medially (Ladefoged and Maddieson 1996, citing Bloomsfield 1956: 8).

Tarascan: Pre-aspirates are reported to occur word-medially after stressed syllables (Silverman 2002, citing Foster 1969). Pre-aspirates vary with pre-spirantized stops; in the case of /t/, it varies to presibilantization after voiced vowels word-medially or after with intervening non-pausal juncture. After [i], pre-aspirates vary freely with vowel length (57).

(57) Tarascan (from Silverman 2002, citing Foster 1969)

(a)	[um.'baʰ̲.p̲a.ni̥]		'to heap things on the floor of the room'
(b)	[a.'ʎaʰ̲.k̲u.ni̥]		'to cut oneself on the hand'
(c)	['pʰaʰ̲.t̲a.ni̥]	~ ['pʰas̲.t̲a.ni̥]	'to touch the metate'
(d)	[kɑ.'tʃuʰ̲.t̲ʃ̲a.ni̥]	~ [kɑ.'tʃuʰ̲.t̲ʃ̲a.ni̥]	'to cut off one's braid'
(e)	['tsɨ ʰ̲.k̲u.ni̥]	~ ['tsɨ̲.ku.ni̥]	'to drop from one's hand'

Summary: Pre-aspiration occurs after stressed vowels; plausibly, pre-aspiration is better perceived in this context (Steriade 1997). In some languages, pre-aspiration occurs after stressed short vowels that arise from underlying long vowels. In languages where pre-aspirated stops derive diachronically from geminates the reason might be that gemination had the effect of shortening the preceding vowel. In the case of Northern Faroese, pre-aspiration is only found after stressed, non-high vowels. It is possible that the restriction of pre-aspiration to after non-high vowels is related to sonority considerations (see discussion in section 4).

Pre-aspiration has two possible sources; post-aspirated stops and geminates. Pre-aspiration derives from post-aspirated stops synchronically. A possible explanation is perceptual; aspiration 'migrates' from its original position in the release of the onset of an unstressed syllable to the pre-closure position after a stressed vowel so that it is better perceived (following Steriade 1997). Pre-aspiration can also derive from voiceless geminates synchronically or diachronically. Debuccalization of the coda portion of the geminate might result in pre-aspiration. In Icelandic, this would be consistent with the extra-long duration for pre-aspiration; the timing of the underlying geminate is maintained, but the place features of the coda portion have been lost.

3.4.3. Glottalization alternations

Post-glottalization refers to the occurrence of a glottal constriction at or after the release of a consonant. In pre-glottalization, a glottal constriction is timed before the oral constriction of a consonant (cf. Howe and Pulleyblank 2001, Steriade 1997). Underlying glottalized consonants are in some cases pre-glottalized after stressed vowels and post-glottalized before them (Coast Tsimshian, Gitksan, Saanich; cf. with Lilloet). Pre-glottalization of underlying non-glottalized consonants is considered in § 3.6.2 under epenthesis.

Table 9

Glottalization

Coast Tshimshian	O	/Sˀ/ → [ˀS]/V_#/'V._V; → [Sˀ]/V_'V	Penutian
Gitksan	O/C	/Sˀ/ → [ˀS]/'V_; _#; → [Sˀ]/_'V;#_	Penutian
Saanich (Səncáθan)	O	/Rˀ/ → [ˀR]/'V_V; → [Rˀ]/V_'V	Salishan
Lilloet (St'át'imcet)	O	/R/ → [ˀR]/'_V; → [Rˀ] elsewhere	Salishan

Coast Tsimhian: In Coast Tsimshian there is a contrast between plain and glottalized stops and sonorants (Kehrein 2001). Glottalized stops are post-glottalized before vowels and pre-glottalized after vowels. Intervocalically, glottalized stops are pre-glottalized if the preceding vowel is stressed and post-glottalized if the following vowel is stressed (Dunn 1995). Glottalized sonorants are always pre-glottalized (Howe and Pulleyblank 2001: 50).

Gitksan: Kehrein (2001) reports that pre- and post-glottalization of stops in Gitksan are conditioned by stress and syllable position. Pre-glottalization occurs word-finally and after stressed vowels; and post-glottalization word-initially and before stressed vowels. Rigsby and Ingram (1990: 251, 262) report that glottalized obstruents have pre-glottalized voiceless allophones pre-consonantally following a stressed vowel. This probably means pre-glottalization occurs in codas of stressed syllables. Rigsby and Ingram (1990) also report that lax glottalized stops occur in pretonic and syllable-final environments.

Saanich: Salish languages also have a plain vs. glottalized contrast for stops and resonants (Kehrein 2001). In Saanich (Sancáθan), a dialect of Straits Salish, intervocalic glottalized resonants are post-glottalized before a stressed vowel, and pre-glottalized after a stressed vowel (Howe and Pulleyblank 2001: 50, 70 and references therein).[63]

Lilloet: Glottalized sonorants are only pre-glottalized before stressed vowels. In all other contexts, glottalized sonorants are post-glottalized (Howe and Pulleyblank 2001: 50-1 and references therein). This pattern does not conform to the preferential perceptual pattern for resonant glottalization —unlike Saanich— because glottalized sonorants tend to be pre-glottalized cross-linguistically. Post-glottalization in resonants would be expected just if there were no preceding vowel, or intervocalically before stressed vowels. See further discussion in section 4.

Summary: Glottalization in laryngealized consonants can be realized before closure or after release. In some languages, this varies according to stress. After a stressed syllable, pre-glottalization occurs. Before a stressed syllable, post-glottalization occurs.

[63] This pattern is referred to in this source as 'attraction of glottalization by the stressed syllable' and compared to Tsimshian in this respect.

3.5. Attraction

Laryngeal and non-laryngeal features alike can be attracted to onsets or codas of stressed syllables. In some instances glottalization is attracted to stressed nuclei. Stress in some languages is attracted by specific consonantal properties such as voicelessness.

3.5.1. Consonantal attraction

Table 10 indicates languages where glottalization is attracted to the coda or nucleus of a stressed syllable.

Table 10

Consonantal attraction[64, 65]

Shuswap	C/N	[c.g.] to 'S	Interior Salish
Twana	C	[c.g.] to ' σ	Central Salish
Thompson River Salish	N	[c.g] to ' N	Interior Salish
Coast Tsimshian	N	[c.g] to ' N	Penutian
Danish	N	[c.g] to ' N	West Scandinavian
Colville	O	Pharyngeal R to stressed suffix	Interior Salish
*Bagneres-de-Luchon French	OO	Liquid to ' σ	Romance

Shuswap: Shuswap has a contrast between pre-glottalized sonorants and post-glottalized obstruents (Steriade 1997 and references therein).[66] Glottalized obstruents are unrestricted. Sonorants can be syllabic or non-syllabic. Non-syllabic glottalized sonorants occur only after vowels, but syllabic sonorants can be glottalized in any context. Steriade (1997) suggests that syllabic sonorants are longer and thus better able to carry the cues for glottalization.

Glottalization in suffixes like /-ilˀəp/ 'foundation', /-kʔ/ 'implement' or /-sxnˀ/ 'rock' is attracted to the final sonorant of a stressed root (58) (Kuipers 1974: 30, Steriade 1997, Kehrein 2001). The final sonorant might be a non-syllabic coda position (58a, c) or a syllabic nucleus (58b, d).[67]

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[64] In Chumash glottalization is attracted to codas (Applegate 1972, cited by Kehrein 2001). The conditions for this process are not well-known (Sharon Inkelas, p.c.).

[65] In Gascon (Occitan) liquids were historically attracted from a complex onset of a non-initial syllable to the preceding syllable if this was heavier than the syllable that the liquid belonged to (Hume 2000, Dumenil 1987). In both its original and final position, the liquid remains part of a complex onset. Some examples include Latin *ca'pra*> Gascon *cra'ba* 'goat' and Latin *ca'stra* > Gascon *cra'ste* 'ditch' (Hume 2000) (the symbol <'> after a vowel means that it has an acute accent).

[66] Citing Kuipers (1974: 24), Kehrein (2001) reports that Shuswap sonorants are pre-glottalized in onsets and post-glottalized in codas.

[67] In Salish languages consonant clusters arise from the deletion of unstressed vowels (Kehrein 2001 and references therein).

(58) Shuswap: Laryngeal attraction (Kehrein 2001, citing Kuipers 1974: 30)

(a)	/'xul-kʔ̱/	['xul̠ˀk]	'firedrill'
(b)	/'tw-kʔ̱/	['tw̱ˀ̱k]	'stg. for sale'
(c)	/-'q'iw-ílˀ̱əp/	['q'iw̱ˀ.ləp]	'chair'
(d)	/'tχ -sxnˀ̱-m-kn/	[tχ.'_ˀ.sx.nm.kn]	'I heat stones'

Steriade (1997) suggests that glottalization attraction to the sonorant in the stressed syllable is a durational effect. Glottalization is realized as pre-glottalization of the sonorant, where the cues for glottalization are carried by the preceding vowel. Since stressed vowels are longer, louder and better able to carry the contextual cues for creak, glottalization is attracted to the stressed syllable (Steriade 1997: 86). Glottalization can also be attracted to a stressed syllabic sonorant, since syllabic sonorants are long enough to carry the cues for glottalization.

Twana: As in Shuswap and other Salishan languages, Twana has stress-triggered glottalization transfer (Thompson 1979, Blevins and Garrett 1998: 525).[68]

Thompson River Salish: Historically, laryngealized resonants in Salishan lost their glottalization to a stressed vowel to the left or to the right (Dunn and Hays 1983: 56, fn. 15, based on Laurence Thompson 1980 p.c.). Thompson River Salish is a clear example of this pattern according to the same authors. This pattern gives rise to glottally interrupted vowels [aʔa] (Kehrein 2001). See also § 3.7.

Coast Tsimshian: Laryngealized codas tend to lose their glottalization to the preceding nucleus, which is laryngealized or glottally interrupted; glottalization can also move to the preceding onset. According to Dunn and Hays (1983: 56, fn. 15), it is possible that this process is stress-related, as in Thompson River Salish. However, they mention that the data is not as clear; they suggest that glottal attraction in these dialects is based on the greater strength of nuclei over codas.

Danish: Stressed vowels in Danish are interrupted (by glottalization); this is usually referred to as stød (Zec 1988 and references therein, Fischer-Jorgensen 1987, Ladefoged and Maddieson 1996).[69]

Colville: Pharyngeal resonants in the root are attracted to the stressed suffix in some words in Colville (Mattina 1979, cited by Blevins and Garrett 1998: 525).

(59) Colville attraction (Blevins and Garrett 1998: 525)

(a)	pʕ̱as	'scared'	c-ps-ʕ̱áyaʔ	'senseless'
(b)	pʕ̱áw	'he ran down'	pw-ən-cʕ̱át-əlx	'they make noise running down'
(c)	qˀʷʕ̱áy	'black'	qˀəy-lscʕ̱át	'his clothes are dirty'
(d)	s-t-qˀʷʕ̱áy-xən-x	'Blackfeet'	qˀʷʕ̱áy-l̥qs	'black robe, priest'

[68] Blevins and Garrett (1998: 525), citing Thompson (1979), report that in Squamish, Nleʔkepmxcín and other Salishan languages, some roots glottalize any sonorants in an immediately following suffix, even if no glottalic element appears in the root; a glottalizing element appears in the roots in the proto-language. It is unclear if stress is relevant in these cases.

[69] Thanks to Uffe Larsen for bringing this data into my attention.

Attraction of /ʕ/ from the root to the stressed suffix is exemplified in (59a-c). (59d) shows that in words where the root is stressed and the suffix unstressed, /ʕ/ remains in the root. According to Bessell (1992, cited by Blevins and Garrett 1998: 525), this process might be foot-sensitive.

Bagneres-de-Luchon French: In Bagneres-de-Luchon French, a liquid in a complex onset of an unstressed syllable is diachronically attracted to a stressed syllable (Blevins and Garrett 1998: 526, Grammont 1905-06). Some examples are included in (60). Grammont (1933) mentions the liquid was attracted to word-initial syllables, but this does not explain (60f).

(60) Liquid attraction in Bagneres-de-Luchon French (Grammont 1933: 339, Blevins and Garrett 1998: 526)

	Stage 1: Latin	*Stage 2*	*Stage 3*	
(a)	'kapṟa		> 'cṟa.bo	'goat'
(b)	'wespera:s	> *wéspṟas	> 'bṟes.pes	'vespers'
(c)	'pawperum	> *páwpṟu	> 'pṟaw.be	'poor'
(d)	'kamera	> *kámbṟa	> 'cṟam.bo	'room'
(e)	'tenerum	> *téndṟo	> 'tṟen.de	'tender'
(f)	'spinula	> espingḻa	> es.'pḻin.go	'safety pin'

Summary: Glottalization is attracted codas and nuclei in stressed syllables. Aspiration can migrate in a non-stress-sensitive fashion, as in Ancient Greek, where aspiration was attracted to the word-initial position (Grassman Law; Collinge 1985 and references therein). Examples of stress-sensitive migration of aspiration might include Icelandic (see Silverman 1997). Stress-sensitive voicing attraction, or voicing attraction in other contexts has not been reported to the best of my knowledge. Glottalization and pharyngeals are attracted by stress in a similar manner. Liquids are attracted from a complex onset in an unstressed syllable to the complex onset of a stressed syllable.

3.5.2. Stress attraction

Stress can be attracted to syllables with specific consonantal properties. This is the mirror image of stress-sensitive consonantal attraction. Stress is attracted by syllables with onsets, especially if these are of low sonority.

Table 11

Stress attraction

Aranda	Stress attracted to onsetful σ	Arandic
Alyawarra	Stress attracted to σ. with (low-sonority) onset	Arandic
Pirahã	Stress attracted to σ. with (low-sonority) onset	Mura
Banawá	Stress attracted to onsetful σ	Arauan
Iowa-Oto	Stress attracted to onsetful σ	Siouan

Aranda: Stress is attracted to onsetful syllables—or, alternatively, repelled by onsetless syllables (Smith 2002 and references therein; Breen and Pensalfini 1999). Aranda has initial stress if the initial syllable has an onset (61a, b). If the initial syllable is onsetless stress moves to the second syllable (61c). Stress cannot be final even if the word is disyllabic and the first syllable lacks an onset (61d).

(61) Aranda stress attraction (Smith 2002)

(a)	pár.pa	'quickly'	rá:.ta.ma	'to emerge'
(b)	kú.tun.gu.la	'ceremonial assistant'	wó.ra.ta.ra	*place name*
(c)	er.gú.ma	'to seize'	u.lúr.ba	'cold; cold wind'
(d)	á:twa	'man'	íl.ba	'ear'

Alyawarra: Stress is attracted to syllables with low-sonority onsets (de Lacy 2001 and references therein). Examples are given in (62).

(62) Alyawarra stress attraction (de Lacy 2001: 9, citing Yallop 1977: 43)

(a)	rín.ha	*3rd person pronoun*	
(b)	i.lí.pa	'axe'	*í.li.pa
(c)	ju.kún.tʲa	'ashes'	*jú.kun.tʲa
(d)	wa.líjm.pa.rra	'pelican'	*wá.lijm.pa.rra

Stress is initial by default (62a). When the initial syllable is onsetless stress falls on the second syllable (62b). When the first syllable has a glide as onset, stress falls on the second syllable (62c, d). Compare Niaofʻou (Polynesian) where glides are avoided in stressed syllables, being realized as high vowel nuclei of a separate syllable (Smith 2002, de Lacy 2001).

Pirahã: Pirahã has the same pattern as Alyawarra; stress is attracted by syllables with (low-sonority) onsets (Everett 1988, Everett and Everett 1984ab, Smith 2002). Stress in Pirahã is final by default (63a) but is attracted by long vowels and diphthongs elsewhere in the word (63b). If there is a tie stress falls on the syllable with a voiceless onset in preference to a voiced onset (63c), or by an onsetful syllable rather than an onsetless one (63d). If all potentially stress-attracting syllables have voiceless onsets, stress falls on the rightmost of them (63d).

(63) Pirahã (from Smith 2002, citing Everett 1988. Underline shows high tone)

(a)	pao̲.hoa.hái	'anaconda'	gi̲.go.gí̲	'what about you?'
(b)	ʔa.ho.áo̲.gi	*proper name*	gíi.so̲.gi	'turtle'
(c)	káa.gai	'word'	bii̲.sái	'red'
(d)	gáo.ii	*proper name*	po̲o̲.hói.hi̲.ai	'fish'

Banawá: This Arauan language spoken in Brazil has left-to-right moraic trochees with main stress on the initial syllable. In words with more than two syllables with initial onsetless syllables, main stress falls on the second syllable (64) (Buller, Buller and Everett 1993, Everett 1996).

(64) Banawá (from Everett 1996: 22)

(a)	wánakàri	'spider'	(c)	úwi	'cry'
(b)	uwárià	'one'	(d)	uwía	'go out (as a fire)'

Iowa-Oto: Stress is also attracted to onsetful syllables in Iowa-Oto (Downing 1998 and references therein).

Summary: Stress is attracted to onsetful syllables or to syllables with voiceless onsets. It has been suggested that non-sonorous onsets in stressed syllables provide a better perceptual consonant-vowel contour, improving sonority in the stressed syllable as a whole and making stress more perceptible (Smith 2002 and references therein).

3.6. Deletion and epenthesis

This section considers prosodically-determined deletion and insertion. Both laryngeal and non-laryngeal features and consonants delete in weak or unstressed positions. Laryngeal consonants are inserted in strong or stressed positions.

3.6.1. Deletion

Various languages are reported to delete laryngeal and non-laryngeal features and consonants in weak and unstressed positions, both in synchronic and diachronic processes.

Table 12

Deletion[70]

English	O	/h/ in σ̆	Germanic
Chali (Tati)	O	/h/ in σ̆	Indo-Iranian
Squamish	O/C	/ʔ, Rˀ/ in σ̆	Central Salish
Oneida	C	/h, ʔ/ in post-tonic σ̆	Iroquoian
Popoloca	O	/ʔ, ʰ, ⁿ/ in σ̆	Otomanguean
Capanahua	C	/ʔ/ in weak footed σ̆	Panoan
Faroese	C	/k/ in unstressed /skt/ cluster	West Scandinavian
Chilean Spanish	C	/s/ in σ̆	Romance
Old English	O/C	[l] in coda of σ̆; [w] in onset of σ̆	Germanic
*Romance	O/C	Liquid in σ̆	Indo-European

English: /h/ is not pronounced in unstressed, non-initial syllables (Borowsky 1986, Hammond 1999, Davis 1999, 2002, Davis and Cho 2003). In (65), the notation <h> represents that /h/ is spelled but not pronounced.

70 Kehrein (2001) reports that in Straits Salish /ʔ/ deletes in unstressed syllables. This is not clear from the description in Thompson, Thompson and Efrat (1974), which mentions a tendency for /ʔ/ to be deleted in coda. The only mention of stress is that some Northern Straits speakers tend to delete all coda /ʔ/, even in stressed syllables (Thompson, Thompson and Efrat (1974: 187).

(65) Deletion of English /h/ (from Borowsky 1986: 271-4, Davis 2002)

(a) Ha'waii	'Hilary	(e) 'Le<h>iste	Le'histe
(b) a<h>!	a'ha!	(f) 'alco,hol	'Ida ho
(c) 've<h>icle	ve'hicular	(g) ˌTarahu'mara	
(d) pro<h>i'bition	pro'hibit	(h) ex<h>i'bition	ex'<h>ibit

/h/ is pronounced word-initially regardless of stress (65a). /h/ is never pronounced in codas (65b). As a word-medial onset, /h/ is only pronounced in stressed syllables (65c, d). Changing the stress in a word has repercussions for the pronunciation of /h/ (65e). Since /h/ is pronounced in stressed syllables only, speakers will or will not pronounce [h] depending on where they are told stress falls. /h/ is pronounced in onset of syllables with secondary stress (65f), and in unstressed syllables between an unstressed and a stressed syllable (65g). Finally, /h/ is not pronounced as a possible second member of an onset (65h).

According to Davis (2002), the distribution of /h/ in English is parallel to the distribution of aspiration. Both aspiration and /h/ have in common the feature [spread glottis]; this feature occurs foot-initially. Davis (2002) proposes that in cases like (65g), where [h] occurs in unstressed syllables, the creation of a superfoot explains the occurrence of [h]. A word like *ˌTarahu'mara* would be footed [('ta.ra.){hu.('ma.ra)}], with [h] being foot-initial (curly brackets indicate a superfoot). For more details see Davis (2002).

Chali Tati: In the Chali dialect of Southern Tati (and probably in other related dialects) /h/ is reported to be 'most apparent' initially or as the onset of a stressed syllable; some examples are [hɔʷ.væ] 'co-wife' and [dø.'høl] 'drum' (Yar-Shater 1969: 34; IPA). From this description, it is ambiguous whether deletion or simply weakening of aspiration occurs in unstressed, non-initial positions. /h/ is reported to usually delete in this dialect in Farsi loanwords in 'final and preconsonantal positions and in secondary contact after a consonant when unstressed'. One example is ['pænj (h)æzar] 'five thousand' (Yar-Shater 1969: 34).

Additionally, preconsonantal coda /h/ deletes but lengthens a preceding short vowel; this process also occurs with coda /ʔ/ and /j/ (Yar-Shater 1969: 34, 52). Stress in Southern Tati is morphophonemic (Yar-Shater 1969: 57-8).

Squamish: Morpheme-initial /ʔ/ in unstressed syllables sometimes deletes after a consonant. One example is /s-(ʔ)əq'ᵒ*i'ʔtl/ 'siblings and cousins'; parentheses around /ʔ/ indicate it is usually or always deleted (Kuipers 1967: 40). Additionally, morpheme-final /ʔ/ is deleted in some morphological formations, as in unstressed syllables of plural reduplication (66) (Kuipers 1967: 52). These processes exemplify a tendency to delete /ʔ/ in unstressed syllables, as suggested in Kuipers (1967: 55).

(66) Plural reduplication: deletion of unstressed /ʔ/ (from Kuipers 1967: 52; stress is marked after the relevant vowel)

(a) lamʔ	'house'	lm-.la'mʔ	'houses'
(b) mənʔ	'child'	mə'nʔ.-mn	'children'

The structure of plural reduplication words in Squamish is reduplicant + base. In plural reduplication, stress maintains its position as in the non-reduplicated stem (66a). Reduplicated monosyllabic stems with /ə/ have stress on the reduplicated syllable (66b) (Kuipers 1967: 100). For related processes, see § 3.3.3.

Oneida: Coda /h, ʔ/ delete in stressed syllables, and in post-tonic syllables before a resonant (Lounsbury 1942, Michelson 1988). In stressed syllables, coda /ʔ, h/ lower the pitch of the syllable; their deletion in this position causes concomitant lengthening of the preceding vowel (Chafe 1977, Michelson 1988: 71). Accent in Oneida usually falls on the penultimate syllable (see Michelson 1988 for details).

(67) Oneida deletion of /h, ʔ/ in post-tonic syllables (from Michelson 1988: 76)[71]

(a)	/k-eh̲ya**h**l-ʔ̲/	['ke·.ya.leʔ̲]	'I remember'[72]
(b)	/k-ʔ̲skoʔ̲-s/	['ke·s.koʔ̲s]	'I keep drowning'
(c)	/hlaw-ehyah̲l-a-ʔ-u/	[la.weh.yah̲.'la· u]	'He did remember
(d)	/waʔ̲-k-ʔ̲sko**ʔ**-nʔ/	[waʔ̲.'ke· s.ko.neʔ]	'I'm drowning, I fell in the water'

Deletion of coda /h, ʔ/ in stressed syllables and concomitant vowel lengthening is shown in (67a, b, d). Bold /h/ and /ʔ/ in (67a, d) delete because they occur in coda of post-tonic syllables. In (67b), /ʔ/ remains because it is followed by an obstruent. Pretonic laryngeal codas do not delete (67c); underlined /ʔ/ in (67d). Word-finally, /ʔ/ remains (67a, d).

Oneida has an additional stress-sensitive phenomenon concerning /ʔ/. Post-tonic /ʔ/ is pronounced as /h/ before a single onset obstruent utterance-medially (68a), and utterance-finally regardless of the number of obstruents (68c, d) (Chafe 1977, Michelson 1988).

(68) Oneida post-tonic /ʔ/ → [h] (from Michelson 1988: 76-7, 89)

(a)	/waʔ̲-k-atkʌhlaʔ̲t-ʔ/	[waʔ̲.kat.'kʌ·.lah̲.teʔ]	'I stopped'
(b)	/wak-atkʌhlaʔ̲t-u-/neʔ/	[wa.kat.kʌh.laʔ̲.'tu·.neʔ]	'I had stopped'
(c)	/tekatjaʔ̲ks/	[te.'ka.tjah̲ks]	'I'm tired'
(d)	/lohsuʔ̲/	['loh̲.suh]	'he finished'

Underlined /ʔ/ is pronounced as [ʔ] in pre-tonic coda (68a, b). In post-tonic syllables before a single onset /ʔ/ is pronounced as [h] (68a, c).

Popoloca: In Los Reyes Mazatlán Popoloca, various consonants or features are reported to delete in unstressed syllables, including /ʔ/, pre-aspiration, and pre-nasalization (Veerman-Leichsenring 1984: 52, cf. Stark and Machin 1977: 79). Post-aspirated /t^h, $tʃ^h$, $ʈʂ^h$/ lose their pre-aspiration, and /k^h, $ʈs^h$/ are pronounced as /x, s/. Additionally, in unstressed syllables there is neutralization between /ʈs/ and /s/, and between /n̥/ and /n/. See also § 3.3.1, 3.4.1 and 3.4.3.

[71] Syllabification in (67, 68) is mine.

[72] [e] is epenthesized into word-final C/ clusters in (67a, d) and (68a). See Michelson (1988: 144-6) for details.

Capanahua: /ʔ/ is reported to delete in codas of even-numbered syllables starting from the beginning of the word (Loos 1969). In metrical terms, this corresponds to weak footed syllables; Capanahua has moraic trochees (Safir 1979, González 2002a).

(69) Capanahua: deletion of /ʔ/ (from Loos 1969).

(a)	/taʔ/	*declarative modal*
(b)	/ɾaʔ/	'probably'
(c)	[(ʔo .tʃi) (ti .ɾa) (**taʔ .**ki)]	'It is probably a dog'
(d)	[(ʔo .tʃi) (ti .ma) (ɾaʔ. **ta)** ki]	'It is probably not a dog'

The declarative modal /taʔ/ maintains the coda /ʔ/ in strong position within a foot (69c). In weak position /ʔ/ deletes (69d). The same occurs with the adverb /ɾaʔ/ 'probably'. See González (2003, 2009) for an extensive analysis of this process, and Elías-Ulloa (2006, 2009) for acoustic data and an alternative approach.

Faroese: /k/ deletes in a /skt/ cluster in unstressed syllables (70) (Hume 2000; Hume and Seo 2001). In stressed syllables, /s/ and /k/ metathesize to [kst].

(70) Faroese deletion (Hume 2000)

(a)	ˈfɛsk	ˈfɛks-t	'fresh-fem. sg./neuter singular'
(b)	ˈrø.sˈɪs.kor	ˈrø.sˈɪs-t	'Russian-stem/neuter singular'

In (70a), the addition of the neuter singular suffix /t/ to a stressed syllable ending in /sk/ causes the change in order of /sk/ to [ks]; the addition of the same suffix to an unstressed position causes the deletion of /k/. For more details, see § 3.7.

Chilean Spanish: In Chilean Spanish and many other Spanish dialects, /s/ tends to be aspirated or even deleted in syllable-final position. For example, in a word like /despues/ 'later', word-final /s/ will be pronounced [des.ˈpweh], [des.ˈpwe], or, less frequently, [des.ˈpwes]. Deletion of /s/ syllable-finally in Chilean Spanish is more likely in unstressed syllables, and aspiration and to a lesser extent /s/ retention are more likely in stressed syllables (Cid-Hazard 2004).

Old English: Deletion of [l] occurred for the weakly stressed variants of *should* and *would* in Old English (Kabell and Lauridsen 1984: 50). It is also thought that /w/ deleted in onsets of weakly stressed syllables, as in *answer* (Kabell and Lauridsen 1984: 83 and references therein).

Romance: In the development of Romance languages, coda liquids were deleted in unstressed syllables (as in French *pa.te.ˈnô.tre* from Vulgar French *pa.ter.ˈnos.ter*) or in onset positions (as in Spanish *a.ˈra.do* from *a.ˈra.tru*) (Grammont 1933: 289-303). Deferrari (1954: 141) reports that in the development from Vulgar Latin to Italian final consonants generally deleted, especially after unstressed vowels. Some examples are *ˈmar.mo* from *ˈmar.mor* 'marble', and *ˈcor.po* from *ˈcor.pus* 'body' (Deferrari 1954: 184, 186).

Summary: Featural and segmental consonantal deletion takes place in unstressed syllables and can affect both onsets and codas. In many cases, the features or segments deleted are laryngeal.

3.6.2. Epenthesis

Laryngeal features and consonants are inserted in stressed or strong positions in various languages. Epenthesis of [t] is found in some dialects of English between a sequence [ns] preceding an unstressed vowel.

Table 13

Epenthesis

English	O	[ʔ] phrase-initially and in 'σ /p, t, k/ → [ˀp, ˀt, ˀk]/ 'V._/foot medially [t]/n_sv̆	Germanic
German	O	[ʔ] morpheme-initially and in ' σ	Germanic
Dutch	O	[ʔ] in 'σ	Germanic
Paipai	O	[ʔ] in word-initial 'σ	Hokan
Walapai	O	[ʔ] in 'σ	Hokan
Silacayoapan Mixteco	O	[ʔ] word-initially and foot-initially	Otomangean
Huariapano	C	[h] in strong open σ	Panoan (extinct)
Urarina	C	[h] in strong open σ	Isolate
Popoloca	O	Stops, affricates → [ˀC]/'V_	Otomanguean

English: Mompeán and Gómez (2011) and Davidson and Erker (2014) show that glottal stops and glottalization are more likely for vowel sequences across word boundaries if the second vowel in the sequence is stressed, for British and American English, respectively (see also Pierrehumbert and Talkin 1992, Pierrehumbert 1995 and Dilley and Shattuck-Hufnagel 1996).

In some dialects, as in Tyneside and London English, intervocalic voiceless stops pre-glottalize between vowels, especially if the first vowel has primary or secondary stress (Carr 1999).[73] Some examples are *clipper* ['klɪ.ʔ̲p̲ʌ], *fitter* ['fɪ.ʔ̲t̲ʌ], and *hacker* ['ha.ʔ̲k̲ʌ]. This pattern also occurs when a sonorant immediately precedes the stop, as in *grumpy* ['gɹTm./pɪ], *auntie* ['ɑːn.ʔ̲t̲ɪ], *hankie* ['haŋ.ʔ̲k̲ɪ]. Carr 1999 suggests that the relevant context is foot-internal position, parallel to flapping in American English.

In many dialects of English a 'brief transitional stop' is optionally epenthesized between the sequence [ns] followed by an unstressed vowel (Clements 1987, Hayes 1995). One example is *mensa* ['mɛnt̲sə] vs. *insane* [ɪn'seɪn] (from Hayes 1995: 12, 13; IPA).

German: In Standard German, [ʔ] is epenthesized as onset morpheme-initially (71a, b) and in primary-stressed syllables (71c, d; cf. with 71e, f) (Wiese 1996, Alber

[73] Tyneside English is spoken around the area of Newcastle-upon-Tyne (Northern England).

2001). Some speakers also epenthesize /ʔ/ in onsetless syllables with secondary stress (71g, h).

(71) Epenthesis of [ʔ] in German (from Alber 2001; IPA)

(a)	*Oase*	[ʔ̲o.'ʔ̲aː.zə]	'oasis'
(b)	*anerkennen*	['ʔ̲an.-ʔ̲er.-'ken.nen]	'to acknowledge'
(c)	*Poet*	[po.'ʔ̲eːt]	'poet'
(d)	*naiv*	[na.'ʔ̲iːf]	'naive'
(e)	*kreativ*	[ˌkre.a.'tiːf]	'creative'
(f)	*Joachim*	['jo.a.chim]	*proper name*
(g)	*Canaan*	['ka.na.ˌʔ̲an]	'Canaan'
(h)	*Michael*	['mi.xa.ˌʔ̲el]	*proper name*

The phonetic study reported in Kohler (1994) shows that stress influences epenthesis morpheme-initially. Epenthesis occurred in morpheme-initial, stressed syllables about 95% of the time, but only about 72% of the time in morpheme-initial unstressed syllables.

Dutch: In Dutch, a sequence of two vowels is broken by a glide or a glottal stop (Jongenburger and van Heuven 1991; Smith 2002, citing Booij 1995). Which glide is inserted depends on the nature of the first vowel (72).

(72) Epenthesis in Dutch (from Smith 2002, citing Booij 1995: 22, 23)

(a) Januari	[ja.ny.'ɥ̲a.ri]	'January'	duo	['dy.ɥ̲o]	'duo'
(b) Diet	[di.'j̲et]	'diet'	Gea	['ɣe.j̲a]	*name*
(c) Ruanda	[ru.' ʋ̲ɑn.da]	'Ruanda'	Houen	['hɔu.ʋ̲ən]	'to hold'
(d) Chaos	['xa. ɔs]	'chaos'	farao	['fa.ra.o]	'pharaoh'
(e) Paella	[pa.'ʔ̲ɛ.lja]	'paella'	aorta	[a.'ʔ̲ɔr.ta]	'aorta'

If the first vowel is front rounded, [ɥ] is inserted (72a). If the first vowel is front unrounded, [j] is inserted (72b). [ʋ] is inserted after non-low back vowel (72c). Glide insertion is insensitive to stress, unlike /ʔ/ insertion. After /a/, no insertion takes place if the second vowel is unstressed (72d); if the second vowel is stressed, [ʔ] is inserted (72e).[74]

Paipai: Epenthesis of [ʔ] appears to occur in various Yuman languages under stress. In Paipai, [ʔ] is reported to occur word-initially before consonants and vowels. It is obligatory before initial stressed vowels, as in ['ʔoχ] 'cough', and optional before initial consonants followed by a stressed vowel, as in ['pa], ['ʔpa] 'man, person' (Wares 1968: 43).[75] Stress in Yuman languages falls on the last syllable of the stem (Wares 1968: 29).

Walapai: Stressed vowels in unextended root forms are always preceded by /ʔ/ or another consonant, while unstressed vowels may occur without a preceding or fol-

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[74] Stress usually falls on the penultimate syllable in Dutch, but there are many exceptional forms with final or antepenultimate stress (Van der Hulst 1984, Kager 1989, Booij 1995, among others).

[75] [χ] corresponds to a 'back velar' voiceless fricative (Wares 1968: 43; cf. 27, 28).

lowing glottal stop. Some examples are *ucíʔ* 'coals' and *wasʔámi* 'doorway' (Wares 1968: 28-29).

Silacayoapan Mixteco: [ʔ] is inserted in onset position word-initially and before stressed vowels, as in /ɪʔ.ní/ [('ʔɪʔ.ní)] 'hot' (North and Shields 1977: 21). See also § 3.3.4.

Huariapano: [h] is epenthesized in codas in odd-numbered syllables from the beginning of the word, provided that the following consonant is voiceless: [ˌyo.mɯrah. ka. 'tih. kæy] '(They) hunted' (Parker 1994, 1998). This distribution coincides with default secondary stress in this language, which is assigned in syllabic trochees constructed left-to-right. See § 4 for a more detailed discussion.

Urarina: Urarina has a process of coda [h] epenthesis that is very similar to Huariapano. It occurs once per root at most, always in odd-numbered syllables, especially if word-initial (Olawsky 2006: 40-42, 868-873). It is never attested in final syllables, non-high toned syllables, or in two syllables in a row. Compare for example the word [kwʉh.tʉ.ri] 'head' with /ka-kwʉtʉri/ [kah.kwʉ.tʉ.ri] 'My head' [1sg = head]. Interestingly, Urarina dialects differ in the exact odd-numbered syllable where [h] is epenthesized (Olawsky 2006: 42, 80). For a more detailed analysis of this phenomenon under a metrical perspective, see (González 2011).

Popoloca: Unaspirated stops and affricates are pre-glottalized in onsets after stressed short vowels (73).

(73) Popoloca pre-glottalization (from Veerman-Leichsenring 1984: 43-4)

(a)	[kuː.'tʃá**ʔ.p**i]	'mocking bird'	(d)	['nù**ʔ.t̪s**é]	'star'
(b)	['ku**ʔ.t**ũ]	'road-runner'	(e)	['ⁿʒi**ʔ.tʃ**à]	'candle'
(c)	['tʃà**ʔ.k**uː]	'face'	(f)	['kà**ʔ.t̪ʂ**uː]	'maguey (pita)'

Fricatives, liquids, approximants and voiced nasals geminate in onsets after stressed vowels. In the same position, pre-nasalized, aspirated, and voiceless nasal consonants are decomposed into a coda and an onset element (§ 3.3.1). Pre-glottalization of unaspirated stops and affricates is a related process; pre-glottalization resyllabifies as the coda of the preceding syllable.

Summary: Epenthesis of laryngeal features and consonants is common in onsets of stressed syllables. Epenthesis of [ʔ] is more common that epenthesis of [h]. For some languages, this distribution is coherent with a foot analysis in which epenthesis takes place foot-initially. Epenthesis of brief transitional elements, as in English, can also be stress-sensitive.

3.7. Metathesis

Metathesis is a reversal in the linear order of adjacent segments or features. It can occur in stressed syllables, in strong footed syllables, or in unstressed syllables.

Table 14

Metathesis[76]

*Cayuga	/CVh, CVʔ/ to /ChV, CʔV/ in non-final weak σ	North Iroquoian
*Mohawk	/CʔV/ to /CVʔ/ in post-tonic (weak) σ	North Iroquoian
Oneida	/CʔV/ to /CVʔ/ in post-tonic (weak) σ	North Iroquoian
Thompson River Salish	/h, ʔ/ onset/coda in pre-tonic σ depending on following segment	Interior Salish
Capanahua	Onset /ʔ/ to coda in strong footed σ	Panoan
Faroese	/skt/ to /kst/ in ' σ	West Scandinavian
*Le Havre French	*rə > ər before non-labial C in σ̆	Romance

Cayuga: /h/ and /ʔ/ in non-final odd-numbered syllables underwent coda-to-onset laryngeal metathesis (74a, b) (Chafe 1977: 175-178, Foster 1982, Michelson 1988: 104, Dougherty 1993, Blevins and Garrett 1998). This had the effect of 'weakening' odd-numbered syllables (Michelson 1988: 104).

(74) Cayuga: laryngeal metathesis (from Chafe 1977: 177-178; IPA)

	Proto-Northern Iroquoian	*Cayuga*	*Gloss*
(a)	*o.cih.'sõʔ̱.taʔ	o.'cih.sʔ̱õ.taʔ	'star'[77]
(b)	*ke**h**.nyaʔ.'saʔ̱.keh	kẹ̥.'nya/.sʔ̱a.keh	'On my neck'
(c)		ke.'ka.haʔ̱.keh	'my eye'

Metathesis of /ʔ/ did not lead to onset glottalization; /ʔ/ is articulated separately (Chafe 1977: 177). Metathesis of /h/ had the effect of devoicing the preceding vowel (74b). No metathesis of /h/ occurred in even-numbered syllables (74a, b). Metathesis was blocked when the onset is a laryngeal (74c).

According to Chafe 1977, odd-numbered syllables in Cayuga are phonologically weaker and never eligible for main stress, which is usually assigned to the rightmost even-numbered, non-final syllable, unless the original accent in Proto-Northern-Iroquoian fell on a long vowel in an open syllable. Footing is iambic; laryngeal metathesis can be described as occurring in the weak element of the iambic foot. Foster (1982: 61) reports secondary stress for even-numbered syllables that occur before the primary stress.[78]

For Blevins and Garrett (1998) the origin of metathesis in Cayuga is phonetic; they analyze this process as an instance of perceptual metathesis, by which a conso-

[76] Zoque (Mixe-Zoquean) has onset-to-coda metathesis that achieves a reduction in the number of syllables (Blevins and Garrett 1998). It is unclear if this case is prosodic.

[77] Penultimate stress from Proto-Northern-Iroquian is maintained if the penult is long; otherwise stress is placed on the rightmost nonfinal even syllable (Michelson 1988: 98-100 and references therein).

[78] Dougherty (1993: 162-263), as cited by Blevins and Garrett (1998), did not find any acoustic correlates of secondary stress in Cayuga in spite of the impression of iambic rhythm.

nant in an ambiguous phonetic string is reinterpreted as originating from a non-historical position. They suggest that nuclei of weak syllables in Cayuga were phonetically shortened. Coda /h/ and /ʔ/ overlapped the nuclei of weak syllables; in the case of /h/, the adjacent vowel was devoiced. CV̥ was interpreted as standing for ChV rather than CVh. The same occurs for coda /ʔ/, which overlapped the preceding vowel with creaky voice. Evidence for their analysis comes from conflicting evidence from orthography as to the position the laryngeal is associated with, and from a phonetic experiment by Dougherty (1993) where 'laryngeal spreading' failed to occur when words were read with pauses before each syllable.

Mohawk: Some /CʔV/ sequences appear to have metathesized to [CVʔ] in post-tonic final position in Mohawk (75) (Blevins and Garrett 1998).

(75) Mohawk metathesis (from Michelson 1988: 56; IPA, syllabification mine)

(a)	/k-at-itʔ̠a-s/	[ka.'ti.taʔ̠s]	'I get into something'[79]
(b)	/hs-rihw-isʔ̠a-s/	[se.rih.'wi.saʔ̠s]	'You always promise'
(c)	/k-ojʔ̠ak-s/	['ko.jaʔ̠ks]	'I throw'
(d)	/wak-nuhs-isʔ̠(a)-u-hatje/	[wakenuhsisuʔ̠'hatje]	'I finish the house a little bit at a time'

This case of apparent diachronic metathesis is frequently considered to involve two separate processes of vowel reduplication and subsequent vowel deletion (Lounsbury 1953: 87, Postal 1969, Michelson 1988: 56-8). For discussion see Blevins and Garrett 1998: 524.

Oneida: Diachronic metathesis of /CʔV/ sequences to /CVʔ/ is reported in post-tonic position, as in Mohawk (Blevins and Garrett 1998: 524-5).

Thompson River Salish: Regardless of the underlying position of /h, ʔ/, these segments surface as codas in Thompson River Salish (Nłeʔkepmxcín) before tonic syllables starting with a consonant or a cluster beginning with an obstruent (76a, c, e; cf. with 70 b, d). They surface as onsets when preceded by tonic syllables whose onset is null or a cluster beginning with a resonant (76) (Thompson and Thompson 1992, Thompson, Thompson and Edgesdal 1996, Blevins and Garrett 1998).[80]

(76) Thompson River Salish metathesis (from Blevins and Garrett 1998: 513)

	Underlyingly prevocalic		
(a)	/məkʷʔ̠u-t-éʃ/	[mkʷuʔ̠.téʃ]	'she wraps it'
(b)	/məkʷʔ̠u-énʔih-n-t-éʃ/	[məkʷʔ̠énˀinʃ]	'she wraps, covers it up'
(c)	/mʔ̠aʕ-újəmˀxʷ/	[maʔ̠.ʕújmˀxʷ]	'it grows light'
(d)	/mʔ̠aʕ-mín-t-ʃej-me/	[mʔ̠aʕmín.tʃi.me]	'it grows light on me'
(e)	/tʃˀʔ̠o-tʃˀʔóz/	[tʃˀoʔ̠.tʃˀʔóz]	'it is rather dark'

[79] Stress in Mohawk falls on the penultimate syllable in inflected words (all verbs and most native nouns) and in some uninflected particles. Other uninflected particles and most borrowings have final stress (Michelson 1988: 53-4).

[80] Resonants in Thompson River Salish are /m, n, l, z, j, ɤ, w, ʕ, ʕʷ/ (Thompson et al. 1996: 615).

Underlyingly postvocalic

(f)	/tʃeh-'əme/	[tʃhém]	'she puts (things) away'
(g)	/tʃeh- t-éʃ/	[tʃe.téʃ]	'he fixes it'
(h)	/tʃˀeʔ-'əme/	[tʃˀʔ'əm]	'she lays out (s.t. to sit on)'
(i)	/ʃ-naʔz- ítʃˀeʔ/	[ʃnaʔ.zí.tʃˀeʔ]	'mountain-goat-hair blanket'

In (76g, i) the laryngeals are underlyingly postvocalic and surface as codas because they precede a single consonant (/h/ is not pronounced in (76g) because non-pre-vocalic /h/ is deleted). In (76f, h) the laryngeals are intervocalic but pre-morpheme-boundary; they surface as onsets because they precede an onsetless vowel. In (76f, h) the vowels immediately preceding the tonic syllable delete (Thompson and Thompson 1992: 31, 39).

Blevins and Garrett (1998: 513) propose that the origin for metathesis in Thompson River Salish is related to coarticulation between the vowel and a following laryngeal. Before a single consonant or a cluster beginning with an obstruent, a laryngeal will make a preceding vowel fully laryngealized. Coda /h, ʔ/ before a cluster beginning with a resonant will only make the preceding vowel partially laryngealized. Fully laryngealized vowels are interpreted as originating from /Vʔ/, while partially laryngealized vowels are interpreted as originating from /ʔV/. See Blevins and Garrett (1998) for details.

Capanahua: Loos and Loos (1998: 21-2) report onset-to-coda /ʔ/ metathesis in odd-numbered syllables, especially in fast speech. If this syllable already has a coda /ʔ/, the onset /ʔ/ deletes.

(77) Capanahua metathesis of /ʔ/ (Loos and Loos 1998: 21, 22; IPA)

(a)	/ketsin-ʔino/	[ke.('tsĩ).)(ĩ)ʔ.no)]	'painted tiger'
(b)	/toaʔiʔka/	[('to.a.)(iʔ.ka)]	'mattress'

Since Capanahua has moraic trochees (Safir 1979, González 2002a), /ʔ/ metathesis occurs in strong footed syllables. In this language, metathesis 'deletes' the onset to produce a coda, a position which is cross-linguistically dispreferred. González (2003, 2009) proposes that metathesis creates a rhythmic contrast between strong and weak footed syllables. See also § 3.6.1.

Faroese: The sequence /skt/ after a vowel or nasal metathesizes to [kst] in stressed syllables (78). In unstressed syllables, /k/ deletes from the sequence (§ 3.6.1). These sequences arise from suffixation of /t/.

(78) Faroese metathesis (from Hume 2000)

(a)	'dansk	'daŋks-t	'Danish-fem. sg./neuter singular'
(b)	'svɛnsk	'svɛnks-t	'Swedish-fem. sg./neuter singular'
(c)	'fɛsk	'fɛks-t	'fresh-fem. sg./neuter singular'
(d)	rø.sˡɪs.kor	'rø.sˡɪs-t	'Russian-stem/neuter singular'
(e)	'falsk	'fals-t	'false, stem/neuter singular'
(f)	'ir.kir	'ir.ti	'write poetry, 2nd/3rd p. pres./past sg'

Metathesis occurs in stressed syllables (78a-c); /k/ deletes from the /skt/ cluster in unstressed syllables (78d). /k/ also deletes from a /skt/ (78e) or /kt/ (78f) cluster in a stressed syllable if preceded by a liquid.

Hume (2000) and Hume and Seo (2001) suggest that Faroese metathesis is triggered by perceptual optimization. Moving /k/ to postvocalic or post-sonorant position in a cluster enhances the perceptibility of /k/ due to the availability of a vowel or sonorant transition.

Le Havre French: Diachronically, /*rə/ metathesized to [ər] in unstressed syllables, except when immediately followed by /f, v, m/. Furthermore, in unstressed syllables before /f, v, m/, /*ər/ became [rə] (79) (Grammont 1909, cited by Blevins and Garrett 1998: 516).

(79) Le Havre French metathesis (Blevins and Garrett 1998: 517; syllabification mine)

Unstressed /*rə/ *to* [ər] *before consonants other than* /f, v, m/

(a)	bretelle	[bər.'dɛl]	'suspenders'
(b)	brebis	[bər.'bi]	'ewe'
(c)	grenier	[gər.'nje]	'granady'
(d)	grésil	[gər.'zi]	'sleet'
(e)	écrevisse	[e.krə.'viʃ]	'crayfish'
(f)	crevasse	[krə.'vaʃ]	'crack'

Stressed /*ər/ *to* [rə] *before* /f, v, m/

(g)	épervier	[e.prə.'vie]	'sparrow-hawk'
(h)	fermé	[frə.'me]	'closed'
(i)	fourmi	[frə.'mi]	'ant'
(j)	gargouiller	[gər.du.'je]	'gurgle'

In (79a-d), /rə/ metathesizes to /ər/ in an unstressed syllable. Metathesis does not occur before /v/, as shown in (79e, f). In (79g-i) /ər/ metathesizes to /rə/ before /m, v/; metathesis does not occur before other consonants (79j). One question is why /f, m, v/ are key in this process.

Summary: Metathesis tends to occur in unstressed syllables. It tends to affect features and segments 'whose acoustic or perceptual cues have relatively long durations' (Blevins and Garrett 1998: 511), including laryngeals and rhotics. Metathesis can also occur in stressed syllables. In both cases, the motivation for this process appears to be perceptual. In unstressed syllables, metathesis appears to take place because of perceptual ambiguity as to the original position of the consonant; in stressed syllables, in order to improve the perceptibility of a consonant.

3.8. Assimilation[81]

Assimilation refers to featural change that makes a segment more like an adjacent segment. One reported case of stress-sensitive assimilation is the Tupí-Guaraní language Guajajára.

Table 15

Assimilation

Guajajára	O	/ts/ → [tʃ]/_i, _ 'e	Tupí-Guaraní

Guajajára: In this language, /ts/ always palatalizes to [tʃ] before /i/. It also palatalizes before /e/ in heavily stressed syllables (Bendor-Samuel 1972: 63). For related processes, see § 3.4.1 and 3.3.4.

3.9. Dissimilation

Dissimilation refers to featural change that makes a segment less like an adjacent segment. Reported cases of stress-sensitive dissimilation are diachronic and include Gothic and other Romance languages.

Table 16

Dissimilation

*Gothic	O/C	Voice dissimilates in σ̆	East Germanic
*Romance	O, C	Liquids dissimilate in σ̆	Indo-European

Gothic: Thurneysen's Law in Gothic refers to the dissimilation in voicing of a consonant from that of a preceding obstruent after an unstressed syllable (Chomsky and Halle 1968, Mossé 1956, Collinge 1985). Dissimilation seems to occur only in three-syllable words (74). Stress in Gothic falls on the first syllable (Wright 1957).

(80) Gothic dissimilation (Chomsky and Halle 1968: 351, Mossé 1956: 68; Collinge 1985: 183; IPA, syllabification mine).

(a)	['ha.tis]	'hatred'	['ha.ti.z̠is]	'hatred (gen. sg.)'
(b)	['a.gis]	'fright'	['a.gi.s̠is]	'fright (gen. sg.)'
(c)	['ɸas.tuβ̠.ni]	'position'	['ɸrais.tuβ̠.ni]	'temptation'
(d)	['wal.duɸ̠.ni]	'force'	['wun.duɸ̠.ni]	'wound'

In (80a, c), there is dissimilation from a voiceless obstruent. In (80b, d) there is dissimilation from a voiced obstruent. In (80c, d) dissimilation is between coda and onset within the same syllable.

[81] This section was not included in González (2003).

Romance: Stress-sensitive dissimilation is common in Romance languages according to Grammont (1933). These changes have to do mostly with liquid dissimilation, and follow the pattern r-'r → l-'r and 'r-r → 'r-l (Grammont 1933: 276). That is, in a word with two rhotics in adjacent syllables, the rhotic in the unstressed syllable dissimilates to a liquid (or a nasal in some instances) from a stressed syllable. Examples include Vulgar Latin *al'berga* from **arberga*, Spanish *'mármol* from Latin *marmor*, and Italian *pelle'grinu* from Latin *peregrinum* (Grammont 1933: 276-286).

Posner (1961: 101) suggests that changes among liquids are relatively frequent in Romance languages since [l, r] are very similar phonetically and are equally important in the phonemic structure of these languages. She also mentions that in many Romance languages and dialects, [r] deleted or dissimilated in unstressed syllables because of the influence of another [r]. However, dissimilation in stressed syllables is also attested; one example would be *ta'ladro* from Latin *taratru* (Posner 1961: 61, 108).

Summary: Stress-sensitive dissimilation is reported diachronically. In the case of Romance, the dissimilation change tends to occur in unstressed syllables, with the segment triggering dissimilation belonging to a stressed syllable. In the case of Gothic, dissimilation occurs after unstressed syllables. See discussion in section 3.

4. Typological Generalizations and Their Underpinnings

This section describes the typological generalizations that arise from the survey presented in sections 3.3-3.9. These comprise generalizations about the consonantal processes and whether they occur in stressed, unstressed, strong or weak syllables; whether stress or foot structure (or both) are relevant, and whether word-position and morphological structure are related. Additionally, this section examines whether there is a relationship between syllabic position (onset/coda) and these processes, whether these processes are variable or categorical, and which segments and features are more likely to be affected.

Section 4 also examines the factors that underlie stress- and foot-sensitive consonantal phenomena: aerodynamics, duration, perception, and rhythmic prominence. It classifies the phenomena surveyed according to them, and it proposes that these are the factors that are minimally needed in order to provide an adequate characterization of these phenomena.

This section also discusses in detail the role of stress and foot structure in consonantal phenomena. Three main cases are found: processes where stress strictly influences consonantal processes (as in frication in North-Central Peninsular Spanish); processes where stress and foot structure converge in conditioning these processes (as in flapping in American English); and processes where foot structure alone is a conditioning factor (as in deletion in Capanahua). Where each of these processes is found is examined in detail. Importantly, it is shown that strictly foot-sensitive consonantal phenomena are driven by rhythmic considerations, that is, the creation of a prominence contrast between strong and weak syllables within a foot. The creation of a rhythmic contrast can compensate for the lack of persistent stress, or it can go against stress assignment in some cases.

This section reviews previous approaches that can account for certain stress-sensitive consonantal alternations, including Licensing-by-Cue (Steriade 1997) and contrast reduction (Crosswhite 2004) for perceptually-based phenomena, and prominence augmentation (Smith 2000, 2002) for prominence-based phenomena. It is shown that the mechanism of Prominence Alignment (Prince and Smolensky 1993) can account for stress- and foot-sensitive consonantal phenomena involving prominence reduction and augmentation. It is also proposed here that Prominence Alignment can also be extended to account for phenomena where duration and aerodynamics are relevant.

The organization of this section is as follows. § 4.1 states the typological generalizations concerning stress and foot structure in consonantal alternations. § 4.2 discusses the typological generalizations related to syllabic, word and morphemic position, and the type of features and segments affected. § 4.3 discusses the factors underlying consonantal processes: perception, aerodynamics, duration and prominence. § 4.4 and 4.5 describe the consonantal alternations that are predicted not to occur, and what processes are within the grammar, respectively.

Sections 4.6 and 4.7 deal with the separation between stress and footing and the notion of rhythmicity. § 4.8 through 4.11 discuss how prominence-based, durational, aerodynamic and perceptual phenomena can be analyzed in the grammar. Finally, § 4.12 is the conclusion.

4.1. Generalizations on stress and foot structure

This section states the generalizations that arise from the survey of stress- and foot- sensitive consonantal phenomena discussed in § 3.3-3.9. The generalizations regarding the relationship between stress/footing and consonantal processes are listed in (81).

(81) Relationship between stress/footing and consonantal alternations

Stressed/strong-footed position

— Fortition occurs in stressed syllables and in foot-initial syllables.
— Consonantal features and segments are attracted to stressed syllables.
— Stress is attracted by onsetful syllables and by low-sonority onsets.
— Consonantal epenthesis occurs in stressed syllables and in strong-footed syllables.
— In laryngealized consonants, the realization of glottalization and aspiration is timed according to stress: glottalization and aspiration will be realized as close to a stressed vowel as possible.
— In stressed syllables, voiceless consonants become voiced, but voiced consonants do not become voiceless.
— Gemination, pre-aspiration and pre-glottalization occur after stressed syllables.
— Assimilation occurs in stressed syllables.

Unstressed/weak-footed position

- — Lenition occurs in unstressed syllables and in foot-medial syllables.
- — Flapping occurs word-medially in unstressed syllables.
- — Consonantal deletion occurs in unstressed syllables and in weak-footed syllables.
- — In unstressed syllables, voiced consonants are devoiced and voiceless consonants are voiced.

All positions

- — Consonants are longer in stressed syllables than in unstressed syllables.
- — VOT for obstruents is longer in stressed syllables than in unstressed syllables.
- — Metathesis and dissimilation can occur in stressed syllables or in unstressed syllables.

An important finding of the survey is that consonantal processes fall into three groups according to whether stress or foot structure condition them (82).

(82) Types of consonantal processes regarding stress and foot structure

(i) Stress only
Consonantal processes can be strictly influenced by stress in the absence of foot structure (as in frication in North-Central Peninsular Spanish).

(ii) Stress and/or foot structure
Consonantal processes can be ambiguous as to whether stress and/or footing condition them since both coincide (as in flapping in American English).

(iii) Foot structure only
Consonantal processes can be strictly influenced by foot structure in the absence of stress (as in deletion in Capanahua).

Strictly stress-sensitive consonantal processes are predicted to potentially occur in languages with only one stress per prosodic word and no evidence for persistent footing (as in Senoufo) and in languages where, even if footing is persistent, a consonantal alternation occurs only in a subset of the stressed syllables in a word, namely, only in main-stressed syllables, or only in secondary-stressed syllables (as in Urubu-Kaapor).

For processes conditioned to some extent by stress, there are three possibilities. The stress of the syllable where the consonant occurs might be relevant, as in epenthesis in German. Alternatively, the lack of stress of the syllable where the consonant occurs might influence its realization, as in flapping in English. Finally, the stress of the immediately preceding syllable might be affecting consonant realization. Gemination in Popoloca exemplifies this last possibility. A summary of the consonantal processes that are attested in each of these contexts is given in (83).

(83) Consonantal processes by stress contexts

Stressed syllables	Unstressed syllables	After stressed syllables
— Longer duration — Longer VOT — Fortition — Post-aspiration — Post-glottalization — Voicing — Metathesis — Assimilation — Dissimilation — Epenthesis	— Flapping — Lenition — Voicing and devoicing — Metathesis — Dissimilation — Deletion	— Gemination — Pre-aspiration — Pre-glottalization

In consonantal processes where both stress and foot structure are possible conditioners, consonantal alternations occur in stressed/strong-footed positions or in unstressed/weak-footed positions. The coincidence of stress and footing is typical of trochaic systems, where the head is foot-initial and stressed and the non-head foot-final and unstressed.

Consonantal processes where only foot structure is relevant occur in three cases: (i) systems where not all feet are assigned stress, as in Capanahua; (ii) iambic systems (as Norton Sound Yupik); and (iii) systems with mismatches between stress and foot structure (as in Huariapano). Each of these cases is explored in § 4.6.3.

Finally, some metrically-conditioned consonantal processes are tendencies or optional (frication in North-Central Peninsular Spanish), while others are fully regularized (deletion in Capanahua). The division between these two processes will be connected to the distinction between phonetics and phonology in § 4.5.

Sections 4.3-4.7 discuss the factors behind stress- and foot-sensitive consonantal phenomena, the distinction between strictly stress-sensitive, strictly foot-sensitive and foot/stress-sensitive consonantal processes and the fact that some processes are optional or categorical. § 4.2 discusses other findings from the survey, including the interaction of stress- and foot-sensitive consonantal alternations with syllabic positions, laryngeal features, and word and morphological position.

4.2. Generalizations on position and features and segments affected

4.2.1. Syllabic positions

In most cases consonantal processes that are influenced by stress or foot structure occur in onset position (as in epenthesis in German) or depend on onsets for their occurrence (as in gemination in Popoloca). However, there are a large number of languages in the survey where codas are absent in the language (as in Maori; Bauer 1993) or are seriously restricted as to segmental content (as in Silacayoapan Mixteco; North and Shields 1977). This leaves uncertain whether the correlation between onset position and stress or foot structure is significant.

Table 17 provides examples of processes that do not exclusively occur in onset position. Processes where it is not clear whether onsets and codas are involved include fortition in Yuman and voicing variation in Wasco-Wisram. Note that glottalization is frequently attracted by coda and nuclei.

Table 17

Consonantal alternations involving codas

Coda only	
— Guayabero	Allophonic variation of /ʔ/ and /d/
— Northern Peninsular Spanish	Frication and devoicing of /b, d, g/
— Capanahua	Deletion of /ʔ/
— Huariapano	Epenthesis of /h/
Coda and onset	
— Spanish	Longer consonant duration
— Guayabero	Allophonic variation /h/, /b/
	Secondary articulation
— German	Post-aspiration
— English	Voicing of 'x'
— Gemination	Onset-to-coda (all cases)
	Coda-to-onset (inverse gemination in Italian)
— Pre-aspiration	All cases
— Pre-glottalization	All cases

4.2.2. Features and segments affected

The majority of the consonantal processes considered in the survey have alternations involving laryngeal segments (/ʔ, h/) or laryngeal features (aspiration, glottalization, and voicing). Stress-sensitive aspiration in the form of longer or stronger VOT, frication, or affrication of voiceless stops occurs in a range of languages for segments that are underlyingly unaspirated. For segments with underlying aspiration, pre-aspiration occurs after stressed syllables, and post-aspiration in stressed syllables. Stress-sensitive deletion and epenthesis of /h/, deletion of aspiration, and stress-sensitive variation between [h] and [ʔ] are also attested. Debuccalization can also produce [h]; metathesis of /h/ is also common.

Glottal stops are frequently deleted, epenthesized, or metathesized in a stress-sensitive fashion. Debuccalization can give rise to [ʔ]. Glottalization is frequently attracted to codas or nuclei of stressed syllables. Non-glottalized consonants are pre-glottalized after stress. Glottalized consonants have variable timing of glottalization according to where stress is assigned. Stronger plosion of /ʔ/ and stronger glottalization in sonorants is also attested in stressed syllables. Glottalization can also delete in unstressed syllables.

Finally, voicing features are involved in various processes, including voicing and devoicing in unstressed syllables and voicing in stressed syllables. Voicing is also involved in flapping; regardless of the underlying voicing of the consonant undergoing flapping, the resulting consonant is voiced. Voicing is also involved in Nganasan rhythmic gradation.

Non-laryngeal processes generally involve sonority and durational properties of segments (as in gemination, fortition, lenition and flapping). Deletion affects a range of consonants and segments, including liquids, /w/, /k/, and nasalization. Stress-sensitive attraction can affect liquids and pharyngeals; metathesis can affect liquids and /k/; dissimilation affects liquids.

Pointing to the pervasiveness of laryngeal features and consonants in stress- and foot-sensitive phenomena is the fact that laryngeals lack supra-laryngeal features. Unless laryngeals co-occur with pharyngeal or uvular consonants in a language, in which case they are pharyngeal, laryngeals have no place of articulation (Rose 1996). Evidence for their lack of place is provided by their phonological behavior cross-linguistically; laryngeals often behave phonologically as if they were placeless in terms of vowel copying, debuccalization, epenthesis, reduplication and other processes (e.g. Steriade 1987, Yip 1991, Stemberger 1993, McCarthy and Prince 1994, Halle 1995, Rose 1996, Ladefoged 1997, Parker 2001). Since there are no supra-laryngeal gestures involved in laryngeal consonants, they are plausibly easier to delete, insert, and relocate.

Another consideration is the close connection between laryngeal features and segments and stress. Variations of suprasegmental features such as pitch and stress are partly due to changes in laryngeal behavior (Ladefoged 1993); it is reasonable that laryngeals are mostly influenced by stress.

4.2.3. Word-position, phrase and utterance position, and morphemic structure

This section discusses the interaction between stress and word position, stress and phrase and utterance position, and morphemic structure and stress in consonantal alternations. Roots, root-initial, and word-initial and final syllables are psychologically prominent; they are important for processing and word recognition. This suggests that these positions would be relevant for any type of segmental process taking place. Previous discussion of the interplay between segmental processes and stress and/or word/morpheme position is found in Beckman (1998), Lavoie (2001), Walker (2001) and Alber (2002).

(a) Word position and stress

This section examines the interaction of consonantal alternations with word-initial, word-final, word-medial, and intervocalic positions.

— Word-initial syllables are relevant in stress- and foot-sensitive consonantal alternations in five cases: (i) stressed word-initial syllables; (ii) unstressed word-initial syllables; (iii) stressed and word-initial syllables; (iv) foot-initial and word-initial syllables. In some cases it is ambiguous whether stress or word-initial position is relevant (v).

(i) *Stressed word-initial:* Some consonantal alternations occur in stressed word-initial syllables, as epenthesis in Paipai and German, which is obligatory or more likely if the syllable is stressed. In German, epenthesis also occurs in stressed syllables elsewhere.
(ii) *Unstressed word-initial*: Some consonantal alternations occur in unstressed word-initial syllables, as in Farsi, where underlying voiced (lenis) consonants are partially devoiced in onsets in this position but fully voiced in onsets of stressed word-initial syllables or intervocalically (in codas, there is total or partial devoicing).
(iii) *Word-initial and stressed syllables*: A process might occur both word-initially and in stressed syllables. Examples include post-glottalization in Gitksan, epenthesis in Silacayoapan Mixteco, deletion blocking in English and Chali Tati, and strong aspiration in English, Pattani and Farsi.
(iv) Word-initial and foot-initial syllables: Fortition is reported to occur word-initially and foot-initially in Aluttiik Yupik (Van de Vijver 1998). Section 3 argues that word-initial positions in Alutiik Yupik can be collapsed with foot-initial positions.
(v) Ambiguity between word initial and stressed position: In languages where word-initial syllables are stressed, it is ambiguous whether stress or word position is relevant for a consonantal alternation. This occurs in Wembawemba and Wergaia, where word-initial syllables are resistant to total devoicing.

— Word-final position is relevant for stress- and foot-sensitive consonantal alternations in two cases: (i) processes occurring in word-final, post-tonic syllables, and (ii) processes occurring in word-final syllables and in unstressed syllables.

(i) *Word-final post-tonic syllables*: In Mohawk epenthesis occurs in word-final post-tonic (unstressed) syllables. Stress usually falls on the penultimate syllable.
(ii) *Unstressed syllables and word final syllables*: Certain phenomena occur in unstressed syllables and in word-final syllables regardless of stress, as in English flapping or in pre-glottalization in Gitksan.

— Word-medial position is relevant for stress- and foot-sensitive alternations in two cases: (i) processes occurring in word-medial unstressed syllables, and (ii) consonantal alternations occurring word-medially after stress.

(i) *Word-medial unstressed*: Flapping occurs in unstressed word-medial syllables (stress-insensitive flapping generally occurs word-medially). Voicing alternations frequently occur word-medially in unstressed syllables, as in Popoloca.
(ii) *Word-medial after stress*: Stress-sensitive pre-aspiration and gemination typically occur word-medially after stress. English pre-glottalization occurs in the same context. In Paamese, voicing of word-medial /nt/ is more common after stress.

— Intervocalic positions are relevant for stress- and foot-sensitive consonantal alternations in two cases: (i) in unstressed syllables, and (ii) after stress.

(i) *Intervocalic unstressed*: Typically, lenition occurs intervocalically in unstressed syllables (English, Senoufo, Somali, Spanish, Kupia, and Silacayoapan Mixteco). Voicing occurs in this same position in Senoufo.
(ii) *Intervocalic after stress:* Pre-aspiration occurs in this context in Toreva Hopi.

Summarizing, word position interacts with stress often. Word-initially, and leaving aside ambiguous cases where it is not clear whether word position or stress are relevant, consonantal processes might be more likely (or obligatory) if the word-initial syllable is stressed, or they can occur both in stressed syllables and word initially. Word-finally, consonantal processes might occur in word-final post-tonic syllables or both in unstressed syllables and word-finally regardless of stress. Word-medially and intervocalically consonantal alternations occur in unstressed syllables or after stress. Farsi and Mohawk do not conform to these generalizations.

(b) Phrase/utterance position and stress

Phrase- or utterance-initial: Lenition in /b, d, g/ in Spanish —which is stress sensitive in some dialects— is blocked in utterance-initial positions. In English, epenthesis of /ʔ/ occurs phrase-initially, especially under stress.

Utterance-final: In Oneida, /ʔ/ was replaced by [h] utterance-medially in post-tonic syllables preceding a single obstruent. In post-tonic utterance-final position, this process occurred regardless of the number of consonants after /ʔ/.

Summarizing, blocking of lenition and epenthesis occurs utterance or phrase-initially. The case of the influence of utterance-final position is Oneida is not clear.

(c) Morphemic structure and stress

Stem/root: In Norton Sound, gemination occurs after a monosyllabic stem so that the stem is closed and can be stressed. In Shuswap, a stressed root attracts glottalization. In Paamese, alternations are found in reduplication; the onset of the reduplicated syllable —which is unstressed— has the weakest consonant, and the syllable from the base —which is generally stressed— the strongest consonant.

Suffix: Contrary to related Shuswap, in Colville a stressed suffix attracts glottalization away from the root.

Morpheme-initially: Epenthesis of [ʔ] occurs morpheme-initially in German, especially under stress, and also in stressed syllables regardless of morphemic structure (Kohler 1994, cited by Alber 2001). In Squamish, deletion of /ʔ/ is reported to occur morpheme-initially in unstressed syllables after a consonant.

Morpheme-finally: Deletion of /ʔ/ is reported to occur morpheme-finally in unstressed syllables in plural reduplication in Squamish (Kuipers 1967).

Summarizing, there are not many cases in the survey where morphological structure interacts with stress or foot structure. Sometimes, stress- or foot-sensitive consonantal processes occur in specific morphemes in the word, as in gemination in Norton Sound, attraction in Shuswap and Colville, fortition in Paamese, and deletion in Squamish. In other cases, a process might occur in a specific morpheme position and in stressed syllables, as in epenthesis of /ʔ/ in German.

4.3. The role of perception, aerodynamics, duration, and prominence

This section discusses the factors that can be seen at work behind stress and/or foot-sensitive consonantal phenomena: aerodynamics, duration, perception, and prominence. These are defined below. In some cases, different factors might be at play at the same time; in other cases, it is unclear what factors are relevant. § 4.3.1-4.3.5 discuss the consonantal alternations falling under each factor.

Perception

A process can occur to improve the perceptibility of features or consonants. One example is Shuswap, where glottalization is attracted to the final sonorant of a stressed syllable. The realization of the glottal feature next to a stressed vowel improves the perceptibility of this feature (Steriade 1997 and references therein). Alternatively, a process can arise in order to avoid features or consonants in perceptually-weak positions. This occurs in Faroese, where /k/ is deleted in the sequence /skt/ in unstressed syllables. /k/ deletes because the unstressed syllable cannot support its cues in this cluster (Hume 2000 and references therein; Hume and Seo 2001).

Last but not least, perceptual ambiguity can motivate consonantal processes. This occurs in certain cases of metathesis, especially in unstressed syllables (Blevins and Garrett 1998). Features or segments with long duration overlap a vowel and possibly other segments, and because of perceptual difficulties in unstressed syllables, speakers might reinterpret the original position of the feature or segment, causing metathesis. One instance is Cayuga, where /h/ and /ʔ/ metathesize from onset to coda in unstressed syllables.

Aerodynamics

The aerodynamics of stress can drive consonantal alternations. Stressed syllables involve increased airflow (Lehiste 1970), which can lead to an increase of aspiration, frication, or affrication. Increased airflow in stressed syllables can also lead to higher subglottal pressure, which in turn would induce more likelihood of voicing.

The aerodynamic effect of stress can also affect voicing in unstressed syllables. Voicing has exact and complex physiological requirements: typically, the vocal cords have to be lightly adducted and there must be enough air passing through them (Ohala 1983). In unstressed syllables, consonantal voicing might be unstable since there is arguably less time to achieve the necessary configuration for voicing. One relevant example from the survey in Silacayoapan Mixteco.

Duration

Stressed syllables are longer than unstressed syllables, and stress can increase the duration of vowels and consonants (Lehiste 1970, Hayes 1995). In unstressed syllables the duration of vowels and consonants is typically reduced. Which segments are affected by stress in this respect depends on the specific language. Both consonants and vowels might be longer in stressed syllables, as in English (Lavoie 2001); only vowels might be longer in this position, as in Swedish (Botinis, Bannert, Fourakis and Pagoni-Tetlow 2002); or only consonants might be longer in stressed syllables, as in Senoufo (Mills 1984).

Apart from being a correlate of stress, duration can also serve to increase prominence. However, in spite of this possible ambiguity, durational processes here are considered to be affected by stress independently of prominence considerations.

Prominence

The term prominence is used frequently in connection to certain positions, including stressed syllables, word-initial syllables and others, which are phonetically or psycholinguistically 'salient', that is, they play a role in word-recognition, are longer, and so on (Beckman 1998 and references therein). Prominence is referred here as the presence of a property that makes a syllable phonologically stronger or weaker. When a prominence contrast is created in the foot structure of a language, it is considered here to be *rhythmic*.

Prominence goes beyond perceptual, durational or aerodynamic factors and can potentially create rhythmic contrasts in a language. Prominence causes strengthening of stressed syllables and reduction of unstressed syllables. Sometimes, both of these go hand in hand. Strengthening and reduction have been well-noted for vowels; in unstressed syllables, vowels tend to reduce to [ə] and even delete, while in stressed syllables, vowels tend to lengthen. Consonants can also be affected by prominence. Stress is usually present in prominence-sensitive phenomena, but it does not have to be, as exemplified by strictly foot-sensitive processes like Capanahua.

4.3.1. The role of perception

Perception-driven processes cause improved perceptibility of features and segments in stressed or strong syllables and the avoidance of features and segments in positions where they are only weakly perceptible. It can also drive alternations through ambiguity in perceptually-challenged positions. Perception is important for some types of attraction, metathesis, variable timing of aspiration and glottalization in laryngealized consonants, and deletion. Perception-driven processes might also cause the voicing of voiceless segments in unstressed syllables and aspiration of voiceless obstruents in stressed syllables.

Perception and attraction: Stress-sensitive featural attraction seems to be driven by perceptual motivations. In Shuswap, [constricted glottis] in an unstressed syllable is attracted to the stressed syllable. Feature attraction from unstressed to stressed syllables improves the perceptibility of a feature or the chance that a feature will be per-

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ceived. This is because stressed syllables are typically longer, louder and better able to carry perceptual cues (Steriade 1997). For stress-sensitive segmental attraction both perception and prominence might be underlying. See § 4.3.2 for more details.

Perception and metathesis: Perceptually-based metathesis is attested within stressed and unstressed syllables. In unstressed syllables it occurs because of perceptual ambiguity. This type of metathesis is known as *perceptual metathesis* (Blevins and Garrett 1998). In stressed syllables, metathesis occurs in order to improve the perceptibility of a feature or segment.

Perceptual metathesis occurs with features or segments with relatively long acoustic of perceptual duration cues, including aspiration, glottalization, rhoticity, and pharyngealization (Blevins and Garrett 1998). Such features or segments are long enough to overlap vowels. In some cases, they overlap vowels fully, and there is ambiguity as to what the original position of the consonant is. This is more likely in unstressed or weak syllables because vowels are shorter and the consonant can overlap the vowel to a greater extent. Full consonantal overlap in the vowel potentially causes metathesis, since the speaker might reinterpret the consonantal feature or segment as originating from a different position (Blevins and Garrett 1998). One example is laryngeal metathesis in Cayuga.

Faroese is the only language in the survey where metathesis occurs within stressed syllables. In /skt/ clusters in stressed syllables, /k/ and /s/ metathesize, with /k/ being realized immediately after the stressed vowel. This makes the cues for /k/ to be better perceived (Hume 2000, Hume and Seo 2001). In unstressed syllables, /k/ in a /skt/ cluster deletes. At first sight, the case of Faroese might seem to contradict the preferential targeting of unstressed syllables by metathesis. However, the generalization is that /k/ is not supported in a /skt/ cluster in Faroese. Only a stressed syllable can retain the segment at all, which it accomplishes by means of metathesis. The deletion that takes place in unstressed syllables effectively removes the potential for metathesis to occur.

While perceptually-based metathesis occurs both within stressed and unstressed syllables, the specific motivation differs for both cases. Perceptual metathesis in unstressed syllables does not make a segment more easily perceived; this type of metathesis is symmetrical; CV > VC cases coexist with VC > CV cases for all segments undergoing perceptual metathesis. One example is Le Havre French, where both **rə > ər* and **ər > rə* metathesis co-occur (Blevins and Garrett 1998) and references therein). This type of metathesis arises though perceptual ambiguity of a phonetic string, which might lead to phonological reinterpretation of the original position of a feature or segment (Blevins and Garrett 1998). On the contrary, metathesis within stressed syllables improves the perceptibility of salient features or consonants—that is, salient features or consonants occur as close to the stressed syllable as possible. It is up for discussion whether in the last case metathesis also serves to improve ease of articulation.

Perception and variable timing of glottalization and aspiration: Perception-driven processes cause variable timing of glottalization or aspiration in laryngealized segments: glottalization and aspiration surface where they can be best perceived

(Steriade 1997; cf. Howe and Pulleyblank 2001).[82] For example, intervocalic glottalized stops in Coast Tsimshian are pre-glottalized if the preceding vowel is stressed, and post-glottalized if the following vowel is stressed. Stress conditions where glottalization occurs, overriding the general preference for glottalization to occur after the release of obstruents, that is, as post-glottalization (Sapir 1938, Kingston 1985). The reason is that stressed syllables are longer, louder and better able to carry perceptual cues (Steriade 1997).

Perception and deletion: Consonantal deletion frequently occurs in unstressed syllables, which are shorter and less loud and consequently not ideal for the perception of features. For example, in Faroese /skt/ clusters in unstressed syllables /k/ deletes because the cues for /k/ are not well perceived in this context (Hume 2000, Hume and Seo 2001). In other instances of deletion, durational and prominence factors might play a role (§ 4.3.3, 4.3.4).

Perception and VOT: The occurrence of longer or stronger aspiration in voiceless segments in stressed syllables can be partly attributed to perceptual reasons. Aspiration can be better perceived in perceptually salient syllables, including word-initial and stressed syllables. One example is English, where aspiration is more audible in these more perceptually salient positions. Aerodynamic and durational factors might also be relevant for longer and stronger aspiration for obstruents in stressed syllables.

Perception and voicing: Voicing pattern (1) —voicing of voiceless segments in unstressed syllables— might be perceptually-motivated. Reduced duration of voiceless segments in unstressed syllables might give the percept of voicing, since voiced obstruents are shorter than voiceless ones (Lavoie 2001). One possible example is Senoufo. Alternatively, voicing contrasts might neutralize in unstressed syllables because this position is perceptually weak (Beckman 1998). Voicing alternations might also be caused by aerodynamic factors, as discussed in 4.2.

4.3.2. The role of aerodynamics

Aerodynamics as a factor behind stress-sensitive consonantal processes refers to the increase in airflow that occurs in stressed syllables and that might lead to increased aspiration or increased subglottal pressure. It also refers to the complex aerodynamic requirements for voicing that are plausibly more difficult to achieve in unstressed syllables because of their reduced duration.

Aerodynamics and increased airflow: Stressed syllables have increased airflow (Ladefoged 1982), which, depending on the configuration of the supraglottal cavity, and provided the glottal folds are apart, can lead to (post) aspiration, frication, or affrication, or a greater strength or likelihood for their occurrence in this position. Longer and stronger aspiration of voiceless stops and affricates in English, increased

[82] Howe and Pulleyblank (2001) examine cases where variable timing of glottalization is not perceptually-based.

likelihood of frication of /b, d, g/ in coda in Northern Peninsular Spanish and affrication of voiceless stops in Maori are examples of aerodynamic processes. For English, it has been suggested that /h/ deletion is connected to the lack of aspiration of voiceless stops and affricates in unstressed syllables (Davis 2002). Increased airflow might also increase subglottal pressure and consequently lead to more likelihood of voicing in stressed syllables, as discussed below.

Aerodynamics and voicing: In unstressed syllables both voicing of voiceless segments (voicing pattern 1, as in Senoufo *and* devoicing of voiced segments (voicing pattern 2, as in Djabugai) are attested. However, in stressed syllables only voicing of voiceless consonants is attested (Voicing pattern 3, as in Wasco-Wisram); devoicing of voiced consonants is not attested in stressed syllables.

A number of properties of these patterns are explained through the aerodynamics of stress. First, the occurrence of voicing but not devoicing in stressed syllables can be explained through the fact that stressed syllables involve higher airflow (Lehiste 1970). Higher airflow might induce higher subglottal pressure, which —provided the glottal cords are adducted (Ohala 1983)— would increase the likelihood of consonantal voicing. Second, the occurrence of both voicing and devoicing processes in unstressed syllables also has an aerodynamic motivation. Voicing tends to be unstable, since it is a particularly complex aerodynamic phenomenon in which a precise supraglottal and subglottal configuration has to be achieved. This configuration is particularly difficult to achieve in unstressed syllables, since there is less time available to do so. This would explain the attested processes of voicing and devoicing in unstressed syllables, even within the same language, as in Silacayoapan Mixteco. This does not exclude that perceptual forces might be allied with aerodynamics, causing voicing to occur more readily in unstressed syllables.

Third, some of these processes are optional or occur in free variation, as in Copala Trique, or partial, as in Farsi. Both of these facts are consistent with the phonetic nature of aerodynamics. This will be considered in more detail in § 4.5.

4.3.3. The role of duration

Stressed syllables are longer than unstressed syllables, and stress can increase the duration of vowels and consonants (Lehiste 1970, Hayes 1995). In some languages longer duration in stressed syllables (or shorter duration in unstressed syllables) might affect consonants, with or without affecting vowels. Consonantal processes motivated by duration include segmental or featural lengthening, flapping, lenition, deletion, and plausibly fortition and epenthesis.

Lengthening: Since stressed syllables are longer than unstressed syllables, the articulation of consonants can be prolonged. The way in which consonant duration is manifested depends on the specific consonant. It might include longer occlusion (for stops), longer frication (for fricatives), or more taps (for rhotics). Consonantal lengthening and increased aspiration also occur in stressed syllables because of the longer duration of stressed syllables. Ensuring optimal consonantal perception could also influence lengthening and increased aspiration (§ 4.3.1).

Duration and flapping: Flapping consists of the reduction of a gesture, whereby a complete occlusion is aimed for but not achieved. Instead, a fast and/or partial occlusion occurs. The cause for this gestural reduction appears to be that unstressed syllables have reduced duration; in this context, a total occlusion is hard to achieve because there is less time to complete it (Kirchner 1998).

Duration, lenition and fortition: Lenition (including approximantization of stops and fricatives, fricativization of oral stops, debuccalization, and flapping) and fortition (including occlusivization of fricatives and approximants, fricativization of approximants and others) have been proposed to have a durational basis (Lavoie 2001). Reduced duration in unstressed syllables provokes gestural 'undershoot', and segments are not realized with complete closure, supraglottal information, appropriate voicing, and so on. In stressed syllables, it has been suggested that there is less gestural overlap in stressed syllables due to hyperarticulation in this position (De Jong, Beckman and Edwards 1993).

Duration, deletion and epenthesis: Since unstressed syllables are shorter than stressed syllables, consonants might delete in this position (but see also 4.1 and 4.4). Epenthesis might take place because of durational factors too, but it is more probably due to prominence considerations, as discussed below.

4.3.4. The role of prominence

Prominence makes a syllable 'stronger' and non-prominence makes a syllable 'weaker'. Rhythmicity (i.e. foot-based prominence) achieves a contrast between strong and weak syllables by way of strengthening the strong syllable, reducing the weak syllable, or both. This might be done in connection with durational, aerodynamic and perceptional factors. Prominence is a factor in aspiration, attraction, gemination, pre-aspiration of non-aspirates, pre-glottalization of non-glottalized consonants, fortition, lenition and flapping, epenthesis, and deletion.

Prominence and aspiration: Aspiration or stronger aspiration occurs in stressed syllables. Aspiration makes a consonant less sonorous. Onsets and specifically low-sonority onsets enhance the perceptual prominence of the syllable (Smith 2000). This is supported by the auditory effect of adaptation; with continued exposure to a stimulus, auditory sentitivity gradually drops, and adaptation occurs (Delgutte 1997). Intermingling syllable onsets between vowels provides the auditory system with the opportunity to recover from adaptation to vowels, thus enhancing prominence. Since low-sonority onsets are maximally distinct from vowels, recovery from adaptation is optimal, and thus prominence is maximally enhanced (Smith 2000; see also discussion in Gordon 2002). The absence of aspiration or the occurrence of weaker aspiration in unstressed syllables decreases the prominence of these positions.

Prominence and attraction: While featural attraction might be strictly perceptually-motivated (a feature is realized in the optimal perceptual position), segmental attraction could in principle be motivated by prominence. One relevant example is attraction of a pharyngeal resonant to stressed suffixes in Colville. It could be argued in this case that attraction increases the prominence of stressed syllables and decreases the prominence of unstressed syllables at the same time.

Prominence and gemination: Gemination generally involves the lengthening of an onset immediately following a stressed syllable so that it is heterosyllabic. Gemination is typically blocked if the stressed syllable has a long vowel or a coda (as in Italian or Guelavía Zapotec). As such, gemination is a way to create a prominence contrast between stressed and unstressed syllables—provided that the coda adds to the overall duration and/or relative strength of the syllable. However, it is plausible that in some languages the coda might make the preceding vowel shorter and the overall duration of the syllable is not altered.

In Italian, an inverse type of gemination is attested whereby a coda in a stressed syllable lengthens and becomes heterosyllabic before an onsetless vowel. Codas in unstressed syllables immediately preceding onsetless syllables resyllabify as onsets and gemination does not apply (Loporcaro 1999, Saltarelli 2003). Prominence also plays a role in this type of gemination, since stressed syllables maintain their codas, unlike unstressed syllables.

Prominence, pre-glottalization and pre-aspiration: As in gemination, pre-aspiration and pre-glottalization split an onset immediately following a stressed syllable into a coda and an onset. This contributes to the prominence of the stressed syllable, especially in segmental cases like Popoloca. In this language, fricatives, liquids, approximants and voiced nasals geminate after a stressed syllable, and complex segments (pre-nasalized, aspirated, and voiceless nasals) are decomposed into a coda and an onset. Additionally, stops and affricates are pre-glottalized in this position. Since all other consonants undergo gemination or 'desintegration' into a coda and onset, pre-glottalization also seems to be segmental and have the same motivation as gemination and 'disintegration' (Veerman-Leichsenring 1984): the creation of a prominence contrast between stressed and unstressed syllables.

The factors behind featural pre-glottalization and pre-aspiration are not clear. One example of apparent featural pre-glottalization are certain English dialects where obstruents are pre-glottalized immediately after stressed syllables, even if a sonorant intervenes between the obstruent and the stressed syllable, as in *grumpy*. The fact that there is already a coda in the preceding syllable suggests that pre-glottalization is featural. Even so, in this and similar cases glottalization might lengthen the stressed syllable or increase its prominence. In contrast, featural pre-aspiration might overlap with the preceding vowel, potentially causing devoicing and plausibly shortening. This might decrease the duration of the stressed syllable or its prominence, since devoiced vowels are not very sonorous and thus not prominent.

In Faroese pre-aspiration is blocked in the context of high vowels. High vowels are cross-linguistically less sonorous than non-high ones (Prince and Smolensky 1993). It is possible that the blocking of pre-aspiration in this case is related to the potential devoicing of the stressed vowel, which would achieve a non-sonorous nucleus in a stressed syllable. It would be worse to have high devoiced vowels than non-high devoiced vowels, especially in stressed syllables, since the former are not very sonorous. It is plausible that pre-aspiration might contribute to prominence in some languages, but that in some others it might interfere with prominence by devoicing the preceding vowel.

Prominence and fortition: Less sonorous consonants are more 'consonantal' than more sonorous consonants. Less sonorant consonants in onsets increase the prominence of a syllable; the less sonorant the onset consonant is, the more distinct it is from an adjacent vowel, and the more opportunities there are for recovery from adaptation to the vocalic stimulus, thus causing prominence (Smith 2000, Gordon 2002). Since fortition involves a decrease in consonant sonority, in onset position fortition will help to enhance the prominence of the stressed syllable. One example would be West Tarangan. Note that in some cases, as in Norton Sound Yupik and in Alutiik Yupik, fortition serves to distinguish foot boundaries (Leer 1985).

For affrication the situation is slightly different. The relative strength of affricates is not clear (Lavoie 2001). In same languages with stress-sensitive affrication, affrication seems to be a stronger form of aspiration. English and Maori are relevant examples. It is clear that debuccalization consists of the reduction of supra-glottal features, which fail to be pronounced in weak position. Stronger 'articulation' or 'emphatic and vigorous plosion' of segments, as in Farsi, would also fall in this group.

Prominence, lenition and flapping: Lenition and flapping are also candidates for a prominence analysis. Lenition (and flapping) involves an increase in consonantal sonority, which makes a consonant more vocalic. If less sonorant consonants in onset positions increase prominence, as explained in the previous paragraph, then more sonorant consonants in onsets would decrease syllabic prominence. Durational factors also seem to be behind these two phenomena (§ 4.3.3).

Prominence and epenthesis: Epenthesis can contribute to the creation of prominence contrasts between strong and weak syllables. One example is Huariapano, where [h] is epenthesized in coda of strong footed syllables.

Prominence and deletion: Deletion potentially contributes to the creation of prominence contrasts between strong and weak syllables. One example is Capanahua, where /ʔ/ deletes in coda of weak footed syllables.

4.3.5. Remaining consonantal alternations

The motivation for some types of consonantal alternations remains unclear. These include voicing pattern 4 (voicing alternations conditioned by the stress of the preceding syllable), secondary articulation and voicing dissimilation.

Voicing pattern 4: It has been suggested that aerodynamics and —to a lesser extent— perception are relevant for voicing patterns 1-3. Other voicing alternations are reported where the stress of the preceding syllable is relevant. These include Paamese —where an immediately preceding stressed syllable is conducive to voicing of word-medial /^{n}t/ (Crowley 1982)— and diachronic alternations in Proto-Germanic and Middle English, where 'non main stressed' and 'weakly stressed' syllables respectively conditioned voicing of voiceless consonants (Wright 1957, Kabell and Lauridsen 1984). It is unclear whether these environments just include unstressed syllablesor both unstressed and secondary-stressed syllables, and how the stress or lack thereof in the preceding syllable influences consonantal voicing.

Secondary articulation: Stress-sensitive secondary articulation as in Guayabero has an unclear motivation. Secondary articulations might add to the overall duration of stressed syllables, or create a prominence contrast between stressed and unstressed syllables. Alternatively, if stressed vowels cause consonant place assimilation, this would be a case where a vowel in a prominent position triggers a phonological process rather than a consonantal process per se (Beckman 1998).

Voicing dissimilation: Finally, the position of stress and the motivation for dissimilation in Gothic is unclear (Collinge 1985).

4.3.6. Summary

Section 4.3 has considered the main factors underlying stress-sensitive consonantal processes. It has been argued that perception, aerodynamics, duration and prominence are responsible for the majority of stress-sensitive consonantal phenomena from the survey. It has been shown that for some processes various factors might be relevant, and problematic cases where the factors behind them are far from clear have been identified.

Table 18 shows all the stress- and foot-sensitive consonantal phenomena discussed for each factor. An asterisk * appears under the relevant column for the motivation. Parentheses () are placed around the asterisk when more than one motivation is plausible.

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Table 18

Factors in stress- and foot-sensitive consonantal phenomena

Alternation	Perception	Aerodynamics	Duration	Prominence
Attraction	(*)			(*)
Stronger/longer aspiration	(*)	(*)		(*)
Variable aspiration	*			
Variable glottalization	*			
Metathesis	*			
Voicing in σ̆ (Pattern 1)	(*)	(*)		
Voicing in 'σ (Pattern 3)		*		
Devoicing in σ̆ (Pattern 2)		*		
Post-aspiration		*		
Frication		*		
Affrication		*		
Consonant lengthening			*	
Flapping			(*)	(*)
Gemination				*
Pre-aspiration				*
Pre-glottalization				*
Lenition			(*)	(*)
Fortition			(*)	(*)
Deletion	(*)		(*)	(*)
Epenthesis			(*)	(*)
Stress attraction				*
Secondary articulation	Unclear			
Voicing dissimilation				
Voicing after 'σ/σ̆ (Pattern 4)				

4.4. Predictions: unattested consonantal alternations

The stress- and foot-sensitive consonantal phenomena attested and the effect of aerodynamics, perception, duration and prominence predict a series of phenomena which should not occur in stress- or foot-conditioned environments (84).

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(84) Predictions: unattested stress- and foot-sensitive consonantal alternations

Durational

— Longer duration of consonants and VOT in unstressed syllables.
— Consonant reduction in stressed syllables.
— Flapping in word-medial stressed syllables.

Prominence-related

— Onset fortition (sonority decrease) in unstressed or in foot-medial syllables in trochees.
— Onset lenition (sonority increase) in stressed or in foot-initial syllables in trochees.
— Flapping in word-medial stressed syllables.
— Attraction of prominence enhancing features to unstressed syllables.
— Stress attraction to syllables without onsets or with high-sonority onsets.
— Feature or consonant deletion in stressed syllables but not in unstressed syllables.
— Gemination, pre-aspiration and pre-glottalization after unstressed syllables.
— Prominence-enhancement in unstressed or weak syllables.
— Prominence-reduction in stressed syllables.
— Alternations that work together to enhance unstressed syllables and reduce stressed syllables.

Aerodynamic

— Longer or stronger frication, aspiration or affrication in unstressed syllables.
— Aerodynamic devoicing of voiced consonants in stressed syllables.

Perceptual

— Perceptual devoicing of voiced consonants in unstressed syllables.
— Feature or consonant deletion in stressed syllables but not in unstressed syllables.
— Salient features in unstressed syllables together with non-salient features in stressed syllables.
— In laryngealized consonants, glottalization and aspiration realized as close to the unstressed syllable as possible.
— Perceptual ambiguity in stressed syllables but not in unstressed syllables.

A case that goes against the predictions in (84) is Lilloet. Glottalized resonants in Lilloet are reported to be post-glottalized in all positions except before stressed vowels, where they are pre-glottalized (Howe and Pulleyblank 2001 and references therein). Glottalization is realized closer to the unstressed vowel in this case, and goes against the general tendency for post-glottalized resonants in this language. To further understand this case it would be necessary to know if sonorants in Lilloet are restricted to post-vocalic or pre-vocalic positions, or whether syllabic structure determines their distribution.

4.5. Phonetics and phonology

Under a modular approach, phonetics will include processes which are optional, gradient or partial, while phonology will include processes which are category-neutralizing, categorical or obligatory (§ 2.3). Discussion on the factors that underlie stress-sensitive consonantal phenomena begs the question of which factors are purely phonetic and which purely phonological. It is proposed that consonantal phenomena with aerodynamic and durational bases are in principle phonetic. This does not exclude that in some cases, aerodynamically- and durationally-based phenomena can be phonologized. Consonantal alternations where perceptual ambiguity is at stake are phonetic, while other perceptually-based consonantal alternations are phonological. Prominence-based consonantal phenomena are always phonological (Figure 2).

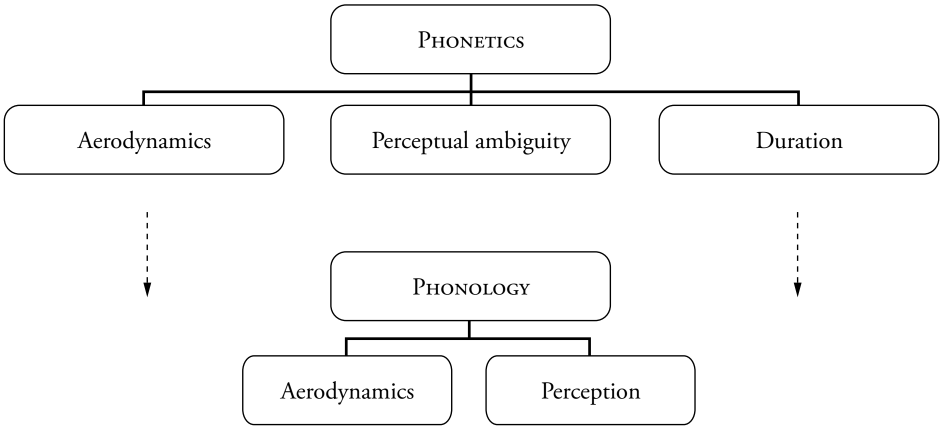

Figure 2

Phonetics and phonology in consonantal phenomena

Aerodynamic and durational factors follow from the articulatory and aerodynamic properties of stress: stress involves longer duration and higher airflow (Lehiste 1970). Aerodynamic and durational consonantal phenomena are frequently variable, as in frication of coda /b, d, g/ in Basque Spanish, and optional, as voicing variation in Silacayoapan Mixteco. Nevertheless, durational and aerodynamically-based consonantal phenomena might be phonologized; one example is flapping and aspiration in voiceless obstruents in English.

Consonantal phenomena where perceptual ambiguity is at stake belong to the phonetics. Phonetic devoicing or glottalization of a vowel by an adjacent laryngealized consonant might be reinterpreted by the speaker in a linguistic community as a different position of the consonant in the phonetic string (see Blevins and Garrett 1998). By contrast, perceptually-based phenomena whereby salient features or segments are avoided in unstressed syllables and preferred in stressed syllables is phonological.

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Last but not least, prominence-based phenomena belong to the phonology. Prominence-based phenomena are not caused by stress, unlike aerodynamically- and durationally-based phenomena. Prominence primarily involves phonological weight. Rhythmicity, a type of prominence found in foot-sensitive contexts, creates a contrast between strong and weak syllables, with or without stress.

4.6. The separation between stress and footing

The survey evidences three different types of stress-/foot-sensitive consonantal phenomena: (i) strictly stress-sensitive cases; (ii) phenomena where stress and footing coincide; and (iii) strictly foot-sensitive cases. The discussion below makes explicit in which contexts each occurs and the types of phenomena (aerodynamic, durational, perceptual or prominence-related) involved in each.

4.6.1. Strictly stress-sensitive consonantal phenomena

Some consonantal phenomena are influenced only by stress. These include alternations based on aerodynamic and durational factors, especially if optional or variable—like optional voicing alternations in Silacayoapan Mixteco, or variable frication of coda /b, d, g/ in Basque Spanish. The reason is that aerodynamics and duration are consequences of stress, not of abstract foot structure. Perceptual ambiguity seems to be related to stress only; metathesis and plausibly other consonantal alternations caused by perceptual ambiguity are more likely to occur in unstressed syllables due to reduced duration in this position (Blevins and Garrett 1998).

Stress-sensitive consonantal alternations are expected to occur in two specific stress systems: in languages with only one stress per word and no evidence for persistent footing, and in languages with persistent stress and consonantal alternations in a subset of stressed syllables. A plausible candidate for the first case is Senoufo, which has a number of reported stress-sensitive consonantal alternations including lengthening in stressed syllables, lenition in unstressed syllables and second articulation in stressed syllables. Urubu-Kaapor is plausibly a candidate for the second case, if, as reported in Kakumasu (1986), optional onset devoicing occurs in non-primary stressed syllables (i.e. secondary-stressed syllables).

4.6.2. Stress/foot structure cases

Most commonly foot structure and stress go hand in hand. Most languages have trochaic rhythms, with stresses falling on the initial syllable of every foot. In such cases it is ambiguous whether stress or foot structure is deterministic since both coincide. This is exemplified by some dialects of English, where /t/ is flapped or debuccalized in unstressed syllables but aspirated in stressed syllables, and where /h/ is not pronounced in unstressed syllables. Since stress and foot structure coincide, it has been proposed that aspiration occurs foot-initially and flapping and debuccalization foot-medially (Hayes 1985, Davis 2002).

Since foot structure has not been studied in all of the languages gathered in the survey some languages are inconclusive as to whether a consonantal process is strictly stress-motivated, or whether stress and footing coincide in motivating it.

4.6.3. Strictly foot-sensitive consonantal phenomena

Finally, there are cases where foot structure but not stress is deterministic in a consonantal process. This situation arises at least in three occasions: (i) iambic systems; (ii) languages with persistent footing that do not stress all feet in the prosodic word; and (iii) languages where, even if the rhythm is trochaic, directionality or alignment between stress and foot structure conflict.

(i) Iambic systems

Iambic systems are right-headed, which might have potential implications for the relationship between stress and foot structure in consonantal processes involving onsets. Onset phenomena in stressed syllables would occur foot-medially in disyllabic feet, but foot-initially in monosyllabic feet. Onset alternations in unstressed syllables would occur foot-initially in disyllabic feet; they would also occur in unfooted syllables (Figure 3).

Stressed		**Unstressed**	
Monosyllabic foot	**Disyllabic foot**	**Disyllabic foot**	**Unfooted**
Foot-initial	Foot-medial	Foot-initial	σ
(ˈσ)	(σ . ˈσ)	(σ . ˈσ)	

Figure 3

Iambic footing and stress for onsets

Not many cases of iambic systems are attested (Van de Vijver 1998). In the survey, the only iambic systems examined are Norton Sound Yupik, Alutiik Yupik and Cayuga. Cayuga exemplifies an instance of a synchronic alternation caused by perceptual metathesis; it is phonetic. Norton Sound Yupik and Alutiik Yupik have foot-sensitive fortition which applies foot-initially. Norton Sound Yupik has left-to-right iambs and secondary stresses except on the final syllable of the word (85c). Initial closed syllables are footed on their own (85c). Foot-final syllables are lengthened if open (85a, b).

(85) Norton Sound Yupik stress and foot structure (from Van de Vijver 1998)

(a)	qajani	[(qa.ˈjaa) ni]	'his own kayak'
(b)	qajapigkani	[(qa.ˈjaa.) (pix.ˌkaa.) ni]	'his own future authentic kayak'
(c)	angjarpangjugtuq	[(ˈaŋ.) (jax.ˌpaŋ.) (jux.tuq)]	'he wants to get a big boat'[83]

[83] In (85c), the second and the fourth syllables of [(ˈaŋ.) (jax.ˌpaŋ.) (jux.tuq)] 'he wants to get a big boat' are transcribed with [j] in the source. This [j] should be fortis [z] because it is following a stressed closed syllable. Plausibly, since these examples illustrate the stress pattern of Norton Sound Yupik rather than the allophonic variants of approximants and fricatives, these are not marked.

Norton Sound Yupik has fortition of /w, j, l/ to fricatives after stressed closed syllables (86a-c). Elsewhere /w, j, l/ are realized as approximants (86d-f).

(86) Norton Sound Yupik /w, l, j/ (from Van de Vijver 1998)

	Fricatives		*Approximants*	*Gloss*
(a)	(ma.ˈjuɣ) (v̠ik)	(d)	(ˈat.) (xaɣ. w̠ik)	‘place to go up/down’
(b)	(ma.ˈjuɣ) (z̠ux.tuq)	(e)	(ˈat.) (xaɣ.ˌj̠ux.) tuq	‘he wants to go up/down’
(c)	(ma.ˈjuɣ) (ɮ̠u.ni)	(f)	(ˈat.) (xaɣ.ˌl̠u.) ni	‘(he) going up/down’

Fortition of /w, j, l/ is unrelated to stress. In (86a) both [w] and [v] occur in unstressed syllables. Approximants might be found in both stressed and unstressed syllables (second column of (86a-c)). It is unlikely that the stress of the preceding syllable conditions fortition, especially since the immediately preceding stressed syllable has a coda, and no ambisyllabicity can apply. Additionally, fortition cross-linguistically affects stressed syllables, not unstressed syllables.

Leer (1985) and subsequent literature proposes that fortition generally marks foot boundaries in Yupik. Fricative allophones of [w, j, l] occur foot-initially and approximants elsewhere, namely, foot-medially and in unfooted syllables.[84]

(ii) Feet without stress

Consonantal processes can be conditioned by foot structure even if stress is not realized in all feet of the prosodic word. One example is Capanahua, a left-to-right, quantity-sensitive trochaic system where only one stress per word has been reported (Loos 1969) (87a). In Capanahua, coda /ʔ/ deletes in the weak syllable of a trochaic foot, regardless of whether stress is realized or not (87b-f).

(87) Capanahua (from Loos 1969; IPA)

(a)	[(ˈʔo.ʂa.)(ka.ʔi.)(niʔ.ki)]		‘he falls asleep’
(b)	/taʔ/		*declarative modal*
(c)	/ɾaʔ/		‘probably’
(d)	[(ˈʔo .tʃi) (ti .ɾa) (**taʔ .**ki)]		‘it is probably a dog’
(e)	[(ˈʔo .tʃi) (ti .ma) (ɾaʔ. **ta)** ki]		‘it is probably not a dog’
(f)	/ʔiʔsap/	[ʔiʔ.(ˈsa)]	‘bird’

(87d, e) show that /ʔ/ is deleted from the morphemes /taʔ/, /ɾaʔ/ in the weak syllable of a foot. No deletion occurs in unfooted syllables (87f). González (2003, 2009) argues that /ʔ/ deletion is a way to create a prominence contrast between strong and weak syllables in the foot; this is supported by the lack of deletion in unfooted syllables, and that /ʔ/ deletion achieves persistent footing in the language and compensates for the lack of secondary stresses.

[84] Unfortunately, I could not find examples of approximants occurring in unfooted positions.

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(iii) Conflicting metrical tendencies

In some consonantal processes footing and stress are antagonistic, with consonantal alternations respecting footing but not stress. Two relevant cases from the survey are Huariapano and Nganasan.

• In Huariapano, main and secondary stress have opposite directionalities and quantity-sensitivity (Parker 1998). Main stress is assigned via a moraic trochee at the right edge of the word (88a, b). Default secondary stress is assigned via syllabic trochees starting from the left edge of the word (88c-e).

(88) Huariapano main and secondary stress (from Parker 1998: 2-5; IPA)

(a)	[ˈ(hi.wi)]	'branch, stick'
(b)	[ka.(ˈno.ti)]	'bow (weapon)'
(c)	[(ˌku.βjaj.) βa.(ˈʂi.ki)]	'I cooked'
(d)	[(ˈwa.nɯ.) ki.(ˈraŋ.) ki]	'they have returned'
(e)	[(ˌjo.mɯ.) (ˌraj.βa.) kan.(ˈʂi.ki)]	'they hunted'

Omitting some details, coda [h] is epenthesized in the strong syllable of syllabic trochees constructed left-to-right provided the following onset is voiceless (89a). This distribution generally coincides with default (left-to-right) secondary stress assignment. However, coda [h] epenthesis also occurs in the main stressed foot (89a, c). In other cases, quantity-sensitivity for main stress assignment might lead to [h] epenthesis in unfooted syllables (89b, left column). Last but not least, in words with secondary stress assigned right-to-left from the main stressed foot, coda [h] epenthesis occurs in the weak syllables of trochaic feet (89d, left column). [h] epenthesis always coincides with the strong syllable in a syllabic trochee built from the left edge (9, right column), even if it clashes with main stress and (non-default) secondary stress assignment and the apparent footing for them. Detailed analyses of Huariapano are given in González (2003, 2009) and, more recently, in Bennet (2012, 2013).

(89) Huariapano: footing for main and secondary stress (from Parker 1994)

	Main/secondary stress footing	[h] *epenthesis footing*	*Gloss*
(a)	[(ˌjo.mɯ.) (ˌrah̲.ka.) (ˈtih̲.kæ̃j̃)]	[(ˌjo.mɯ.) (ˌrah̲.ka.) (ˈtih̲.kæ̃j̃)]	'(they) hunted'
(b)	[(ˌja.na.) pah̲.(ˈkw̃iŋ)]	[(ja.na.) (pah̲.ˈkw̃iŋ)]	'(I) will help'
(c)	[(ˌβo.no.) (ˈʂih̲.kæ̃j̃)]	[(ˌβo.no.) (ˈʂih̲.kæ̃j̃)]	'(they) will take'
(d)	[βis.(ˌma.noh̲.) (ˌko.no.) (ˈʂi.ki)]	[(βis.ˌma.) (noh̲.ˌko.) (no.ˈʂi.) ki)]	'I forgot'

• Nganasan has a process of 'rhythmic gradation', by which intervocalic [h, t, k, s, c] lenite to [b, d/ð, ɡ, z, j] in certain contexts (Vaysman 2002).[85] Nganasan builds left-to-right syllabic trochees (Helimsky 1998, de Lacy 2002). Main stress tends to fall on the penultimate syllable.[86] Secondary stresses are reported to occur in words with five or more syllables (Helimsky 1998).[87] (90) provides examples of stress and footing in this language; the foot structure in (90c) will be questioned later.

[85] These same segments undergo a different type of gradation related to syllabic weight (see discussion in section 3).

[86] Stress is optionally assigned to the antepenultimate syllable if this has a mid or low vowel [a, e, o] and the penultimate has a high or central vowel [i, y, u, ə, ɨ] (Helimsky 1998, de Lacy 2002).

[87] Helimsky (1998) does not mention secondary stress in words of less than five syllables long.

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(90) Nganasan stress and footing (from Helimsky 1998: 486-7; IPA)

(a)	(ˌkə.rɯ) (ˌga.ʎi) ('ti.ni)	'in marches'
(b)	(ˌkin.tə) (ˌləb.tɯ) ('ku.ciŋ)	'you are smoking'
(c)	(ˌkə.rɯ) (ˌga.ʎi) (ti.'ni.nə)	'in my marches'
(d)	bə.('lou.kə)	'a kind of movable dwelling on runners'

According to Helimsky (1998), rhythmic gradation is conditioned by foot structure, with [h, t, k, s, c] occurring foot medially—as in [('rə.k̲ɯ)] 'similar'—and [b, d/ð, g, z, j] foot-initially—as in (ˌkə.rɯ.) (ˌgə.ʎi.) ('rə.kɯ) 'similar to a march'. In words with an even number of syllables the distribution of [h, t, k, s, c] and [b, d/ð, g, z, j] is straightforward: voiceless allophones occur foot-medially (91a). However, in words with an odd number of syllables, voiced allophones are also found foot-medially (91b, c).

(91) Rhythmic gradation: All syllabic trochees (from Helimsky 1998: 490)

(a)	('nɯ.t̲ɯ)	'his wife'	(hɯ.a).('ɟə.t̲ɯ)	'his thumb'
(b)	bɯ.('nɯ.ð̲i)	'his rope'	(kə.rɯ.) gə.('ʎi.ð̲i)	'his march'
(c)	nɯ.('rə. g̲ɯ)	'similar to a woman'	(ˌbɯ.nɯ.) ('rə.k̲ɯ)	'similar to a rope'

I propose an alternative analysis of the stress system of Nganasan based on a prohibition against stressed final syllables. In odd-numbered syllables the last syllable is unparsed to avoid stress. This means that the final foot is iambic and that there are no medial unparsed syllables or feet with more than two syllables. Under this analysis, main penultimate stress is consistent with left-to-right footing, and the distribution of [h, t, k, s, c] and [b, d/ð, g, z, j] is captured. Voiceless allophones correlate with foot-medial position (92a, c), and voiced allophones with either foot-initial or unfooted syllables (92b, c).

(92) Rhythmic gradation: Final iamb (Helimsky 1998: 490)

(a)	('nɯ.t̲ɯ)	'his wife'	(hɯ.a).('ɟə.t̲ɯ)	'his thumb'
(b)	(bɯ. 'nɯ).ð̲i	'his rope'	(kə.rɯ.) (gə.'ʎi.) ð̲i	'his march'
(c)	(nɯ.'rə.) g̲ɯ	'similar to a woman'	(ˌbɯ.nɯ.) ('rə.k̲ɯ)	'similar to a rope'

A final iambic foot in an otherwise trochaic system is motivated by the avoidance of both final stress and unfooted medial syllables (see Kager 1999, Van de Vijver 1998). It allows the distribution of 'rhythmic gradation' to be equal in all feet in the word. An analysis where all feet are syllabic trochees does not capture these facts.

Rhythmic gradation in Nganasan relates to foot structure rather than stress; voiced allophones would occur both in stressed and unstressed syllables. Regardless of the type of feet in the prosodic word, voiceless allophones are kept in foot-medial position and voiced allophones in foot-initial and unfooted positions.

If rhythmic gradation in Nganasan is an instance of lenition, then this language contradicts one of the predictions in (84). The allophones [b, d/ð, g, z, j] are more sonorous than [h, t, k, s, c]. While the former are found foot-initially and in unfooted positions, the later are found foot-medially. It would be expected that foot-initially the less sonorous allophones would be found, since less sonorous consonants make better onsets and provide the auditory system with recovery from the adaptation to the vocalic stimulus, hence enhancing prominence (Delgutte 1997, Smith 2000). However, the opposite is found.

I speculate that gradation in Nganasan is voicing-based. Recall from § 3.4.1 that four different voicing patterns are attested; in voicing pattern 1, underlying voiceless consonants became voiced in unstressed syllables; in voicing pattern 2, underlying voiced consonants become voiceless in unstressed syllables; in voicing pattern 3, underlying voiceless consonants become voiced in stressed syllables; in voicing pattern 4, the stress of the preceding syllable influences onset voicing. Depending of whether [b, d/ð, g, z, j] or [h, t, k, s, c] are considered to be underlying, Nganasan would exemplify voicing pattern 2 or 3. The fact that the voiced allophones are found in unfooted syllables suggests that these are underlying, and that consequently, Nganasan exemplifies voicing pattern 2: underlying voiced consonants become voiceless in weak syllables. If consonant gradation in Nganasan is voicing-based, this pattern does not contradict the predictions made in (84). Further research on the nature of gradation in this language would help to dilucidate this case.

4.6.4. Summary

Summarizing, neither stress nor foot structure alone are sufficient in order to characterize the range of attested consonantal alternations. Both can coincide in conditioning consonantal phenomena, but they do not have to, as evidenced by strictly stress-sensitive and strictly foot-sensitive phenomena. More research on the foot structure of most languages is needed in order to determine whether the coincidence of stress-footing is a universal tendency, or whether the three possibilities (strictly stress, strictly footing, both) are equally salient in the languages of the world.

4.7. Rhythmicity

Foot-sensitive phenomena seem to be motivated by prominence considerations, in the sense that a prominence contrast is created between strong and weak footed syllables in the absence of or in opposition to stress. This prominence contrast might increase the prominence of the foot head (as in Huariapano) or decrease the prominence of the foot non-head (as in Capanahua).

I would like to use the term *rhythmicity* to refer to the occurrence of a prominence contrast within a foot. Rhythmicity typically involves an alternation among stressed and unstressed syllables. It is often observed in stress placement (Hayes 1995). But stress is not the only way that rhythmicity manifests itself; it can also be expressed through consonantal alternations. These can make strong footed syllables stronger or more prominent through processes like gemination, pre-aspiration, preglottalization, fortition and epenthesis. They can make weak footed syllables weaker or less prominent through lenition, flapping and deletion. Rhythmicity can make strong footed syllables more prominent and weak syllables less prominent at the same time. Some attraction processes and metathesis (as in Capanahua) may achieve this effect.

I suggest that rhythmicity achieves a balance between the drives of maximizing perceptibility and minimizing effort. Rhythmicity does not go to infinite; strong syllables are not infinitely strengthened and weak syllables are not infinitely reduced. If they did, reduced syllables would be totally deleted and strong syllables strengthened to a great extent. Consider the following two scenarios. In the first, all syllables in a word or sentence are equally strong. This would mean that perception is maximized, but so is effort. In the second, all syllables in a word are equally reduced. This would mean that effort is minimized, but so is perception. Thus, a language where there is a contrast between strong and weak syllables does the best for minimizing effort and maximizing perception at the same time. This does not exclude that certain other tendencies or pressures in the system might conflict with rhythmicity and obscure it, as discussed for stress systems in Hayes (1995).

Rhythmic contrasts are observed in stress patterns, consonantal processes, vocalic processes and tonal phenomena (93) (see also Hayes 1995). All of these processes can work together to achieve rhythmicity. However, some languages might 'select' some of these patterns over others as better suited to express prominence contrasts. For instance, while stress and foot structure typically correspond to each other, they do not in certain languages, either because of the absence of secondary stress (as in Capanahua), or other considerations, including diachronic change (this plausibly occurs in Huariapano; see González 2003, 2009). Alternatively, some languages might have foot-sensitive vocalic phenomena but not consonantal phenomena, or the other way around.

(93) Examples of rhythmic contrasts

Stress

— Stress in strong syllables but no stress in weak syllables.
— Avoidance of clashes and lapses in stress patterns.

Consonants

— Fortition in strong syllables and lenition in weak syllables.
— Epenthesis in strong syllables and deletion in weak syllables.
— Codas/onsets in stressed syllables and no codas/onsets in weak syllables.

Vowels

— Long vowels in strong syllables and short vowels in weak syllables.
— Deletion of vowels in weak syllables.
— Sonorous vowels in strong syllables and non-sonorous vowels in weak syllables.
— Vocalic feature attraction from weak syllables into strong syllables.

Tone

— Tone in stressed syllables.
— High tone in strong syllables and low tone in weak syllables.

Foot-sensitive consonantal alternations achieve rhythmicity and with it the organization of syllables into groups of strong and weak syllables. These processes are typically categorical and obligatory for all speakers. However, even in cases where they are optional, as in metathesis of /ʔ/ in Capanahua, the fact that these processes achieve the organization of syllables into higher constituents makes them a part of the grammatical knowledge that speakers have. The following section puts forward a proposal to account for foot-sensitive consonantal prominence cases.

4.8. Accounting for prominence-based consonantal alternations

This section proposes an analysis of prominence-based consonantal phenomena for stress-sensitive and foot-sensitive phenomena. Section 4.8.1 reviews previous prominence-type analyses, including prominence augmentation (Smith 2000, 2002) and prominence reduction through prominence alignment (Prince and Smolensky 1993, Crosswhite 2004, among others). Sections 4.8.2 and 4.8.3 show that Prominence Alignment can capture prominence-based foot-sensitive consonantal phenomena. Section 4.8.4 is the conclusion.

4.8.1. Previous analyses

(a) Augmentation in strong positions

Prominent positions —onsets, long vowels, stressed syllables, initial syllables, and roots— are augmented in many languages, achieving enhanced prominence (Smith 2000, 2002). For instance, stressed syllables might become heavy (as in Mohawk), acquire tone (as in Slave), have an epenthetic onset (as in Dutch) or reject high-sonority onsets (as in Niaufo'ou). On the other hand, prominent elements may attract stress; stress can be attracted to heavy syllables (as in Aguacatec), to high-toned syllables (as in Golin), to syllables with onsets (Arrernte) or to syllables with low-sonority onsets (Piraha) (Smith 2000, 2002).

Both augmentation of stressed syllables and stress attraction phenomena are attested in the survey. Phenomena where augmentation is at stake included gemination, pre-aspiration, pre-glottalization, epenthesis and segmental attraction —the last one possibly hand in hand with prominence reduction— and possibly longer or stronger aspiration. Various instances of stress attraction are also gathered in the survey; some examples are Arrernte and Piraha.

One possible approach that captures augmentation phenomena is given in Smith (2000, 2002). Smith (2000, 2002) proposes to capture augmentation cases through the ranking of M/Str(ong) (henceforth M/Str) constraints, that is, markedness constraints that make specific reference to strong positions. Only markedness constraints that enhance prominence can be relativized to a strong position. This is known as the 'prominence condition'. For example, heaviness enhances the prominence of a stressed syllable. This is expressed by the constraint Heavyσ/ˈσ (14). If M/Str and stress location constraints outrank faithfulness, augmentation will occur. If M/Str and faithfulness constraints outrank stress location, stress attraction will occur (Smith 2000, 2002).

(94) Heavyσ/'σ For all syllables x, if x is a 'σ, then x is heavy (bimoraic)
'Stressed syllables are heavy' (Smith 2000)

A problem with this approach is that strictly foot-sensitive consonantal processes cannot be captured, since foot heads (independent of stress) are not part of the prominent categories. Additionally, this approach targets augmentation only, not reduction. Prominence Alignment (Prince and Smolensky 1993) is discussed next; it can capture both prominence reduction and augmentation in stress- and foot-related contexts.

(b) Prominence Alignment

Prominence-alignment is a mechanism first proposed to account for the preferential alignment of sonorous segments with syllabic nuclei and for the preferential alignment of non-sonorous segments with syllabic margins (Prince and Smolensky 1993). The basic idea behind Prominence Alignment is that two prominence scales can be crossed in order to encode the preference of prominence reduction in non-prominent positions and higher prominence in prominent positions. To give one example, Crosswhite (2004) accounts for stress-sensitive prominence reduction in vowels by means of crossing the accentual prominence scale with the vocalic prominence scale (95) (prominence-reduction applies in cases where loud and long vowel qualities are reduced in unstressed positions, while prominent positions show augmentation or faithfulness to underlying qualities).

(95) Prominence reduction and augmentation for vowels (Crosswhite 2004)

Scale 1: Accentual prominence	stressed $_{prom}$ > unstressed
Scale 2: Vocalic prominence	a $_{prom}$ > ɛ, ɔ $_{prom}$ > e, o $_{prom}$ > i, u $_{prom}$ > ə

Prominence reduction for vowels: Constraint Hierarchy
*unstressed/a>>*unstressed/E, >>*unstressed/e,o>>*unstressed/i,u>>*unstressed/

Prominence faithfulness/augmentation for vowels: Constraint Hierarchy
*stressed/ >>*stressed/i, u>>*stressed/e,o>>*stressed/E, >>*stressed/a

The accentual prominence scale expresses the fact that stressed syllables are more prominent than unstressed syllables. The vocalic prominence scale encodes the fact that sonorous vowels are more prominent than non-sonorous vowels. Crossing the unstressed member of the accentual prominence scale with the members of the vocalic prominence scale achieves a hierarchy of constraints prohibiting sonorous (i.e. prominent) vowels in unstressed positions. The ranking among the resulting constraints is fixed and captures the implicational relationship among them. Namely, if a language permits, say, /a/ in unstressed syllables, it also allows for all other vowels in this position.

If the stressed member of the accentual scale is combined with the vocalic sonority scale, the resulting hierarchy of constraints expresses the fact that non-sonorous (i.e. non-prominent) vowels are dispreferred in stressed syllables. Depending on the relative ranking with markedness and faithfulness constraints, this can account for faithfulness of underlying vowel sonority in this position and/or 'augmentation' in the sonority in stressed syllables. Thus, the mechanism of prominence alignment offers a way to capture both prominence reduction and augmentation.

Prominence Alignment has also been employed to account for syllabic prominence (Prince and Smolensky 1993), stress prominence (Kenstowicz 1996), moraic prominence (Crosswhite 1999), and tonal prominence (de Lacy 1999). The following sections show that Prominence Alignment can also be extended to stress-sensitive and foot-sensitive consonantal phenomena involving prominence reduction or augmentation.

4.8.2. Prominence Alignment and stress-sensitive consonantal prominence

Prominence-based consonantal phenomena where stress is relevant include augmentation cases (gemination, pre-aspiration, pre-glottalization, fortition, epenthesis, and possibly attraction and longer aspiration) and reduction cases (lenition, flapping, and deletion and possibly attraction). All of these can be analyzed with Prominence Alignment by means of combining the accentual and segmental scales in (96).

(96) Accentual and segmental scales

Accentual prominence	$'\sigma_{prom} > \breve{\sigma}$	(Crosswhite 2004)
Coda prominence	$C]_{\sigma\, prom} > V]_{\sigma}$	
Moraic prominence	$\mu\mu_{prom} > \mu$	(Crosswhite 1999)
Vocalic prominence	$a_{prom} > e, o_{prom} > i, u$	(Prince and Smolensky 1993)
Consonantal sonority	w > f > p	(based on Venneman 1988)

The accentual scale can be combined with the coda prominence and consonant sonority scale. Different instantiations have been proposed for the sonority hierarchy for consonants (see discussion in Crosswhite 2004). Simplifying over the different proposals for this hierarchy, stops are less sonorous than fricatives, and fricatives less sonorous than glides. Onset consonants enhance syllable prominence because they provide the auditory system with recovery from adaptation to a constant vocalic stimulus (Delgutte 1997, Smith 2000). Since less sonorous consonants are maximally different from vowels, they will also help to enhance syllable prominence. This will mean than in stressed syllables, less sonorous onsets will be preferred to more sonorous onsets in order to express prominence (97).

(97) Stress prominence and consonant sonority in onsets: constraint hierarchies

$*'\sigma/_{\sigma}[w >> *'\sigma/_{\sigma}[f >> *'\sigma/_{\sigma}[p$	'Stressed syllables lack sonorous consonants in onsets'
$*\breve{\sigma}/_{\sigma}[p >> *\breve{\sigma}/_{\sigma}[f >> *\breve{\sigma}/_{\sigma}[w$	'Unstressed syllables lack non-sonorous consonants in onsets'

The constraints in (97) account for onset lenition in unstressed syllables and onset fortition in stressed syllables. For example, West Tarangan has fortition of /w, j/ in onsets of stressed syllables (Nivens 1992). High-ranked * 'σ/$_σ$[w outranks the constraint enforcing sonority identity from input to output. As a result, /w, j/ fortify to [g, dz] in stressed syllables (Table 19).

Table 19

Fortition in West Tarangan

/suwakan/ 'elephant tusk'	*** σ/$_σ$[w**	**Ident (sonority)**
☞ a. su. 'ga.kən		*
b. su. 'wa.kən	*!	

A partial typology of prominence-based consonantal phenomena in onsets where stress and sonority interact is given in (98). Fortition will take place in onsets if any member of the hierarchy *'σ/$_σ$[w >>*'σ/$_σ$[f >>*'σ/$_σ$[p outranks Ident (sonority). Lenition or flapping will take place in onsets if any member of the hierarchy *σ̆/$_σ$[p>>*σ̆/$_σ$[f >>*σ̆/$_σ$[w outranks Ident (sonority).

(98) Partial typology: Consonant sonority in onsets

Augmentation in 'σ	*'σ/$_σ$[w >> Ident (son)	Fortition:	*West Tarangan*
Reduction in σ̆	* σ̆/$_σ$[p >> Ident (son)	Lenition:	*Senoufo*
Faithfulness in σ̆	Ident (son) >>* σ̆/$_σ$[p	Non-sonorous C:	?
Faithfulness in 'σ	Ident (son) >> *'σ/$_σ$[p	Sonorous: C	?

The accentual scale can also be combined with the coda prominence scale. The resulting constraints are given in (99).

(99) Coda prominence: constraint hierarchies

'σ/V]$_σ$ >>'σ/C]$_σ$	'Stressed syllables are not open'
*σ̆/C]$_σ$ >>*σ̆(/V]$_σ$	'Unstressed syllables are not closed'

The universal ranking *'σ/V]$_σ$>>*'σ/C]$_σ$ expresses the fact that there is a tendency for stressed syllables to achieve prominence by means of having a coda. If *'σ/V is sufficiently high-ranked, it can drive consonant attraction to the stressed syllable and gemination, pre-aspiration and pre-glottalization immediately following the stressed syllable. The universal ranking *σ̆/C]$_σ$ >>*σ̆(/V]$_σ$ captures the fact that there is a tendency for unstressed syllables to avoid extra prominence from a coda. If *σ̆(/ C]$_σ$ is sufficiently high-ranked, it can drive coda deletion. A partial typology of coda prominence related to stress is given in (100).

(100) Partial typology: coda prominence and stress

Coda augmentation	*'σ /V]$_σ$ >>INTEGRITY	*Popoloca*:	desintegration
Coda reduction	*σ̆/C]$_σ$ >>MAX	*Oneida*:	[ʔ, h] deletion
Faithfulness to underlying coda	FAITH>>*'σ /V]$_σ$	*Senoufo*:	CV in 'σ
	FAITH>>*σ̆/C]$_σ$	*Guayabero*:	CVC in σ̆

Other stress-related prominence consonantal phenomena that can be analyzed through Prominence Alignment include onset epenthesis in stressed syllables and segmental attraction to complex onset. The next section discusses the extension of Prominence alignment to foot-sensitive prominence-based consonantal phenomena.

4.8.3. Prominence Alignment and foot-sensitive consonantal prominence

Previous research on the interaction between stress and vocalic sonority and stress and tone has shown that reference to heads in constraints does not capture the full range of cross-linguistic data for certain processes that apply in non-heads (Kenstowicz 1996, de Lacy 1999, Crosswhite 2004). In other words, reference to both heads and non-heads is necessary to account for the attested cross-linguistic patterns. This is also evident from the survey, where some prominence phenomena affect foot heads (as in Huariapano), but others affect foot non-heads (as in Capanahua). The mechanism of Prominence Alignment makes it possible to refer both to foot heads and foot complements for prominence-based phenomena.

Prominence alignment for foot positions is discussed below for coda prominence, consonant prominence and accentual prominence. The scales relevant for this discussion are given in (101).

(101) Prominence and sonority scales

Foot prominence	Head $_{prom}$>Weak	(Kenstowicz 1996)
Accentual prominence	'σ $_{prom}$ > σ̆	(Crosswhite 2004)
Coda prominence	C]$_{σ\ prom}$ > C]$_σ$	
Consonantal sonority	w >f >p	(based on Venneman 1988)

Note that Head $_{prom}$>Weak is assumed here rather than Head $_{prom}$>non head. Head $_{prom}$>Weak means that strong footed syllables are more prominent than weak footed syllables. Head $_{prom}$>non head means that strong footed syllables are more prominent that both weak footed and unfooted syllables. The choice of Head $_{prom}$>Weak is grounded in the aim of contrast within the prosodic constituent. However, the selection of one scale over the other, or the fact of whether a ternary scale that includes heads, weak syllables and unfooted syllables is needed is an empirical question and interacts with the accentual prominence scale. For further discussion, see section 6.

The foot prominence scale can be combined with other prominence scales to capture the full range of prominence phenomena in both foot heads and foot complements. The constraints that result from combining foot and coda prominence scales are given in (102).

(102) Coda prominence: constraint hierarchies

*HEAD/ V]$_\sigma$ >> *HEAD/ C]$_\sigma$	'Foot heads are not open'
*WEAK/ C]$_\sigma$ >>*WEAK/ V]$_\sigma$	'Foot complements are not closed'

The ranking *HEAD/V]$_\sigma$>> *HEAD/C]$_\sigma$ expresses the fact that foot heads want to be prominent by means of having a coda. If *HEAD/V]$_\sigma$ is sufficiently high-ranked, it can drive coda epenthesis and onset-to-coda metathesis in foot heads, as attested in Huariapano and Capanahua. Prominence reduction occurs when *WEAK/C]$_\sigma$ >>*WEAK/V]$_\sigma$ is visibly active. High-ranked *WEAK/C]$_\sigma$ can result in coda deletion in weak footed syllables, as in Capanahua (Table 20). A partial typology of foot prominence related to codas is given in (103).

Table 20

Coda /ʔ/ deletion in Capanahua

/bitʃiʔ/ 'I grab'	*WEAK/C]$_\sigma$	Max
☞ a. ('bi. tʃi)		*
b. ('bi. tʃiʔ)	*!	

(103) Partial typology of foot prominence/codas

CVC head	*HEAD/V]$_\sigma$ >> DEP	*Huariapano*
CV head	NO CODA>>*HEAD/V]$_\sigma$	*Maori*
CV weak	*WEAK/C]$_\sigma$ >> MAX	*Capanahua*
CVC weak	MAX >>*WEAK/ C]$_\sigma$	*Norton Sound Yupik*

Foot prominence can also be combined with consonantal sonority. It is suggested here that, similarly to the case of stressed syllables, less sonorous onsets enhance prominence in foot heads since onsets and especially low-sonority onsets achieve recovery from adaptation to the vocalic stimulus (Delgutte 1997, Smith 2000). For this reason non-sonorous consonants are preferred in onsets of foot heads while sonorous consonants are preferred in onsets of weak footed syllables. The relevant constraints are in (104). From the survey, cases involving onset consonantal sonority relate to stress rather than footing or involve foot boundary marking, as in Norton Sound and Alutiik Yupik. However, a predicted partial typology of foot-related prominence phenomena involving consonantal sonority is given in (105) (for vocalic sonority and foot prominence, see Kenstowicz 1996 and González 2003, 2009 on Shipibo).

(104) Foot prominence and consonant sonority in onsets

*Head/$_\sigma$[w >>*Head/$_\sigma$[f >>*Head/$_\sigma$[p	'Foot heads lack sonorous consonants'
*Weak/$_\sigma$[p >> *Weak/$_\sigma$[f >>*Weak/$_\sigma$[w	'Foot complements lack non-sonorous consonants'

(105) Predicted partial typology of foot-sensitive consonantal sonority in onsets

Heads have non-sonorous onsets	*Head/$_\sigma$[w>>Ident (C)
Heads have sonorous onsets	Ident (C)>>*Head/ $_\sigma$[w
Weak positions have non-sonorous onsets	*Weak/ $_\sigma$[p >> Ident (C)
Weak positions have sonorous onsets	Ident (C)>>*Weak/ $_\sigma$[p

Foot prominence can also be realized through stress. There is a cross-linguistic preference for foot heads to have stress and for foot non-heads to be unstressed. The relevant constraints are given in (106).

(106) Footing and stress prominence

*Head/σ̆	'Foot heads are not unstressed'
*Weak/ 'σ	'Weak footed syllables are not stressed'

To the best of my knowledge, constraints such *Head/σ̆ and *Weak/'σ have not been proposed before. These constraints express the universal tendency for stress to occur in foot heads. It could be argued that the interaction between Grwd=Prwd, Parse and All-Feet (left/right) suffices to account for stress systems. If Parse>>All-Feet (L/R), only one foot will be constructed in a prosodic word; where All-Feet (L/R)>>Parse, feet will be persistent in a prosodic word. However, the interaction among Grwd=Prwd, Parse and All-Feet (L/R) does not capture cases where footing is persistent but stress is not (as in Capanahua). Attested foot-sensitive consonantal alternations where stress is not relevant argues for the inclusion of constraints that derive footing independently of stress.

Making *Head/σ̆ violable has interesting repercussions for stress systems. If *Head/σ̆ is undominated or sufficiently high-ranked stress will surface in all foot heads. If *Head/σ̆ is low-ranked or not active not all feet will have stress. One example is Capanahua, where only the initial foot is stressed.

*Weak/ 'σ expresses the fact that weak syllables tend not to be stressed. This is apparently always the case cross-linguistically, with the possible exception of Huariapano (see González 2003). Plausibly this is because, unlike for *Head/σ̆, few or no constraints at all dominating *Weak/ 'σ have the effect of driving stress in weak footed syllables. Note that (26) does not include *Head/'σ or *Weak/σ̆ as possible rankable constraints. The reason for this is that these constraints might not be well-motivated in any grammar.

A partial typology of footing and stress is given in (107). Max stress enforces one and only one stress per prosodic word (González 2002a, 2003). Non-finality prohibits final stress (Kager 1999: 117), and *Clash prohibits two stresses being realized in adjacent syllables (Kager 1999: 130 and references therein). If any of these constraints outranks *Head/σ̆, not all foot heads in the prosodic word will be stressed.

(107) Partial typology of footing and stress

All heads stressed	Undominated * Head/σ̆	*Icelandic*
One head stressed	Max stress>>*Head/σ̆	*Capanahua*
Most heads stressed	Non-finality>>*Head/σ̆	*Norton Sound Yupik*
Weak σ unstressed	Undominated Clash, *Weak/ˈσ	*Most languages*
Weak σ stressed	*Head/CV, Ident (Stress)>>*Weak/ˈσ	*Huariapano*

4.8.4. Conclusion

It has been shown that Prominence Alignment can be extended not only for stress-sensitive consonantal phenomena where prominence is at stake, but also for foot-sensitive consonantal processes. Additionally, Prominence Alignment can make reference to stressed and unstressed positions and to strong and weak footed positions for both augmentation and reduction phenomena. This mechanism is independently needed to account for other phenomena (Prince and Smolensky 1993, Kenstowicz 1996, Crosswhite 1999, 2004, de Lacy 1999). Deploying this mechanism is just extending logical properties of the theory.

Languages might enforce prominence through sonority, coda and stress alternations. Other possibilities, like onset prominence, have not been shown in detail to avoid redundancy, and also because other motivations (such as duration) might be involved.

Combining foot prominence with stress and segmental prominence predicts three types of foot-sensitive, prominence-related consonantal phenomena (Figure 4). Prominence enhancement and reduction can take place in two different phenomena in the same language (as in Capanahua); additionally, both can be achieved by the same phenomenon (as in Bagneres-de-Luchon French attraction).

+ Prominence (heads)	**– Prominence (weak footed σ)**	**+ Prominence (heads) & – Prominence (weak footed σ)**	
		Same process	**Same language**
Epenthesis (Huariapano)	*Deletion* (Capanahua)	*Attraction* (Bagneres-de-Luchon French)	*Metathesis & deletion* (Capanahua)

Figure 4

Predictions for foot-based prominence

4.9. Accounting for duration-based consonantal alternations

Stress-sensitive consonantal processes where duration is a factor include consonantal lengthening and shortening, lenition, flapping, and plausibly fortition. For consonantal lengthening and shortening the relationship between stress and duration is straightforward: a consonant will be longer in a stressed syllable than in an unstressed syllable. Stress-sensitive lenition and flapping involve both durational and magnitude reduction in unstressed syllables (Browman and Goldstein 1990, 1992). Stress-sensitive fortition has been shown to occur in stressed syllables through a decrease in articulatory overlap in this position due to hyperarticulation (De Jong, Beckman and Edwards 1993).

Previous formal analyses (Kirchner 1998, Flemming 2001) allow for the incorporation of stress in durational phenomena. Lenition and flapping are captured by the effort-type approach (Kirchner 1998), where perceptual motivations and the drive to maintain contrasts conflict with a general drive to minimize effort. The effort approach does not explicitly discuss stress-sensitive lenition, but it can be extended to capture it. Since unstressed syllables have reduced duration, the target duration and constriction of a segment cannot be as easily achieved as in stressed syllables. This will cause lenition, deletion, and general shortening. Kirchner (1998) suggests that processes where insertion of gestures occurs might be driven by perceptual considerations, i.e., by making clear the relevant contrasts.

In Flemming's (2001) approach, both categorical and scalar phenomena are formalized through the interaction of (mostly) scalar constraints, with overall constraint weighting rather than strict domination. Flemming (2001) acknowledges the need to incorporate stress-sensitive constraints in this model, including stress-sensitive durational constraints or rhythmic constraints of the Iambic-Trochaic law type (Hayes 1995). However, he does not develop an analysis for stress-sensitive durational phenomena.

Both durational and prominence can be factors for lenition, flapping and fortition phenomena. The previous section proposed an analysis for phonological, prominence-related phenomena that includes these. Phonological consonantal lengthening and shortening also need to be analyzed in the grammar. Prominence Alignment can be extended to account for stress-sensitive durational processes with are obligatory and categorical. The relevant scales and constraints that obtain are given below:

(108) Prominence alignment for duration

Scales	
Accentual prominence	'σ $_{prom}$>
Consonantal length	Cː $_{prom}$>Cˑ $_{prom}$>C
Vocalic length	Vː $_{prom}$>Vˑ $_{prom}$>V
Constraints	
*σ̆/Cː >>*σ̆/Cˑ>>*σ̆/C	'Unstressed syllables don't have long consonants'
'σ/C >> σ/Cˑ>>*'σ/Cː	'Stressed syllables don't have short consonants'
'σ/V>> σ/Vˑ>>*'σ/Vː	'Stressed syllables don't have short vowels'
*σ̆/Vː >>*σ̆/Vˑ >>*σ̆/V	'Unstressed syllables don't have long vowels'

Focusing on consonantal phenomena, shorter consonants tend to occur in unstressed syllables and longer consonants in stressed syllables crosslinguistically. One example is Urubu-Kaapor, where onsets are lengthened (but not geminated) in main stressed syllables (Kakamasu 1986) (Table 21). A partial typology of stress-related durational phenomena is given in (109).

Tableau 21

Urubu-Kaapor onset lengthening

/katu/ ‘it is a good’	***'σ/C**	**Ident (length)**
☞ a. ka.'tːu		*
b. ka.'tu	*!	

(109) Partial typology: stress-related durational phenomena

Shortening in σ̆	*σ̆/C >>*σ̆/C·>>*σ̆/C	*American English flapping*
Lengthening in 'σ	*'σ/C >>* σ/C·>>* σ/Cː	*Urubu-Kaapor*
No length difference	IDENT-(LENGTH)>> *'σ/C IDENT-(LENGTH)>> *σ̆/Cː	*Swedish*

It is predicted that lengthening can also be foot-sensitive. In such cases, the foot prominence scale should be combined with the durational scale.

4.10. Accounting for aerodynamic-based consonantal alternations

Few analyses have been proposed to capture aerodynamic processes (see Davis 2002 for English aspiration and flapping). The reason might be that aerodynamic processes are usually variable and gradient and thus not included in the grammar. However, in some cases aerodynamic phenomena are part of the grammar (as in English aspiration). Prominence Alignment can be extended to capture aerodynamic processes. Focusing on aspiration, the relevant scales and resulting constraints are given below.

(110) Aerodynamic phenomena: scales and constraints

Scales	
Accentual prominence	'σ $_{prom}$>σ̆
Aspiration	Aspiration $_{prom}$>No aspiration
Constraints	
*[asp]/σ̆>>*No [asp]/σ̆	‘unstressed syllables have no aspiration’
No [asp]/'σ >>[asp]/'σ	‘stressed syllables don’t lack aspiration’

This family of constraints predicts that aspiration will be greater or more likely in stressed syllables than in unstressed syllables. One example involving is English, where /h/ is not pronounced in unstressed syllables (table 22). For aspiration, a partial typology of possible cases is given in (111).

Table 22

/h/ in English

/vɪhɪkl/ 'vehicle'	*σ̆/[asp]	Max
☞ a. vɪ.ɪ.kl		*
b. vɪ.hɪ.kl	*!	

(111) Partial typology (aspiration)

Aspiration admissible everywhere	IDENT(asp)>>*[asp]/σ̆, *No [asp]/'σ	*Thai*
Deletion in σ̆	*σ̆/[asp]>> MAX	*English*
Epenthesis in 'σ	*'σ/no [asp] >>Dep	*English*
No aspiration anywhere	*[asp], *[asp]/σ̆ >> *No [asp]/'σ	*Spanish*

4.11. Accounting for perception-based consonantal alternations

Perceptual processes can achieve a better perception of features or segments, avoid features or consonants in positions where they cannot be perceived; or cause perceptual ambiguity in perceptually-challenged positions. Perceptual approaches that take into consideration the role of stress include Licensing-by-cue (Steriade 1997) and contrast reduction (Crosswhite 2004).

Steriade (1997) examines laryngeal neutralization and concludes that neutralization arises due to absent or diminished perceptual cues in certain environments. Perceptual cues include quantity, quality, and duration. For laryngealized consonants, the timing of aspiration and glottalization depends on whether the consonant is a stop or a sonorant. If a stop, aspiration and glottalization will tend to fall on the following vowel; the consonant will be post-aspirated or post-glottalized. Laryngealized sonorants will tend be pre-aspirated or pre-glottalized. In intervocalic position, the timing of aspiration or glottalization will depend on stress. If the preceding vowel is stressed, the consonant will be pre-aspirated or pre-glottalized. If the following vowel is stressed, the consonant will be post-aspirated or post-glottalized. The reason for this is that cues are better perceived in stressed vowels.

Steriade (1997) suggests fixed perceptibility scales which depend on the environment where a consonant is realized. These perceptibility scales include pre- or post-vocalic environments, before or after a resonant, and so on. These perceptibility scales are formalized as segmental context constraints. These constraints are ranked with faithfulness constraints in a language-specific basis. If faithfulness ('preserve') constraints outrank the whole hierarchy of segmental context constraints, features are preserved in all contexts. If the perceptual hierarchy outranks the relevant faithfulness constraint a given feature or segment will not surface in the language. However, in many languages features occur in certain positions where cues are relatively perceivable. This is captured through the ranking of the specific perceptual constraint over the relevant faithfulness constraint. Crucially, Steriade claims that syllable positions do not play a role. [88]

This and similar approaches account for variable timing of glottalization and aspiration (Steriade 1997), metathesis in stressed syllables (Hume 2001), and perceptually-based consonant attraction. Licensing-by-Cue cannot obtain perceptually-motivated consonantal processes where perceptual ambiguity is at stake. Since in perceptual metathesis a change arises because of perceptual ambiguity, and since both CV>VC and VC>CV changes are attested for all features or segments undergoing metathesis, it is not possible to invoke the interaction between markedness and improved perception as a driving force (Blevins and Garrett 1998). Moreover, perceptual metathesis is in many cases diachronic (Blevins and Garrett 1998).

Crosswhite (2004) examines vowel reduction processes and distinguishes between prominence-reduction and contrast enhancement cases. In contrast enhancement, perceptually-challenging vowel qualities are limited to stressed positions, while these contrasts are eliminated in unstressed positions. Contrast enhancement processes are formalized through licensing constraints in which marked features are licensed in contexts enhancing correct perception. The range of processes that this approach captures is similar to Licensing-by-Cue.

As an example, let us examine how speech perception-based accounts capture metathesis and deletion in Faroese. The analysis is taken from Hume and Seo (2001). Only the basic analysis distinguishing metathesis and deletion will be presented. For details, see Hume and Seo (2001).

Recall that in Faroese, the cluster [skt] metathesizes to [kst] in stressed syllables, while in unstressed syllables [k] deletes. Hume and Seo (2001) consider that metathesis enhances the perceptibility of [k] in Faroese. The cues for [k] are not well perceived between two consonants, so [k] metathesizes to a position right after the stressed vowel to enhance its cues. In unstressed syllables the cues for [k] are not well perceived, so [k] deletes. The perceptual constraints proposed by Hume and Seo 2001 are given below:

(112) Perceptual constraints in Faroese (from Hume and Seo 2001: 9, 12)

Avoid X/Y (*x/y)	Avoid a segment type X in context Y
*stop/obst__stop	Avoid a stop between an obstruent and a consonant.
*stop/v̆__c	Avoid a pre-consonantal stop after an unstressed sonorant
*stop/ˈv__c	Avoid a pre-consonantal stop after a stressed sonorant

[88] Cf. Howe and Pulleyblank (2001), who argue that in some cases prominent prosodic structure (onsets or moras) licenses features like glottalization regardless of perceptual considerations.

Avoid X/Y are contextual constraints that capture the perceptual factors behind cross-linguistic patterns and that reflect the scale perceptibility of the segments involved. For example, *stop/v̆__c >> *stop/'v__c captures the fact that it is worse for a stop to be pronounced in the vicinity of an unstressed sonorant than after a stressed sonorant, because the cues for the stop will be better enhanced after stress (since stress has increased duration and/or amplitude of cues) (Hume and Seo 2001).

The perceptual constraints proposed by Hume and Seo (2001) interact with Max-C and Linearity in the following way: *stop/obst__stop, *stop/v̆__c >> Max-C. This ranking will trigger [k] deletion in a [skt] cluster: it is better to delete [k] than to have it before a consonant after an unstressed sonorant or between two other consonants (Table 23). Since *stop/'v__c outranks Linearity, [k] will metathesize in stressed syllables (Table 24).

Table 23

Deletion of [k] is [skt] clusters (from Hume and Seo 2001: 12)

/fØːrɪsk-t/ 'Faroese'	*stop/obst__ stop	*stop/v̆__c	Max-C	*stop/'v__c	Linear
a. 'føː.rɪskt	*!				
b. 'føː.rɪkst		*!			*
☞ c. 'føː.rɪst			*		

Table 24

Metathesis in [skt] clusters in Faroese (from Hume and Seo 2001: 12)

/fEsk-t/ 'fresh'	*stop/obst__ stop	*stop/v̆__c	Max-C	*stop/'v__c	Linear
a. 'fɛskt	*!				
☞ b. 'fɛkst				*	*
c. 'fɛst			*!		

4.12. Conclusion

This section has summarized the main findings of the survey reported in § 3.3-10. It has discussed the main generalizations by process and position and how these relate. Additionally, it has explored the factors behind stress- and foot-sensitive consonantal phenomena: perception, aerodynamics, duration, and prominence/rhythmicity, classifying the consonantal phenomena in the survey according to these. It has proposed that alternations with durational, aerodynamic or perceptual ambiguity bases are phonetic (but can be phonologized) while prominence-based and perceptually-based alternations (excluding perceptual ambiguity) are phonological.

An important finding is that three different types of consonantal phenomena are attested: strictly stress-sensitive, strictly foot-sensitive, and stress/foot sensitive. Rhythmicity is distinguished from prominence as the drive for the rhythmic organization of syllables within a word. Strictly foot-sensitive consonantal processes are mainly rhythmic (prominence) oriented. Prominence-related approaches to foot structure are not very common; exceptions include Kenstowicz (1996) for vowel sonority and (De Lacy 1999) for tonal phenomena. This section has shown in detail how prominence-related, durational and aerodynamic phenomena can be analyzed by means of Prominence Alignment (Prince and Smolensky 1993). Stress-sensitive perceptual-based phenomena are straightforwardly captured in the grammar via approaches like licensing-by-cue and others, which formalize the notion that cues are avoided in perceptually-challenged positions (Steriade 1997, Hume and Seo 2001, among others).

Case studies on aerodynamically and rhythmically based alternations are provided in González (2003). These demonstrate in more detail how Prominence Alignment works in relation to foot structure and stress. For detailed analyses of stress-related perceptual and durational phenomena see Steriade (1997), Hume and Seo (2001), and Crosswhite (1999).

5. Concluding remarks

This paper has examined stress and foot-sensitive consonantal processes in 78 languages from 37 language families. It has shown that a large number of languages evidence consonantal phenomena which are caused either by stress or by foot structure. The examination of such phenomena suggests four main factors underlying them: aerodynamics, perception, duration, and prominence/rhythmicity.

It is proposed that aerodynamic and durational factors are mostly stress-related and can influence consonantal phenomena in a phonetic (i.e. variable, partial and gradient) way. They can also be phonologized. Perceptual factors related to perceptual ambiguity and reinterpretation are mostly phonetic, while other perceptual considerations concerning the avoidance of salient features or segments in unstressed or weak positions are mostly phonological. Finally, prominence/rhythmicity is phonological.

One of the most important findings of this study is that stress and footing are separate forces that can govern consonantal processes. Strictly stress-sensitive consonantal phenomena and strictly foot-sensitive phenomena coexist with consonantal phenomena where both stress and footing coincide. This is especially true of trochaic languages, where foot heads are typically initial and stressed and foot complements medial and unstressed. Strictly stress-sensitive consonantal phenomena are mostly aerodynamic or durational, as in Basque Spanish.

Strictly foot-sensitive consonantal phenomena are found in three main situations: iambic languages, languages with persistent footing but not stress in all feet, and languages where stress and footing seem to diverge. In iambic languages, stress and foot-based processes are not expected to coincide because foot heads are stressed but medial, and foot complements unstressed but foot initial. Iambic systems evidence consonantal processes that are foot-sensitive rather than stress-sensitive; one example is Norton Sound Yupik, where fortition occurs to signal foot boundaries rather than to increase the prominence of stressed syllables or as a consequence of stress. In languages with persistent footing where not all feet are stressed, consonantal alternations can create rhythmicity and thus compensate for the absence of secondary stress; one example is Capanahua. In some other cases, footing for stress and for consonantal processes seems to differ; this is the case of Huariapano.

The finding that both strictly foot-sensitive and strictly stress-sensitive phenomena are attested has implications for the current metrical theory, which tends to equate footing with stress. This study proposes that footing does not necessarily depend on stress, and that rhythmicity can be expressed through stress, consonantal or vocalic alternations, and tone.

An important proposal of this paper is that prominence- and rhythmic-based consonantal phenomena can be analyzed with Prominence Alignment (Prince 1993). Prominence Alignment, which is based on the combination of segmental and prosodic scales, derives stress- and foot-sensitive consonantal processes where prominence is at stake. Prominence in a stressed syllable or a foot head can be realized through stress, reduced consonantal sonority, or by the realization of codas, while prominence is reduced in unstressed syllables or foot complements through lack of stress, increased consonantal sonority, or lack of codas. Which option is chosen depends on the individual language considered.

Prominence Alignment also captures the independent nature of stress and foot structure. Foot prominence and stress prominence can be combined into rankable constraints that express the universal tendencies for foot heads to be stressed and for foot complements to be unstressed. The fact that these constraints are rankable allows for situations where these universal tendencies are overridden, causing foot heads not to be stressed, or even (more rarely) foot complements to be stressed. Prominence alignment is also suggested to capture stress-sensitive, phonological consonantal phenomena with aerodynamic and durational basis.

This investigation also bears on the relationship between phonetics and phonology. It has been proposed that aerodynamic and durational processes are phonetic because they follow from the articulatory and aerodynamic properties of stress: stress involves longer duration and higher airflow (Lehiste 1970). Additionally, aerodynamic and durational consonantal phenomena are frequently variable and optional. Consonantal phenomena where perceptual ambiguity is at stake belong to the phonetics; by contrast, perceptually-based phenomena whereby salient features or segments are avoided in unstressed syllables and preferred in stressed syllables is phonological. Finally, prominence-based phenomena belong to the phonology; prominence is not an effect of stress, and it primarily involves phonological weight. Perceptual and prominence-based phenomena are categorical and obligatory.

The fact that durational and aerodynamically-based consonantal phenomena are phonetic does not exclude their possible phonologization. Consonantal processes with a phonetic motivation might be phonologized if they become obligatory and categorical. These cases can be analyzed through the extension of Prominence Alignment to account for categorical or obligatory processes with aerodynamic or durational bases.

Additional findings of this study relate to the factors interacting with stress and footing in consonantal processes: word position, morpheme position, and phrase/utterance position. It is found that word position interacts with stress in most cases, while morpheme and phrase/utterance position are rarely reported to be relevant to stress- or foot-sensitive processes. This study also examines the role of syllabic positions, and it finds that most stress- and foot-sensitive consonantal phenomena occur in onsets or depend on onsets for their occurrence. However, the significance of this finding is not clear, especially since a large number of languages lack or have restrictions on codas.

Furthermore, it is found that a large number of stress- and foot-sensitive phenomena are related to laryngeal segments and features. This is especially true in epenthesis phenomena. Except in one case, all attested epenthesis cases involve laryngeal consonants or features, especially glottalization. It is suggested that laryngeal phenomena are the most sensitive to stress and foot structure because the lack of supra-laryngeal features makes laryngeal segments and features to be deleted, epenthesized and moved around more easily. Also, laryngeal features are related to stress, since variation in laryngeal behavior can produce modifications of stress and pitch.

The following pages discuss some further points that merit further investigation related to the relationship between stress and footing and phonetics and phonology. The first relates to the status of foot heads and the possibility that they are considered prominent categories.

6. Further issues

6.1. Are foot heads prominent categories?

On the one hand, stress and footing are separate entities which can coincide but do not need to. On the other hand, foot-influenced consonantal processes are prominence-related. In other words, foot-sensitive consonantal processes frequently create a rhythmic contrast between strong and weak footed syllables and may do so in the absence of or in spite of stress. The prominence distinction between foot heads and complements has been expressed in the foot prominence scale Head $_{prom}$ > weak (Kenstowicz 1996); however, foot heads—independently of stress—are not considered to be in the set of prominent categories. This set has been shown to include stressed syllables, onsets, word-initial syllables, and roots (Beckman 1998, Smith 2000, 2002).

Prominence-enhancing frequently correlates with foot heads, and prominence-reduction with non-heads. This cannot be expressed by means of making reference to other prominent categories; clearly not to onsets and roots, and neither to word-initial syllables, since foot-sensitive consonantal processes are iterative. Stressed syllables cannot make reference to these processes either, since in many occasions, foot heads are not stressed. One example is Capanahua. This suggests that foot heads should be included in the set of prominent categories.

Footing can have stress as its rhythmic expression, but in the absence of stress other segmental or prosodic material can express rhythm. The data examined in this paper suggests this is the case. Including foot heads in the set of prominent categories would achieve more than to refer to the domain of application of consonantal (or other segmental or prosodic) phenomena. It would also make possible to make direct reference to foot positions for different phenomena. This could include positional faithfulness, positional markedness, and others. Additionally, the inclusion of foot heads in the set of prominent categories would mean that M/Str constraints (Smith 2000, 2002) could be extended to cases of augmentation in foot heads.

6.2. Consonantal vs. vocalic alternations

This paper concentrates on stress- and foot-conditioned consonantal processes. It shows that many languages undergo these processes. However, in most languages it is vowels that are affected by these prosodic factors. A question to investigate is whether rhythmic alternations of consonants or vowels depend on the correlates of stress that are predominant in the language, or whether there is some other explanation.

Since vowels are mostly affected by stress (Hayes 1995), most phonetic studies concentrate on this effect. If stress has as correlates pitch and duration, and then amplitude, vowels will be more readily affected by stress and better suited to express rhythmicity. More phonetic studies on the influence of stress on consonants could show that actually, many languages evidence stress effects on both vowels and consonants. This is especially true for lesser known languages that have not been widely studied. Rhythmicity has been shown to occur with and without the effect of stress; more study of strictly foot-sensitive consonantal and vocalic processes would add to our understanding of these processes.

6.3. The asymmetry between trochaic and iambic systems revisited

It is well established that trochaic and iambic systems are asymmetric in many respects; for example, iambic systems express a difference in duration and trochaic in intensity (Iambic Law, Hayes 1995); iambic systems are also rarer across languages (see, for instance, Van de Vijver 1998).

An asymmetry in iambic and trochaic systems is also evident in this survey; very few of the languages examined are iambic. Iambic systems are special in that stress and foot position are inverse than in trochaic systems, and thus stress and footing can hardly coincide in conditioning a process. Foot-sensitive processes seem to mark foot boundaries. Additional consonantal phenomena in iambic systems would aid to our knowledge of the drives of consonantal patterns in these systems.

Related to this is the assumption that foot initial position arises from the interaction of stressed syllables and word-initial positions, and that foot medial positions arise from the interaction between unstressed and medial positions (Lavoie 2001). From the examination of stress and position, it is shown that different patterns concerning position and stress exist. In one, consonantal alternations occur in word initial stressed syllables. But in others, a process occurs in stressed syllables and in word-initial syllables regardless of stress. More investigation of these issues is needed.

6.4. The ambiguity of stress and word position

Lavoie's (2001) survey on lenition finds that only a small number of cases mention stress as a conditioning context, while word position is pervasive. However, her phonetic studies find that stress correlates more often than word position with lenition. Lavoie suggests that there is a bias towards considering word position as the relevant factor for lenition processes, and that this arises from the fact that it is easier to see the relationship between segmental distribution and word position than that of segmental distribution and stress. Also, she notes that word position leads to phonologization more often than stress. As shown in this study, in some cases it is ambiguous whether stress or word position is relevant. Word initial positions, for instance, tend to be stressed, and word-final positions unstressed.

6.5. Unfooted syllables

An interesting issue is the patterning of unfooted syllables with respect to foot-sensitive consonantal phenomena. This is decisive in the formulation of prominence scales. For example, there are two possibilities for the prominence scale: $\text{Head}_{\text{prom}}$ > non Head, or $\text{Head}_{\text{prom}}$ > weak. Which one is correct, or whether both are needed separately to account for different languages is an empirical issue. $\text{Head}_{\text{prom}}$ > non Head would correspond more closely to stress-sensitive phenomena; a process occurs in stressed syllables, or in unstressed syllables. On the contrary, the scale $\text{Head}_{\text{prom}}$ > weak implies three distinct foot-sensitive elements: head syllables, complements, and unfooted syllables.

There are reasons to suggest that $\text{Head}_{\text{prom}}$ > weak is correct. There are consonantal processes that affect just weak footed syllables syllables and not unfooted syllables; one example is Capanahua. Further investigation is needed to confirm this conclusion.

It is plausible that unfooted syllables are essential in distinguishing cases of stress sensitive and foot sensitive phenomena. In languages with iterative footing, even in the absence of secondary stress, unfooted syllables should not behave like unstressed, footed syllables. In Capanahua, unfooted syllables do not undergo /ʔ/ deletion. /ʔ/ deletion is a characteristic of weak-footed syllables, not of all unstressed syllables.

6.6. The 'after' pattern

Several alternations considered in this article are reported to have a conditioning environment of 'after' stressed or unstressed syllables. Examples are gemination, (pre-glottalization), pre-aspiration, some cases of voicing alternations, dissimilation, and others.

In the case of gemination, epenthesis and pre-aspiration the reference to 'after a stressed syllable' makes sense; consonants are 'doubled' in some sense for prominence reasons. However, in some other cases, the reference to the after context is not clear. Some examples include voicing alternations in Paamese, Middle English, and Proto-Germanic (Verner's Law). In Paamese, a medial /nt/ is voiced obligatorily after stress; in Middle English and Proto-Germanic, lack of stress was necessary for voicing alternations to arise. Dissimilation in Gothic is another example. In these cases, it is unclear what the 'after' pattern means; whether it means that the stress of the preceding syllable is conditioning the process, or that the consonant was/is syllabified as a coda, or whether the preceding stress makes more airflow available, causing more voicing, fortition, or other phenomena. These issues remain to be investigated.

Appendix

Languages mentioned in main text.

Language	Language Family	Alternations	Section	References
Alutiik Yupik	Yupik	Gemination Fortition	§ 3.4.1 § 3.4.3	Van de Vijver 1998
Alyawarra	Arandic	Stress-attraction	§ 3.5.2	Yallop 1977, de Lacy 2001
American English	Indo-European: Germanic	Flapping	§ 3.3.2	Lisker and Abranson 1967, Umeda 1977, Kiparsky 1979, Kahn 1980, Borowsky 1986, Crystal and House 1988, Turk 1992, 1996, Hayes 1995, Davis 2002
Aranda	Arandic	Stress-attraction	§ 3.5.2	Breen & Pensalfini 1999
Bagneres-de-Luchon French	Indo-European: Romance	Attraction	§ 3.5.1	Grammont 1933, Blevins and Garrett 1998
Banawá	Arauan	Stress-attraction	§ 3.5.2	Buller, Buller and Everett 1993, Everett 1996
Basque Spanish	Indo-European: Romance	Aspiration	§ 3.4.2	González 2002b
Canadian English	Indo-European: Germanic	Flapping	§ 3.3.2	De Hasebe Ludt 1987
Capanahua	Panoan	Deletion Metathesis	§ 3.6.1 § 3.7	Loos 1969, 1999, Safir 1973, González 2002a, 2007a, 2009
Cashinawa	Southeastern Panoan	Fortition Sec. articulation	§ 3.3.3 § 3.3.5	Kensinger 1963, 1995, Shell 1975
Cayuga	Northern Iroquoian	Deletion	§ 3.6.1	Chafe 1977, Foster 1982, Michelson 1988, Dougherty 1993, Blevins and Garrett 1998
Chacobo	Southern Panoan	Lenition	§ 3.3.4	Shell 1975
Chali (Tati)	Indo-Iranian	Post-aspiration Deletion	§ 3.4.2 § 3.6.1	Yar-Shater 1969
Cocopa	Hokan	Fortition	§ 3.3.3	Wares 1968
Colville	Interior Salish	Attraction	§ 3.5.1	Mattina 1979
Coast Tshimshian	Penutian	Glottalization Attraction	§ 3.4.3 § 3.5.1	Dunn and Hayes 1983, Dunn 1995, Kehrein 2001, Howe and Pulleyblank 2001
Copala Trique	Otomanguean	Lengthening Lenition Voicing	§ 3.3.1 § 3.3.4 § 3.4.1	Hollenbach 1977

Language	Language Family	Alternations	Section	References
Danish	West Scandinavian	Attraction	§ 3.5.1	Fisher-Jorgersen 1989, Zec 1988
Diegueño	Hokan	Fortition	§ 3.3.3	Wares 1968
Djabugai	Pama-Nyungan	Flapping Voicing	§ 3.3.2 § 3.4.1	Patz 1991
Dutch	Indo-European: Germanic	Epenthesis	§ 3.6.2	Jongenburger and van Heuven 1991, Booij 1995, Smith 2002
English	Indo-European: Germanic	Lengthening Lenition Voicing Post-aspiration Deletion	§ 3.3.1 § 3.3.4 § 3.4.1 § 3.4.2 § 3.6.1	Borowsky 1986, Clements 1987, Hayes 1995, Pierrehumbert 1995, Dilley and Shattuck-Hufnagel 1996, Hammond 1999, Davis 1999, 2002, Lavoie 2001, Mompeán and Gómez 2011, Davidson and Erker 2014
Faroese	West Scandinavian	Pre-aspiration	§ 3.4.2	Petersen et alia 1998
Farsi	Indo-Iranian	Fortition Voicing Post-aspiration	§ 3.3.3 § 3.4.1 § 3.4.2	Samareh 1977
German	Indo-European: Germanic	Post- aspiration Epenthesis	§ 3.4.2 § 3.6.2	Kohler 1977, 1994, Gegerich 1989, Iverson and Salmons 1995, Wiese 1996, Alber 2001
Gitksan	Penutian	Glottalization	§ 3.4.3	Rigsby and Ingram 1990, Kehrein 2001
Gothic	Eastern Germanic	Dissimilation	§ 3.9	Mossé 1956, Collinge 1985, Chomsky and Halle 1968, Wright 1957
Greek	Indo-European: Greek	Lengthening	§ 3.3.1	Botinis, Fourakis and Bannert 2001
Guajajára	Tupí-Guaraní	Lenition Voicing Assimilation	§ 3.3.4 § 3.4.1 § 3.8	Bendor-Samuel 1972
Guayabero	Guahiban	Fortition Lenition Sec. articulation	§ 3.3.3 § 3.3.4 § 3.3.5	Keels 1985
Guelavía Zapotec	Otomanguean	Lengthening	§ 3.3.1	Jones and Knudson 1977
Gundidj	Victorian	Gemination	§ 3.3.1	Hercus 1986
Huariapano	Panoan	Epenthesis	§ 3.6.2	Parker 1994, 1998
Icelandic	West Scandinavian	Pre-aspiration	§ 3.4.2	Thráinsson 1974, Silverman 1997

Language	Language Family	Alternations	Section	References
Ingush	North-East Caucasian	Pre-aspiration	§ 3.4.2	Nichols 1994
Iowa-Oto	Siouan	Stress attraction	§ 3.5.2	Downing 1998
Irish	Celtic	Pre-aspiration	§ 3.4.2	Ni Chasáide and Docherty 1984
Italian	Indo-European: Romance	Gemination	§ 3.3.1	Chierchia 1982, Loporcaro 1999, Saltarelli 2003
Kiliwa	Hokan	Fortition	§ 3.3.3	Wares 1968
Kupia	Indo-Iranian	Flapping Lenition	§ 3.3.2 § 3.3.4	Christmas and Christmas 1975
Le Havre French	Indo-European: Romance	Metathesis	§ 3.7	Grammont 1909, Blevins and Garrett 1998
Lilloet	Salishan	Glottalization	§ 3.4.3	Howe and Pulleyblank 2001
Maori	Austronesian	Lengthening Fortition Post-aspiration	§ 3.3.1 § 3.3.3 § 3.4.2	Bauer 1993
Maricopa	Hokan	Fortition	§ 3.3.3	Wares 1968
Middle English	Indo-European: Germanic	Voicing	§ 3.4.1	Kabell and Lauridsen 1984
Mohave	Hokan	Fortition	§ 3.3.3	Wares 1968
Mohawk	Northern Iroquoian	Metathesis	§ 3.7	Michelson 1988
Narinari	Victorian	Gemination	§ 3.3.1	Hercus 1986
Nganasan	Uralic	Lenition	§ 3.3.4	Helimsky 1998, Vaysman 2002
North Yuman	Hokan	Fortition	§ 3.3.3	Wares 1968
Northern Faroese	West Scandinavian	Pre-aspiration	§ 3.4.2	Petersen et alia 1998, Kehrein 2001, Ladefoged and Maddieson 1996
Norton Sound Yupik	Central Yupik	Gemination Fortition	§ 3.3.1 § 3.3.3	Jakobson 1985, Leer 1985, Van de Vivjer 1998
Ojibwa	Algonquian	Pre-aspiration	§ 3.4.2	Bloomfield 1956
Old-English	Indo-European: Germanic	Deletion	§ 3.6.1	Kabell and Lauridsen 1984
Oneida	Northern Iroquoian	Deletion Metathesis	§ 3.6.1 § 3.7	Lounsbury 1942, Michelson 1988, Chafe 1977, Blevins and Garrett 1998

Language	Language Family	Alternations	Section	References
Paamese	Austronesian	Lenition Voicing	§ 3.3.4 § 3.4.1	Crowley 1982
Paipai	Hokan	Fortition Epenthesis	§ 3.3.3 § 3.6.2	Wares 1968
Pattani	Sino-Tibetan	Post-aspiration	§ 3.4.2	Sarma 1982
Pirahã	Mura	Stress attraction	§ 3.5.2	Everett and Everett 1984ab, Everett 1988
Popoloca	Otomanguean	Gemination Voicing Glottalization Deletion	§ 3.3.1 §3.4.1 §3.4.3 § 3.6.1	Stark and Machin 1977, Veerman-Leichsenring 1984
Proto-Germanic	Proto-Germanic	Voicing	§ 3.4.1	Wright 1957
Romance	Indo-European	Dissimilation	§ 3.9	Grammont 1933, Posner 1961
Saanich	Salishan	Glottalization	§ 3.4.3	Howe and Pulleyblank 2001
Scots Gaelic	Celtic	Pre-aspiration	§ 3.4.2	Ni Chasáide and Dochartaigh 1984
Senoufo	Niger-Congo	Lengthening Flapping Lenition Sec. articulation Voicing	§ 3.3.1 § 3.3.2 § 3.3.4 § 3.3.5 § 3.4.1	Mills (1984)
Shuswap	Interior Salish	Attraction	§ 3.5	Kuipers 1974, Steriade 1997
Silacayoapan Mixteco	Otomanguean	Gemination Lenition Voicing Post-aspiration	§ 3.3.1 § 3.3.4 § 3.4.1 § 3.4.2	North and Shields 1977
Somali	Cushitic	Gemination Lenition	§ 3.3.1 § 3.3.4	Armstrong (1964)
Spanish	Indo-European: Romance	Lengthening Lenition	§ 3.3.1 § 3.3.4	Quilis 1981
Squamish	Central Salish	Fortition Post-aspiration	§ 3.3.3 § 3.4.2	Kuipers 1967
Standard Faroese	West Scandinavian	Pre-aspiration	§ 3.4.2	Kehrein 2001, Ladefoged and Maddieson 1996
Taipai	Hokan	Fortition	§ 3.3.3	Wares 1968
Tarascan	Tarascan	Pre-aspiration	§ 3.4.2	Foster 1969, Silverman 2002
Thompson River Salish	Interior Salish	Attraction	§ 3.5	Dunn and Hays 1983

Language	Language Family	Alternations	Section	References
Toreva Hopi	Uto-Aztecan	Pre-aspiration	§ 3.4.2	Whorf 1946
Turkish	Altaic	Lengthening	§ 3.3.1	Jonathan Barnes p.c.
Twana	Central Salish	Attraction	§ 3.5	Thompson 1979, Blevins and Garrett 1998
Urarina	Isolate	Epenthesis	§ 3.6.2	Olawski 2006
Urubu-Kaapor	Tupí-Guaraní	Lengthening Voicing	§ 3.3.1 § 3.4.1	Kakamasu 1986
Walapai	Hokan	Fortition	§ 3.3.3	Wares 1968
Wasco-Wisram	Penutian	Voicing	§ 3.4.1	Sapir 1925
Wembawemba	Victorian	Voicing	§ 3.4.1	Hercus 1986
Wergaia	Victorian	Gemination Voicing	§ 3.3.1 § 3.4.1	Hercus 1986
West Tarangan	Austronesian	Fortition	§ 3.3.3	Nivens 1992
Yuman	Hokan	Fortition	§ 3.3.3	Wares 1968

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