Bibliographic Details

The Blackwell Companion to Phonology

Edited by: Marc van Oostendorp, Colin J. Ewen, Elizabeth Hume and Keren Rice

eISBN: 9781405184236

Print publication date: 2011

39. Stress: Phonotactic and Phonetic Evidence

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Sections

1 Introduction

Stress can be signaled through a number of different acoustic properties, including increased duration, greater intensity, and higher fundamental frequency. Stress may also affect segmental and syllable structure. Typically, stressed syllables trigger qualitative fortition and/or lengthening, whereas unstressed syllables are associated with lenition and/or shortening. To take an example of a stress-driven fortition process affecting syllable structure, Dutch (**Booij 1995**) inserts an intervocalic glottal stop as an onset to stressed vowels; epenthesis does not interrupt vowel sequences in which the second vowel is unstressed. We thus have pairs such as ['xa.ɔs] 'chaos' and [[a.'ˀɔr.ta] 'aorta', in which the presence of glottal stop is predictable from stress. American English provides well-described cases of lenition in unstressed syllables. For example, post-vocalic coronal stops weaken to taps before unstressed syllabic sounds, e.g. /sɪti/ → [sɪɾi] 'city'. Furthermore, most unstressed vowels reduce to schwa, e.g. ['kan,tɛkst] *context vs.* [kən'tɛkstʃuəl] *contextual*, or may delete in certain contexts delete, e.g. ['tmeɪɾoʊ] ~ ['təmeɪtoʊ] *tomato*, ['ksændɹə] ~ [kə'sændɹə] *Cassandra*.

While most segmental effects of metrical structure can be transparently linked to stress, there are others that are not predictable from stress, despite displaying properties typically associated with stress-induced alternations. For example, Nganasan, a Uralic language (**Tereshchenko 1979**; **Helimski 1998**; **Vaysman 2009**), has an alternation between strong and weak intervocalic consonants, termed "consonant gradation," whereby strong consonants, generally voiceless or prenasalized obstruents, alternate with weak consonants, typically voiced or not prenasalized. The appearance of strong and weak consonants is predictable from syllable count (1). In the onset of even-numbered non-initial syllables, the strong grade appears, while the weak grade appears in the onset of odd-numbered non-initial syllables. Long vowels interrupt the alternating syllable count and, as long as they are not word-initial, are always preceded by weak consonants.

(1) *Nganasan consonant gradation* (**Vaysman 2009**: 43)

ˌjama'ða-tu 'his/her/its animal'
ˌŋoru'mu-tu 'his/her/its copper'
suː'ðəː-ðu 'his/her/its lung'
ŋu'hu-ðu 'his/her/its mitten'

As Vaysman shows, this pattern is explained if one assumes that words are parsed into binary feet starting at the left edge of words with long vowels forming monosyllabic feet and degenerate feet allowed word finally. Strong consonants occur foot medially and weak consonants occur in foot-initial syllables that are not also word-initial (2).

(2) *Nganasan consonant gradation as a reflex of foot structure* (**Vaysman 2009**: 43)

(ˌjama)('ða-tu) 'his/her/its animal'
(ˌŋoru)('mu-tu) 'his/her/its copper'
(suː)('ðəː)-(ðu) 'his/her/its lung'
(ŋu'hu)-(ðu) 'his/her/its mitten'

The interesting feature of the Nganasan data is that stress does not always fall on syllables predicted to be stressed by the metrical structure diagnosed by consonant gradation. Primary stress in Nganasan falls on the penultimate syllable in all the words in (2), with a secondary stress occurring on initial syllables that are not adjacent to the primary stress. The monosyllabic foot in the last two words is thus completely unstressed, as is the first foot in the penultimate word.

This chapter provides a typological overview of the phonetic correlates of stress and the various types of effects of stress and metrical structure on segment-level features, exploring how these effects can offer insight into the nature of stress and metrical structure and their formal representation (see CHAPTER 40: THE FOOT, CHAPTER 41: THE REPRESENTATION OF WORD STRESS and CHAPTER 57: QUANTITY-SENSITIVITY for related issues). The structure of the chapter is as follows. §2 examines supra-segmental correlates of stress including the phonetic parameters of duration, fundamental frequency, and intensity. §3 examines segmental alternations conditioned directly by the presence or absence of stress. §4 focuses on the role of foot structure in predicting fortition and lenition of vowels and consonants. §5 addresses segmental changes triggered by foot structures that conflict with metrical constituency as diagnosed by the stress system. §6 explores the role of history in shaping these mismatches between stress and the foot structure relevant for segmental alternations. Finally, §7 summarizes the chapter.

2 Suprasegmental phonetic correlates of stress

Fry (1955, 1958) pioneered research on the acoustic correlates of stress in his examination of the effect of stress in English on duration, intensity, and fundamental frequency. Focusing on the vowels in noun—verb minimal pairs such as ‘*convert* (noun) *vs. con'vert* (verb) and ‘*import* (noun) *vs. im'port* (verb), Fry found that stressed vowels were associated with greater duration, greater intensity, and higher fundamental frequency than their unstressed counterparts, with the last of these properties being most reliable as a cue to stress.

Since Fry's work, phoneticians have considerably broadened the typological database on stress correlates by examining other potential correlates of stress and by targeting a diverse set of languages for phonetic study. This research program has yielded many important results. For example, beyond the acoustic domain, stress is also associated with hyperarticulation of segments, which has ramifications for the segmental alternations discussed in §3. Furthermore, other potential acoustic correlates of stress have come to light, such as measurements of stress that are sensitive to spectral tilt (**Sluijter and van Heuven 1996a, 1996b**) or that integrate intensity over time (**Lieberman 1960**; **M. Beckman 1986**). Finally, typological study has shown that many languages are similar to English in using duration, intensity, and/or fundamental frequency to signal stress, e.g. Polish (**Jassem *et al.* 1968**), Tagalog (**Gonzalez 1970**), Mari (**Baitschura 1976**), Indonesian (**Adisasmito-Smith and Cohn 1996**), Pirahã (**Everett 1998**), Aleut (**Taff *et al.* 2001**), Chickasaw (**Gordon 2004**), Turkish (**Levi 2005**), and Kabardian (**Gordon and Applebaum 2010**). It has also become increasingly clear that the phonetic study of stress is a complicated matter for several reasons.

Languages differ in their relative reliance on different cues to stress where the relevance of certain properties is functionally constrained in many languages by the extent to which potential stress correlates are used to mark phonemic contrasts other than stress. For example, lexical tone languages – e.g. Thai (**Potisuk *et al.* 1996**) and Pirahã (**Everett 1998**) – are less reliant on fundamental frequency to cue stress, and languages with phonemic length contrasts, e.g. Finnish, may have phonetically longer unstressed vowels than stressed vowels.

There are also languages in which potential phonetic markers of stress do not converge on a single syllable but rather are shared between multiple, often, though not always, adjacent syllables. For example, in Welsh (**Williams 1985**) an unstressed final syllable often has higher fundamental frequency and longer vowel duration than an unstressed penultimate syllable in the same word. In such cases, lengthening of the consonant immediately following the stressed vowel seems to be the most reliable correlate of stress. A similar situation arises in Estonian, where the primary stressed initial syllable, if it contains a phonemic short vowel, will be shorter than the immediately following syllable and often have less intensity and lower fundamental frequency (**Lehiste 1965**; **Eek 1975**; **Gordon 1995**). Lengthening of the consonant in the onset of the stressed syllable serves as the most reliable cue to stress in Estonian (**Lehiste 1966**; **Gordon 1997**). **Hyman (1989)** discusses cases in Bantu of different diagnostics leading to different conclusions about the location of stress. For example, certain Eastern and Southern Bantu languages display evidence for metrical prominence on the penultimate syllable, such as vowel lengthening, attraction of high tone, and even phonetic stress. However, these properties may conflict with other properties that suggest stress on another syllable, e.g. high tone on the antepenult in Zulu, even though the penult conditions vowel lengthening. A similar pattern of high tone on the antepenult preceding a stressed penult is found in the Northern Iroquoian language Onondaga (**Chafe 1970, 1977**; **Michelson 1988**), the Polynesian language Tongan (**Schütz 1985**), and several Micronesian languages (**Rehg 1993**). In "split-cue" stress systems such as those described in this paragraph, determining the location of stress is potentially problematic.

The separation of high tone and stress ties in with another problematic issue in the phonetic realization of stress. Since Fry's work on stress correlates in English, it has become apparent that word-level stress must be distinguished from phrase-level intonational prominence, which is characteristically associated with a prominent fundamental frequency event or "pitch accent" (see also CHAPTER 116: SENTENTIAL PROMINENCE IN ENGLISH). Because a word uttered in isolation constitutes an entire phrase, this means that stress in isolated words is confounded with phrasal pitch accent. Many studies intending to examine correlates of word-level stress but targeting words in isolation are thus more accurately regarded as studies of phrasal rather than word-level stress, although there is potentially overlap between the two levels of prominence in their acoustic manifestations. **Sluijter and van Heuven (1996a, 1996b)** are important acoustic studies that show that a frequency-dependent measure of intensity skewed toward higher frequencies rather than either an overall measure of intensity or a measure of fundamental frequency acts as a reliable predictor of word-level stress disambiguated from phrasal pitch accent in Dutch and English. Unfortunately, cross-linguistic phonetic research aimed at disentangling word-level stress from higher-level pitch accent is in its relative infancy.

A related issue involving the relationship between prominence at different prosodic levels is the interplay between phrasal tones falling at or near boundaries of intonational constituents larger than the word but smaller than the domain characterized by pitch accents. In certain languages, such as Korean (**Jun 1993**) and French (**Jun and Fougeron 1995**), the prominence traditionally regarded as stress has turned out to be attributed to fundamental frequency peaks assigned by a phrase-level intonational constituent termed an Accentual Phrase. For example, in French, the prominence associated with phrase-final syllables is due to a high tone aligned with the right edge of an Accentual Phrase (**Jun and Fougeron 1995**). It is conceivable that the stress in many, if not most, languages described as having a phrasal rather than a word-level distribution will turn out to be a tonal property attributed to the intonational system, as in French.

Another important issue lurking in the typology of stress correlates is the relationship between the phonetic manifestations of stress and the taxonomy of prominence systems (see also CHAPTER 45: THE REPRESENTATION OF TONE and CHAPTER 42: PITCH ACCENT SYSTEMS). The prototypical stress language possesses a number of characteristics that differentiates it from a tone language, one of these differences lying in the phonetic realization of prominence as primarily a fundamental frequency phenomenon in a tone language but potentially distributed over multiple phonetic parameters – e.g. duration, intensity, and spectral tilt – in a stress language. **M. Beckman (1986)** demonstrates the phonetic validity of this distinction in her comparative study of English and Japanese, in which she shows that a measure of intensity integrated over time is an important correlate of prominence in English but not in Japanese, a language employing tone-based lexical contrasts. In practice, however, a purely phonetic characterization of prominence is unlikely to yield a perfect dichotomy of languages into prosodic prototypes, especially for languages possessing some traits of a stress system but other traits of an – albeit limited – tone system; these languages are often regarded as having a "pitch accent" system (**Hyman 2006**).

3 The taxonomy of segmental correlates of metrical structure

Fortition and lenition effects associated with metrical structure may be broadly classified into three groups according to the property triggering these segmental alternations. The first type of segmental effect is well documented and involves stress (or lack thereof) directly as a trigger of fortition and/or lenition. A second type of segmental effect is predictable from constituent structure rather than stress, but the constituent structure motivating the segmental change accords with the metrical parse evinced by the stress system. A third type of segmental alternation, exemplified by Nganasan, is linked to metrical constituency, where the foot structure diagnosed by the segmental change is at odds with that suggested by the stress system. In the following sections we take a closer look at examples of each of these types of relationships between segmental properties and metrical structure.

3.1 Stress-driven segmental phenomena: Fortition and lenition

Many languages display segmental changes that are conditioned by stress or lack of stress. The typical pattern is for sounds to strengthen in stressed contexts and to weaken in unstressed positions. Fortition and lenition can target either consonants or vowels. In the case of consonants, unstressed position is usually associated with decreased resistance to coarticulatory effects and hypo-articulation (**de Jong 1995**), resulting in reduced constriction either temporally or in magnitude. **Kirchner (2001)**, **Lavoie (2001)**, **Bye and de Lacy (2008)**, and **Vaysman (2009)** summarize a number of segmental alternations conditioned by stress, of which I mention a few here (see CHAPTER 66: LENITION for an overview of the typology of lenition). Post-vocalic coronal stops in American English reduce to flaps before an unstressed syllabic sound, and stops become aspirated in the onset of stressed syllables. In Kupia (**Christmas and Christmas 1975**), the stops /p ʈ/ have lenited variants in the onset of unstressed syllables: /p/ is realized as a fricative and /ʈ/ as a tap. West Tarangan (**Nivens 1992**) displays fortition in the onset of stressed syllables: /j/ affricates to /ʤ/, and /w/ occlusivizes to /g/, a change that also applies to word-initial consonants. In the development from Proto-Samurian to pre-Lezgian (Topuria 1974; Giginejshvili 1977; Yu 2004), voiced stops devoiced, a type of fortition, and geminated in the onset of stressed syllables.

Stress often also triggers lengthening of consonants. Thus, in Urubu Kaapor (Kakumasu 1986) and optionally in Tukang Besi (Donohue 1999) oral stops lengthen in the onset of primary stressed syllables. Lengthening is also employed as a strategy to beef up the rime of stressed syllables. Hayes (1995: 83) discusses several cases of lengthening in order to enhance the weight of stressed syllables. For example, in Munsee (Goddard 1979), a consonant geminates after metrically prominent short vowels, thereby converting the stressed syllable from light (CV) to heavy (CVC).

Vowels are also subject to fortition and lenition processes conditioned by stress. As in the case of consonantal alternations, vowels may be affected either qualitatively or quantitatively by the presence or absence of stress. Cross-linguistically, it is very common for vowels to lengthen in stressed syllables. Hayes (1995: 83) catalogs a number of cases of vowel lengthening under stress, where the lengthening effect is quite substantial, even potentially neutralizing an underlying phonemic length contrast. Vowel lengthening can also be associated with qualitative differences as well. The short low central vowel /ɐ/ in Kabardian lengthens and lowers to /aː/ under stress in the first syllable of disyllabic nouns and adjectives (Colarusso 1992). Revithiadou (2004) discusses the Livisi dialect of Greek, in which stressed high vowels lower to mid vowels, a shift which increases the sonority of the stressed vowel.

Conversely, vowels often shorten and qualitatively reduce in unstressed syllables. Crosswhite (2001, 2004) presents a typology of vowel reduction, in which she broadly classifies reduction into two groups. One type involves centralization of unstressed vowels. For example, most vowels in English reduce to a schwa-like vowel when unstressed. This type of reduction is typically linked to articulatory factors. The smaller duration of unstressed vowels leaves relatively little time for the tongue to reach more peripheral targets in the articulatory space. Crosswhite also points out that this type of reduction has the advantage of reducing the intrinsic prominence of unstressed vowels.

The other type of vowel reduction in Crosswhite's taxonomy involves vowels becoming more, rather than less, peripheral in unstressed syllables. This increase in peripherality can be manifested as either vowel raising or lowering, depending on the language. For example, the phonemic mid vowels /e o/ raise to the high vowels [i u] when unstressed in Luiseño (Munro and Benson 1973), and unstressed /ɛ ɔ/ raise to [e o] in standard Italian (Maiden 1995). In Belarussian, on the other hand, the unstressed mid vowels /e o/ lower to [a] (Kryvitskij and Podluzhni 1994). Crosswhite attributes this superficially less intuitive raising type of reduction to the goal of maximizing the perceptibility of contrasts in unstressed contexts where they are perceptually more vulnerable. Either raising mid to high vowels or lowering mid to low vowels in unstressed syllables creates greater perceptual dispersion of different phonemic vowel qualities in the face of the shorter duration and reduced intensity associated with unstressed vowels.

The most extreme manifestation of vowel reduction is deletion (see CHAPTER 68: DELETION), which often targets unstressed vowels. It is pervasive in casual speech in English, even creating syllable structures that are otherwise illicit underlyingly, e.g. ['tmeɪroʊ] ~ ['təmeɪroʊ] *tomato*, ['pteɪroʊ] ~ ['pəteɪroʊ] *potato*. Vowel deletion in certain contexts has the advantage of increasing the weight of stressed syllables. For example, deletion of the medial vowel in ['pæɹˌlel] parallel creates a heavy initial stressed syllable, thereby increasing its prominence (see Gordon 2001 and Gouskova 2003 on the relationship between vowel deletion and syllable weight).

The increased strength of stressed syllables can also manifest itself in harmony systems. Flemming (1994) identifies three types of harmony patterns that are sensitive to metrical structure. One pattern involves spreading of a feature from a stressed syllable to unstressed syllables. Eastern Mari (Vaysman 2009) provides an example of a language in which harmony propagates from a stressed vowel to a neighboring unstressed vowel. Stress in Eastern Mari falls on the rightmost full, i.e. non-schwa, vowel in monomorphemic roots (3a) and otherwise on the initial syllable in non-derived words containing only reduced vowels underlyingly (3b). (We abstract away from cases where an underlying schwa alternates with a full vowel on the surface.)

(3) *Eastern Mari stress* (Vaysman 2009: 62—64)

a.	koŋ'ga	'oven'
	ʃer'ge	'comb'
	køgør'ʧen	'dove'
	'teŋgəz	'sea'
	'olək	'meadow'
	'joŋələʃ	'mistake'
	pu'ʃaŋgə	'tree'
b.	'βəɲər	'canvas'
	'əʃkəl	'step'
	'ləβə	'butterfly'

Rounding harmony is propagated rightward from the stressed vowel in a word. Thus, the 3rd person possessive suffix surfaces as [ʃe] when the stressed vowel is unrounded (4a) but as [ʃø] or [ʃo] when the stressed vowel is a rounded vowel (4b). (The backness of the rounded vowel is conditioned by a process of front—back harmony.)

(4) *Eastern Mari rounding harmony* (Vaysman 2009: 92)

a.	'ergəʃe	'his/her/its boy'
	y'reməʃe	'his/her/its street'
	pykʃer'me-ʃe	'his/her/its walnut tree'
b.	'ʃyrə-ʃø	'his/her/its soup'
	kəʎ'mo-ʃø	'his/her/its shovel'
	'ʃoʃə-ʃo	'his/her/its spring'

Another type of harmony that is sensitive to stress involves the propagation of a feature from an unstressed syllable up through a stressed syllable, which blocks further spreading of the harmonizing feature. Tudanca Spanish (Penny 1978) instantiates this type of harmony. In Tudanca, underlying final high vowels, which surface as more centralized than their non-final counterparts, induce centralization (in the front/back and/or height dimension depending on the vowel) of preceding vowels up to and including the stressed vowel (5). (Centralized vowels are marked by the ˣ diacritic.) Stress is lexically governed and may fall on either the penultimate or antepenultimate syllable.

(5) *Tudanca laxness harmony* (Penny 1978: 54—55)

'pi̽ntu̽	'male calf'	cf. 'pinta	'female calf'
'se̽ku̽	'dry (MASC)'	cf. 'seka	'dry (FEM)'
'po̽rti̽ku̽	'portico'		
'pu̽lpi̽tu̽	'pulpit'		
anti'gwi̽si̽mu̽	'very old'		
o're̽ga̽nu̽	'oregano'		

Walker (2004, 2005) discusses several cases of metaphony in Romance languages involving harmonizing in height of a stressed vowel to a posttonic one (see also CHAPTER 110: METAPHONY IN ROMANCE for an overview of similar processes in Italian dialects). In some language varieties, as in Tudanca Spanish, harmony propagates left-wards from the triggering vowel to the stressed vowel through any intervening unstressed vowels. In other varieties, e.g. Asturian Lena Bable (Hualde 1989, 1998), the stressed vowel is transparent to the harmonizing feature, which propagates past the stressed vowel leftward to the pre-tonic vowel.

3.3 Exceptional lenition in prominent syllables

Despite the cross-linguistic tendency for stressed syllables to be associated with increased segmental strength, this pattern is not universal. Mokša Mordvin (Vaysman 2009) optionally lenites consonants in the onset of stressed syllables that are not word initial. Stress in Mokša is sensitive to a distinction between the low-sonority vowels [i u ə] and the high-sonority vowels [a á o e]. In words containing vowels belonging to the same sonority class, stress falls on the first syllable of a word (6a). In words consisting vowels of different sonority classes, stress falls on the leftmost vowel belonging to the higher-sonority group (6b).

(6) *Mokša Mordvin stress* (Vaysman 2009: 135—137)

a.	'bʲənətʃ	'boat'
	'məkur	'buttocks'
	'kuʃin	'jug'
	'juʒə	'skin'
	'aka	'older sister, aunt'
	'lopæ	'leaf'
	'pango	'mushroom'
	'sʲeja	'goat'
b.	tsʲə'ræ	'son'
	vi'na	'alcohol'
	əz'na	'older sister's husband'
	sʲir̥ək-'ka	'elm (PROLATIVE)'

Lenition in stressed onsets entails voicing of underlying voiceless obstruents, liquids, and glides, the spirantization of underlying voiced stops, the conversion of /m/ to / w/ and the deletion of /n/, with concomitant nasalization of the stressed vowel. Crucially, lenition does not target word-initial consonants, as the examples in (7) indicate.

(7) *Mokša Mordvin lenition in stressed onsets* (Vaysman 2009: 142—143)

kur'ka	~ kur'ga	'turkey'
sʲər'pe	~ 'sʲər'be	'heart'
bʲənʲə'ʧ-oze	~ bʲənʲə'ʤ-oze	'my boat'
pəjə'l̥ʲ-oze	~ pəjə'lʲoze	'my knife'
bu'jæ-ze	~ bu'jæ-ze	'my end'
tʲə'bʲe-ze	~ tʲe'βʲe-ze	'my work'
pin'gæ-ze	~ pin'ɣæ-ze	'my period of time'
pʲi'ma	~ pʲi'wa	'large cup, mug'
kə'nak-oze	~ kə'ãk-oze	'my guest'

3.4 The phonetic basis for fortition and lenition in stressed syllables

The tendency for consonants to undergo fortition in the onset of stressed syllables finds an explanation in terms of speech perception (see CHAPTER 98: SPEECH PERCEPTION AND PHONOLOGY), as suggested by **J. Smith (2000, 2004)** and **Gordon (2005)**. In the Smith and Gordon accounts, two key independently known aspects of auditory processing underlie the relationship between sonority and stress. First, the auditory system is most attuned to the beginning of a stimulus before a gradual decline in sensitivity sets in. This reduction in sensitivity, termed "adaptation," has both physical and psycho-acoustic manifestations, including a reduction in auditory nerve firing rates (**Delgutte 1982**) and a lessening of perceived loudness (**Plomp 1964**; **Wilson 1970**; **Viemeister 1980**). On the other hand, after a phase of silence or reduced acoustic intensity, auditory nerve firing rates and perceived loud-ness increase during an immediately following sound characterized by greater intensity, reflecting a process of auditory "recovery" (**R. Smith 1979**; **Viemeister 1980**; **Delgutte 1982, 1997**; **Delgutte and Kiang 1984**).

Given the auditory benefit afforded by a period of reduced intensity or silence, it is easy to see the perceptual advantage of fortition. By either devoicing a consonant in the onset of a stressed syllable or increasing its degree of constriction, the immediately following stressed rime – including the vowel and coda consonants, if any are present – receives a boost in auditory prominence. Under this auditorily driven account of fortition, prominence is not enhanced directly, by the increased strength of the onset consonant, but rather indirectly, through its effect on the following rime.

A limitation of this approach is its apparent failure in predicting lenition in the onset of stressed syllables, as optionally occurs in Mokša Mordvin. Since lenition increases the sonority, and thus the acoustic intensity, it would be expected under the Smith and Gordon account to actually decrease the auditory prominence of the immediately following rime by reducing the positive effects of recovery. The reconciliation of lenition with a phonetically driven approach to stress-sensitive fortition must await further research.

3.5 The formal analysis of stress-driven alternations in segments and syllables

3.5.1 Positional faithfulness

The analysis of stress-driven effects on segmental properties and syllable structure has attracted substantial attention in the phonology literature, in particular within the optimality-theoretic framework. There are two basic approaches to stress-induced segmental phenomena. One approach (e.g. **Casali 1997**; **Steriade 1997**; **J. Beckman 1998**; **Lombardi 2001**) focuses on cases in which underlying contrasts are asymmetrically preserved in stressed syllables (as well as other prominent positions) but lost in unstressed contexts. In this type of analysis, termed "positional faithfulness," input—output faithfulness constraints requiring preservation of an underlying property are divided into two classes: those that are context free and those that are only enforced in prosodically privileged positions such as stressed syllables. Positional faithfulness arises when a markedness constraint is prioritized above a generic faithfulness constraint but below a positional faithfulness constraint. This constraint interaction can be illustrated by considering the analysis of Guaraní vowel harmony developed in **J. Beckman (1998)**. In Guaraní (**Gregores and Suárez 1967**), nasalized and oral vowels contrast in stressed syllables, but in unstressed syllables nasalized vowels may only surface before a nasal consonant. The [nasal] feature also spreads leftward from a prenasalized stop and from a phonemic nasalized vowel up to but not including a stressed vowel (8). Nasalization additionally spreads rightward (as the examples below indicate) although its phonetic properties are different, which has led certain researchers, e.g. **Flemming (1994)**, to analyze it as phonetic rather than phonological. Beckman thus does not develop an analysis of rightward spreading of nasality.

(8) *Guaraní nasal harmony* (**Gregores and Suárez 1967**: 69)

/amaa'porõre'ju/	→	ʔãᵐbaʔa'porõrẽju	'if I work you come'
/je' intena/	→	je'intẽnã	'just once more!'
/ija,kãra'ku/	→	ʔĩnã,kãrã'ku	'is hot-headed'
/rojotopa'pamarõro'xova,rã/	→	rojotopa'pamãr̃õr̃õ'xoṽã,r̃ã	
		'if now we meet all of us, we will have to go'	

Two faithfulness constraints play a pivotal role in Beckman's analysis. First, a generic faithfulness constraint, Ident(nasal), requires that segments underlyingly associated with a [nasal] feature preserve that feature on the surface. The second constraint is the positionally defined analog to Ident(nasal), Ident-σ́(nasal), which requires that surface segments in stressed syllables preserve their underlying [nasal] specification. The existence of contrastive nasality on stressed vowels but not on unstressed vowels follows from the ranking of a markedness constraint banning nasalized vowels, $*V_{nasal}$, above generic Ident(nasal) but below position-specific Ident-σ́(nasal). This ranking ensures that any underlyingly nasalized vowel will lose its nasality if it surfaces in an unstressed position. Critical to the analysis of nasal harmony in Beckman's analysis is an alignment constraint, Align-L(nasal), requiring that all instances of the feature [nasal] be aligned with the left edge of a word. This constraint is honored in forms in which nasality either is underlyingly associated with a segment in the first syllable or has propagated to the first syllable through nasal spreading. One violation is incurred for each segment intervening between a nasal feature and the left edge of the word. By sandwiching Align-L(nasal) above Ident (nasal) but below Ident-σ́(nasal), nasality is correctly predicted to spread as far leftward as the stressed syllable, where it is blocked from spreading any further (9).

(9)

/je'intenã/ 'just once more'	Ident-σ́(nas)	Align-L(nas)	Ident(nas)
☞ a. je'intẽnã		***	*
b. nẽ'ĩntẽna	*!		***
c. je'intenã		***, *!*****	

Lenition in unstressed syllables can be handled similarly in the positional faithfulness approach. A constraint banning non-lenited segments is ranked above a generic faithfulness constraint, but below a positional faithfulness constraint requiring featural identity between underlying forms and their surface correspondents in stressed syllables. The result is a typologically common type of system; cf. many of the vowel reduction patterns described by **Crosswhite (2001, 2004)**, in which a contrast between lenited and non-lenited segments in stressed syllables is neutralized to the lenited variant in unstressed syllables.

3.5.2 Positional markedness

Another approach to stress-induced segmental alternations employs positional markedness constraints (**Zoll 1998**; **J. Smith 2000, 2004**; **de Lacy 2001**; see also the positional licensing constraints of **Walker 2004, 2005**), targeting stressed and other prominent positions. A positional markedness approach has an advantage over the positional faithfulness approach in capturing fortition phenomena, since it explicitly predicts that faithfulness will be violated in strong positions. To illustrate the positional markedness approach, let us consider **J. Smith's (2000, 2004)** analysis of glottal stop epenthesis before vowel-initial stressed syllables in Dutch. An anti-epenthesis constraint, Dep, is ranked above a generic markedness constraint requiring that syllables have an onset, Onset, but below a positional markedness constraint, Onset-σ́, mandating that stressed syllables have an onset. The result is insertion of a glottal stop before an otherwise onsetless stressed syllable but not before an unstressed syllable beginning with a vowel (10).

(10)

/aɔrta/ 'aorta'	Onset-σ́	Dep	Onset
☞ a. a.'ʔɔr.ta		*	*
b. a.'ɔr.ta	*!		**
/xaɔs/ 'chaos'			
☞ a. 'xa.ɔs			*
b. 'xa.ʔɔs		*!	

The common process of stressed vowel lengthening is also standardly attributed to a positional markedness constraint requiring that stressed syllables be heavy, the Stress-to-Weight Principle (**Crosswhite 1998**), or its counterpart specific to primary stress, Main-to-Weight (**Bye and de Lacy 2008**). By ranking the Stress-to-Weight Principle above the constraint banning surface moras that do not have a correspondent in the underlying representation, Dep-μ, lengthening of the stressed syllable results. Whether the lengthening targets a vowel or consonant is attributed to the relative ranking of faithfulness constraints pertaining to the two types of segments.

The blocking of lenition in stressed syllables can also be captured by assuming that the constraint driving lenition – e.g. **Kirchner's (2001, 2004)** Lazy constraint banning articulatory effort – outranks a generic faithfulness constraint, but is ranked below a constraint blocking the type of segment resulting from lenition from surfacing in stressed contexts. For example, the lenition of coronal stops to flaps in post-tonic contexts in English can be attributed to a constraint banning the amount of articulatory effort required to produce a full-fledged stop in intervocalic position. This constraint is ranked above a generic faithfulness constraint requiring preservation of the features characterizing a stop, but below a constraint banning flaps in stressed syllables.

Likewise, the blocking of feature spreading by stressed syllables, e.g. nasality in Guaraní, can be handled by assuming a positional markedness constraint banning that feature in stressed syllables. While this type of analysis is equipped to handle the harmony process, underlying featural restrictions holding of unstressed syllables are difficult to treat formally. For example, the ban on contrastive nasalized vowels in lexically unstressed syllables in Guaraní does not follow from the same markedness constraint blocking nasal spreading onto stressed syllables.

Cases of lenition in stressed syllables, e.g. in Mokša Mordvin, are problematic for principles of markedness in general, independent of the paradigm in which they are couched, since such processes contradict the scales of segmental strength observed in most languages (see CHAPTER 4: MARKEDNESS). It is possible to posit a positional markedness constraint requiring that stressed syllables be associated with lenited segments, but such a constraint would undermine the restrictiveness of the theory by admitting both lenition and fortition constraints referring to the same context. The proper formal treatment of apparently "unnatural" phenomena such as lenition in stressed syllables hinges on the understanding of the motivating factors driving them. It is conceivable that phonetic considerations offer an explanation for lenition in stressed syllables, but it is also possible that a confluence of historic events have conspired to produce a phonology whose synchronic naturalness has been rendered opaque (see §6).

4 Metrically harmonic constituency-driven segmental alternations

4.1 Foot-initial fortition

A second type of effect of metrical structure on segmental properties requires reference to feet for an adequate characterization, but these feet correspond to the feet diagnosed by stress placement. One subclass of these effects involves foot-level manifestations of phonetic patterns characteristic of prosodic words and larger constituents. For example, the Alutiiq dialects of Yupik (**Leer 1985**) have a process of fortition affecting consonants in foot-initial position. **Leer (1985**: 84–85) describes:

> two major distinguishing characteristics of the fortis consonant: complete lack of voicing with voiceless consonants (stops and voiceless fricatives), and preclosure [which is a voiceless interval following the preceding segment], during which the mouth also assumes the configuration of the [fortis] consonant.

Leer further observes that the phonetic distinction between fortis and non-fortis consonants is most salient in the Prince William Sound dialect of Chugach Alutiiq, "where lenis stops may become so loosely articulated as to sound virtually like voiced fricatives," which themselves also either weaken to an approximant or are deleted, thereby avoiding neutralization.

Feet in Alutiiq are iambic, with long vowels and word-initial (but not word-medial) CVC counting as heavy. A key feature of stress, however, that has implications for footing and by extension the analysis of fortition is that stress adheres to a ternary pattern where there are consecutive light syllables word medially between the first and last foot of a word (see CHAPTER 52: TERNARY RHYTHM). For example, stress (indicated here uniformly as primary stress, since it is unclear which stress is most prominent) falls on the first and fourth syllables in the four-syllable Chugach Alutiiq word /'antʃi**q**u'kut/ 'we'll go out' (**Leer 1985**: 84). The strengthened consonant (in bold) occurs in the onset of the pretonic syllable, which is analyzed by **Hayes (1995)** as the first syllable in a disyllabic foot comprising the pretonic and the tonic syllable. Under his approach, which assumes that a post-tonic light syllable is skipped over in the metrical parse (a phenomenon termed "weak local parsing" by Hayes) in languages with ternary stress intervals, /'antʃi**q**u'kut/ is footed as ('an)tʃi(qu'kut). A virtue of this analysis is that fortition in Alutiiq can be characterized as a foot-initial phenomenon, thereby bringing it into line with the general cross-linguistic pattern of strengthening associated with initial position of prosodic domains (e.g. **Pierrehumbert and Talkin 1992**; **Byrd 1994**; **Dilley *et al.* 1996**; **Cho and Keating 2001**; **Keating *et al.* 2003**). In contrast, the locus of fortition is not easily defined with reference only to stress; it would need to be described as fortition in the onset of pretonic syllables, which would not appear to be a natural phenomenon with parallels in other languages. CHAPTER 41: THE REPRESENTATION OF WORD STRESS describes several other segmental alternations that require reference to foot structure as opposed to stress for an adequate characterization.

4.2 Foot-final lengthening

The parallel between the foot and larger prosodic domains has also been proposed to extend to other phonetic properties. In his analysis of consonant gradation in Finnic languages, **Gordon (1998)** proposes that a phenomenon of foot-final lengthening accounts for certain lengthening phenomena found in the language family. According to Gordon's account, foot-final lengthening played a crucial role in the proto-language in triggering consonant gradation. Gordon argues that vowels in absolute foot-final position, i.e. in foot-final open syllables, lengthened in the proto-language, thereby disrupting the prosodic profile of the trochaic feet characteristic of the proto-language. This disruption ultimately triggered lengthening in the consonant immediately preceding the lengthened foot-final vowel. Gordon's analysis can be seen most clearly when cast in moraic terms. Assuming consonants were non-moraic and there were no phonemic long vowels in the proto-language (see

Gordon 1998), the lengthening of a foot-final vowel created a light-heavy trochaic foot, a prosodically non-optimal foot in which the unstressed syllable is heavier than the stressed syllable. Lengthening the consonant preceding the lengthened foot-final vowel may thus be viewed as a foot optimization process, beefing up the light stressed syllable in a trochee. The result was a chain shift whereby single consonants became geminates and geminates became overlong before foot-final vowels (CVCV → CVCːVː and CVCːV → CVCːːVː, but CVCVC → CVCVC and CVCːVC → CVCːVC), thus setting in motion the paradigmatic consonant gradation alternations that still exist, albeit in modified form, in many languages in the Finnic and Sámi language families. The reconstructed process of foot-final lengthening finds support from analogous phenomena found in certain modern Finnic languages, such as Ingrian. Broader cross-linguistic evidence for foot-final lengthening comes from a pattern reported by Teranishi (1980) of lengthening targeting the second vowel in a disyllabic sequence, analyzed by Poser (1990) as a foot, in recited Japanese verse. Finally, foot-final lengthening may be viewed as the foot-level manifestation of the well-attested phenomenon of final lengthening observed at levels above the foot, such as the word and phrase (Wightman *et al.* 1992). Foot-final lengthening has also been appealed to by Revithiadou (2004) as a factor in promoting the cross-linguistically pervasive phenomenon of iambic lengthening discussed in the next section.

4.3 Iambic/trochaic length asymmetries

Certain asymmetries in quantitative alternations are also best explained with reference to foot structure rather than directly to stress. In particular, stressed syllables in iambic and trochaic feet appear to display fundamentally different length characteristics (see Hayes 1985, 1995 and CHAPTER 44: THE IAMBIC-TROCHAIC LAW). Stressed syllables in languages employing an iambic parse are often lengthened cross-linguistically, whereas those with trochaic feet characteristically either fail to lengthen the stressed syllable, or, in some cases, even shorten the stressed syllable. Chickasaw (Munro and Ulrich 1984; Munro and Willmond 1994, 2005; Munro 1996, 2005; Gordon *et al.* 2000; Gordon 2003, 2004; Gordon and Munro 2007) is an iambic language in which closed syllables and syllables containing long vowels are heavy, i.e. are parsed as monosyllabic feet word-initially or following a stressed syllable. The final syllable is also parsed as a foot even if it is light (CV). The rightmost stress, i.e. the one on the final syllable, is the primary one, except that a long (or lengthened) vowel in pre-final position attracts the primary stress from a final CV(C). As shown in (11), stressed vowels in open non-final syllables substantially lengthen, where the output of lengthening is a vowel that is either nearly neutralized or completely neutralized in length with a phonemic long vowel depending on the vowel and the speaker (see Gordon *et al.* 2000 for phonetic duration results).

(11) *Iambic lengthening in Chickasaw* (lengthened vowels indicated by ˑ)

(ʧiˌpiˑ)(saˈliˑ)(ˌtok)	'I looked at you.'
	cf. (piˈsaˑ)(liˌtok) 'He looked at you.'
(ʧiˌʧoˑ)(ˌkoʃ)(koˈmoˑ)(ˌʧi)	'He makes you play.'
	cf. (ʧoˌkoʃ)(koˈmoˑ)(ˌtok) 'He played.'
(ʧiˌkiˑ)(siˈliˑ)(ˌtok)	'He bit you.'
	cf. (kiˈsiˑ)(liˌtok) 'He bit it.'
(aˌsaˑ)(biˈkaˑ)(ˌtok)	'I was sick.'
	cf. (aˈbiˑ)(kaˌtok) 'He was sick.'

The process of iambic lengthening has an intuitive purpose, in that it enhances the prominence of the stressed syllable. In some languages, the beefing up of the stressed syllable in an iambic foot is achieved by lengthening a consonant rather than a vowel (see Hayes 1995: 82–83 for a survey of iambic lengthening; but see Bye and de Lacy 2008 for re-analyses of iambic consonant lengthening). This consonant can either be the coda consonant in a stressed CVC syllable, as in the Chevak dialect of Central Alaskan Yupik (Woodbury 1981) or the onset of the following syllable, the first half of which ends up closing the stressed syllable, as in Delaware (Goddard 1979, 1982).

Interestingly, substantial lengthening of stressed syllables in trochaic feet appears to be less sparsely attested, and those cases that do exist differ in certain important respects from their iambic counterparts (Hayes 1985, 1995; Mellander 2001). Cases of trochaic lengthening are found in languages with quantity-insensitive stress systems unlike cases of iambic lengthening, which are limited to languages with quantity-sensitive stress systems. Particularly striking is the existence of trochaic languages that shorten stressed syllables. For example, in Fijian (Schütz 1985) a trochaic foot is constructed at the right edge of a word. Phrases that underlyingly end in a heavy penult (one containing a long vowel) followed by a light ultima shorten the long vowel in the penult; thus, underlying /mbuːŋgu/ 'my grandmother' surfaces as (ˈmbuŋgu) (Schütz 1985: 528). Mellander (2001) finds that languages with trochaic shortening differ from those reported to display trochaic lengthening in being quantity-sensitive.

5 Segmental alternations predicted by foot structure rather than stress

5.1 Nganasan consonant gradation

In the introduction, we briefly examined the consonant alternations in Nganasan (Tereshchenko 1979; Helimski 1998;

Vaysman 2009) that were shown to be predictable from foot structure but not from stress. Stress is confined to a three-syllable window at the right edge of a word, falling on the final syllable if it contains a long vowel or diphthong (12a) and otherwise on either the penult or antepenult depending on vowel quality in those syllables. If the penult contains a vowel other than the central vowels [ɨ ə], stress falls on the penult (12b). If the penult contains a central vowel and the antepenult contains a non-central vowel, stress falls on the antepenult (12c). Cases involving a central vowel in both the penult and the antepenult display a more complex and variable pattern that will be discussed along with secondary stress below.

(12) *Nganasan stress* (Vaysman 2009: 23, 52)

a.	ky'ma:	'knife'
	le'hua	'board'
b.	ba'kunu	'salmon'
	'kaðar	'light'
c.	ku'butənu	'skin, fur (LOC SG NON-POSS)'
	'hʷa:tənu	'tree (LOC SG NON-POSS)'

Consonant lenition is predictable if one assumes a left-to-right parse into binary feet, with stray syllables being parsed into a monosyllabic foot: lenition targets foot-initial consonants that are not also word-initial. Lenition entails a number of different alternations including the loss of prenasalization (/ᵑh/ → [h], /ⁿt/ → /t/, /ᵑk/ → [k], /ⁿs/ → [s], /ᵑç/ → [ç], /ᵑc/ → [c]), voicing with or without a change in manner (/t/ → [ð], /k/ → [g], /s/ → [ɟ], /ç/ → [ɟ], /c/ → [ɟ]), and a shift from /h/ to [b] and from /j/ to zero. Data illustrating the consonant alternations for two suffixes and their relationship to foot structure appear in (13).

(13) *Nganasan consonant alternation and foot structure* (Vaysman 2009: 43, 52)

(ˌjama)('ða-tu)	'his/her/its animal'
(ˌŋoru)('mu-tu)	'his/her/its copper'
(su:)('ðə:)-(ðu)	'his/her/its lung'
(ŋu'hu)-(ðu)	'his/her/its mitten'
(ba:r)('pə-ⁿtə)(nu)	'master, chief (LOC SG NON-POSS)'
(hia)('ʧə-ⁿtə)(nu)	'thumb (LOC SG NON-POSS)'
(ku'bu)(tənu)	'skin, fur (LOC SG NON-POSS)'
('hʷa:)(tənu)	'tree (LOC SG NON-POSS)'

As these examples show, the strong variant of the 3rd person possessive suffix (beginning with [t]) and the locative singular non-possessive suffix (beginning with a prenasalized [ⁿt]) surface foot medially, whereas the weak allophone (beginning with [ð] and plain [t] in the two suffixes, respectively) occurs foot initially. The strong grade and the weak grade both occur in the onset of unstressed syllables, meaning that stress does not predict the alternation. Furthermore, the foot structure diagnosed by the consonant alternations does not accord with the foot structure that would be required to predict primary stress.

It is not the case, however, that stress assignment in Nganasan is completely blind to foot structure. Secondary stress falls on odd-numbered syllables counting from the left edge of a word in keeping with the footing predicted by consonant gradation (14a). Two provisions to this generalization, however, make the relationship even between secondary stress and foot structure opaque. First, secondary stress may not clash with an immediately following stress (14b) and, second, secondary stress skips over a light (CV) syllable in favor of a heavy (CVV) syllable (14c). In both situations, a final syllable is potentially footed but unstressed, and a word may display a mix of iambic and trochaic feet.

(14) *Nganasan secondary stress* (Vaysman 2009: 24)

a.	(ˌbaku)(ˌnumə)('numə)	'my salmon (PROLATIVE)'
	(ˌtiri)(ˌmimə)('numə)	'my caviar (PROLATIVE)'
b.	(ˌkaðar)(mə'nu)(mə)	'my light (PROLATIVE)'
	(ˌʧemɲi)(mə'nu)(mə)	'my salary (PROLATIVE)'
c.	(ky)(ˌma:)(mə'nu)(mə)	'my knife (PROLATIVE)'
	(le)(ˌhua)(mə'nu)(mə)	'my board (PROLATIVE)'

A further context in which foot structure is relevant to stress arises in words in which both the penult and the antepenult contain a central vowel. We abstract away from cases in which the penult and antepenult contain different central vowels, a situation that gives rise to variability in the location of stress, and consider here only cases in which both the penultimate and antepenultimate syllables contain the same central vowel. In words of this profile, the penult attracts stress if it is foot-initial (15a) but the antepenult carries the stress if the penult is foot-final (15b).

(15) *Nganasan stress in words with the same central vowel in the penult and antepenult* (Vaysman 2009: 36)

a. (ˌbiði)(ˈtirə) ‘you (SG) are drinking (INTR)’
(ˌɲili)(ˈtirə) ‘you (SG) are living’
b. (ˈbini)(mə) ‘my rope’
(ˌbiðip)(ˈtiti)(rə) ‘you (SG) are drinking (TR)’

The location of stress in these words is consistent with an analysis assuming a left-to-right parse into trochaic foot in keeping with the foot structure diagnosed by consonant gradation and secondary stress. As in the case of secondary stress assignment in many words, however, a stray final light syllable is predicted to be footed by consonant gradation but is unstressed if the penult and antepenult together form a foot.

5.2 Eastern Mari schwa fortition

Vaysman (2009) presents another case of a foot-driven segmental alternation that is not predictable from stress in Eastern Mari, another Uralic language. As discussed in §3.2, stress in Eastern Mari falls on the rightmost full, i.e. non-schwa, vowel in monomorphemic roots (16a) and otherwise on the initial syllable in non-derived words containing only reduced vowels underlyingly (16b).

(16) *Eastern Mari stress* (**Vaysman 2009**: 62–64)

a. koŋˈga ‘oven’
ʃerˈge ‘comb’
køgørˈʧen ‘dove’
ˈteŋgəz ‘sea’
ˈolək ‘meadow’
ˈjoŋələʃ ‘mistake’
puˈʃaŋgə ‘tree’
b. ˈβəɲər ‘canvas’
ˈəʃkəl ‘step’
ˈləβə ‘butterfly’

In addition to rounding harmony (see §3.2), Eastern Mari also has an alternation between reduced and full vowels. Underlying reduced vowels surface as full vowels in absolute word-final position, i.e. not in final closed syllables, under conditions that Vaysman argues are metrically governed. Schwa only strengthens to a full vowel in final position of a foot, where feet are parsed from left to right and a stray syllable left at the end of the word remains unparsed. Thus, unlike Nganasan, which allows degenerate feet at the end of the word, Eastern Mari does not. The quality of the full vowel resulting from fortition is determined by both front/back and rounding harmony. The examples in (17) illustrate the fortition of schwa foot finally in the suffix meaning ‘the one who/that is’ (17a), and the preservation of schwa in metrically unparsed final syllables (17b).

(17) *Eastern Mari vowel fortition* (**Vaysman 2009**: 83)

a. (ˈtaŋ-se) ‘the one who is a friend’
(ˈmy-sø) ‘the one that is honey’
(ˈjoŋə)(ləʃ-so) ‘the one that is a mistake’
(puˈʃaŋ)(gə-so) ‘the one that is a tree’
b. (ˈjeŋə)-sə ‘the one who is human’
(okˈsa)-sə ‘the one that is money’
(oˈla)-sə ‘the one that is a city’
(puʃaŋ)(gə-ˈna)-sə ‘the one that is our tree’
(pare)(ŋə-ˈna)-sə ‘the one that is our potato’

That we are dealing with fortition of schwa rather than lenition of full vowels to schwa is demonstrated by the patterning of alternating schwas as light syllables in the stress system. Thus, vowels that are underlyingly schwa pass stress on to a preceding full vowel even if they wind up as full vowels due to foot-final fortition (18).

(18) *Eastern Mari rejection of stress by alternating schwa* (**Vaysman 2009**: 79)

ˈsusko	‘scoop’	*susˈko	cf. ˈsuskəm	‘scoop (ACC SG)’
ˈmuno	‘egg’	*muˈno	cf. ˈmunə	‘egg (ACC SG)’
ˈjeŋe	‘human’	*jeˈŋe	cf. ˈjeŋəʒ	‘human (LAT SG)’

The Nganasan consonant alternations and the Eastern Mari vowel alternations present problems both for theories that attempt to link fortition and lenition directly to stress and for theories that analyze stress patterns without recourse to foot structure (e.g. **Prince 1983**; **Selkirk 1984**; **Gordon 2002**). On the other hand, stress cannot be predicted from the type of metrical structure needed to account for segmental alternations in these languages.

6 The role of history in foot-driven segmental alternations

The mismatch between stress and metrical structure diagnosed through segmental alternations raises the question of whether such cases are the result of a confluence of historical events that have removed an originally transparent link between stress and the alternations. The literature contains a number of cases of seemingly unprincipled synchronic patterns being veiled by later diachronic changes that have obscured a process that at one time was clearly phonetically grounded (e.g. **Buckley 2000**; **Hyman 2001**; **Yu 2004**).

In fact, there is evidence that the cases of disharmony between stress and segmental alternations in the Uralic languages Eastern Mari and Nganasan are the result of diachronic changes. Let us first consider the case of Eastern Mari schwa fortition (§5.2). Recall that this alternation involved the strengthening of word-final schwa in absolute foot-final position, e.g. /puʃaŋgə-sə/ → (pu'ʃaŋ)(gə-so) 'the one that is a tree' but ('jeŋə)-sə 'the one who is human'. As we have seen, this alternation falls out from an analysis positing binary feet constructed from left to right. These feet, however, do not accord with the stress system, which places a single stress on the rightmost full, i.e. non-schwa, vowel in monomorphemic roots and otherwise on the initial syllable in non-derived words containing only reduced vowels.

It is likely the case that the binary feet evinced through schwa fortition at one time corresponded to those diagnosed through stress. The dominant stress pattern in the Uralic language family, of which Mari is a member, involves stress on the initial syllable of a word, with many languages displaying a binary trochaic pattern from left to right. In keeping with the synchronic evidence, **Sammallahti (1988)** thus reconstructs a binary trochaic stress system for the proto-language. **Bereczki (1988)** reconstructs initial stress for pre-Mari on the basis of vowel reduction shifts occurring in non-initial syllables. Initial stress is also the default pattern for Eastern Mari words with all light syllables.

It is plausible that the binary pattern reconstructed for Proto-Uralic existed through the period during which schwa fortition developed as a productive alternation in Eastern Mari. Assuming this to be the case, the foot structure required to account for fortition was transparently linked to stress at one time. Furthermore, schwa strengthening becomes a phonetically motivated phenomenon driven by the same process of foot-final lengthening claimed by **Gordon (1998)** to drive consonant gradation in Proto-Saamic-Fennic (§4.2) and by **Revithiadou (2004)** to play a role in iambic lengthening cross-linguistically (§4.3). Schwa is phonetically much shorter than its non-reduced counterparts in Mari (**Gruzov 1960**; **Vaysman 2009**) and, more generally, in other languages with a weight distinction between central and peripheral vowels (**Gordon 2002**). Assuming that foot-final vowels are lengthened in Eastern Mari, the conversion from schwa to a peripheral vowel foot-finally plausibly follows from the incompatibility of schwa with increased duration. The reason this lengthening is likely confined to foot-final vowels that are also word final is due to the tendency for an enhanced lengthening effect in word-final position, which is independently predisposed to lengthening cross-linguistically. Support for this analysis comes from languages such as Yupik (**Reed *et al.* 1977**) and Javanese (**Horne 1974**), where underlying schwa in word-final position shifts to a peripheral vowel quality on the surface (see also **CHAPTER 26**: SCHWA).

It is also possible to pursue a diachronic approach to the mismatch between stress and the foot structure required to account for rhythmic consonant gradation in Nganasan (§5.1), although the complexity of the data complicates the discussion. Recall that consonants in foot-initial position are lenited in Nganasan, e.g. foot-initial (ku'bu)(tənu) *vs.* foot-medial (hɨa)('tʃə-^{n}tə)(nu), where footing adheres to a trochaic pattern from left to right. Stress, on the other hand, is limited to a three-syllable window at the right edge of a word.

As mentioned above, a trochaic stress system is reconstructed for Proto-Uralic. Indeed this basic pattern is preserved in the placement of secondary stress in Nganasan itself subject to interruptions in the alternating count due to heavy syllables. If one assumes that a trochaic stress pattern existed at the time rhythmic gradation became entrenched as a process, the link between gradation and foot structure diagnosed through stress becomes transparent. Under this analysis one puzzling aspect of consonant gradation remains, however: the fact that segments in foot-initial, i.e. historically stressed, syllables undergo lenition rather than fortition.

Regardless of the historical origins of mismatches between stress and the metrical structure driving segmental alternations, a synchronic analysis must admit the possibility of orthogonal representations of stress and foot structure. Furthermore, the data from languages like Nganasan and Eastern Mari suggest that stressless feet are a possibility even if typologically rare (see **Hyde 2002** for a recent constraint-based theory explicitly allowing for stressless feet).

7 Summary

Stress or lack of stress is associated with both suprasegmental and segmental properties. On a suprasegmental level, stress typically triggers lengthening, higher fundamental frequency, and greater intensity, although there are many languages in which these properties do not converge on a single syllable but rather are distributed over multiple syllables. On a segmental level, stress characteristically, although not always, triggers consonant fortition or blocks lenition targeting unstressed syllables. Some metrically conditioned segmental alternations, on the other hand, are better explained with reference to foot structure. For example, boundary-driven processes such as foot-initial fortition and foot-final lengthening are plausibly the foot-level analogs of well-documented phenomena applying at the word level. Furthermore, stressed vowel lengthening in many languages is explicable in terms of stress, but its cross-linguistic bias toward applying in iambic stress systems suggests that it is sensitive to foot structure. A final type of segmental alternation cannot be accounted for with reference to stress but rather suggests the relevance of foot structure that is orthogonal to the stress system in certain languages. Examination of historical data potentially provides insight into these mismatches between foot structure diagnosed by fortition and lenition and foot structure diagnosed by stress by showing that the segmental changes became entrenched at a chronologically earlier stage, when stress and foot structure coincided.

ACKNOWLEDGMENTS

The author wishes to thank two anonymous reviewers and the editors for their many helpful comments and suggestions on an earlier draft of this chapter.

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Cite this article

Gordon, Matthew. "Stress: Phonotactic and Phonetic Evidence." *The Blackwell Companion to Phonology*. van Oostendorp, Marc, Colin J. Ewen, Elizabeth Hume and Keren Rice (eds). Blackwell Publishing, 2011. Blackwell Reference Online. 16 January 2012 <http://www.companiontophonology.com/subscriber/tocnode?id=g9781405184236_chunk_g978140518423641>