A Perceptually Grounded OT Analysis of Stress-Dependent Harmony

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1 Introduction

Stress-dependent harmony (SDH) systems are systems in which an unstressed vowel must agree with the stressed vowel of the word in terms of one or more harmonic feature(s). In this paper, I provide cross-linguistic support for the notion of SDH. I then provide an Optimality Theoretic analysis of the SDH of Old Norwegian. In addition to providing a core analysis that accounts for the SDH in several typologically distinct languages, I provide external support for my analysis with experimental studies that phonetically ground the constraint driving the harmony.

In exploring the phonetic basis of SDH, I am drawing on a rich history of inquiry into the relationship between phonetics and phonology. Two methodological approaches can be distinguished: constraining phonological analyses via phonetic grounding through formal modeling of phonological phenomena (e.g. Archangeli and Pulleyblank 1994, Beckman 1998, Hayes 1996, Kaun 1996, Myers 1996, Padgett 1998, Steriade 1997), and experimental approaches that seek to explain phonology systems by providing grounding via empirical studies (Busa and Ohala 1997, Cohn 1990, De Jong et al. 1993, Doran 1998, Fowler 1981, Guion 1996, Hura et al. 1992, Keating 1985, Kohler 1990, Myers 1998, Pierrehumbert 1980). These approaches have the same goal: to place constraints on phonological analyses such that they have external explanations lying outside of the formal theory being used to capture the phonological pattern under scrutiny. Using both formal and experimental methods of phonetic grounding provides a more complete analysis of the relationship between phonetics and phonology.

1.1 Stress-dependent harmony

The table in (1) contains a list of languages containing SDH systems. Overall, the languages shown in (1) are typologically distinct, sharing only minimal contact and genetic ancestry.

(1)

Language Family		Language	Harmonic Feature(s)	Source
Austronesian		Chamorro	height	Topping 1968
Finno-Ugric		Eastern Cheremis (Mari)	color	Isanbaev 1975, Sebeok et al. 1961
Gondi		Koya	all (total)	Tyler 1969
Indo-European	Celtic	Breton	height	Anderson 1974
	Germanic	Old Norwegian	height	Hagland 1978
	Romance	Pasiego Montañes Spanish Brazilian Portuguese	height height	McCarthy 1984 Bisol 1989
Semitic		Tiberian Hebrew	all (total)	McCarthy 1979
Sino-Tibetan		Lhasa Tibetan	height	Ultan 1973
Tupi		Ava Guaraní Chiriguano	nasal nasal	Gregores&Suarez 1967 Dietrich 1986

The languages in the table in (1) and the harmonic features therein form such a diverse group that it is highly unlikely that the SDH systems present in these languages are due to language contact or an inherited linguistic trait. These systems no doubt arose independently of one another and since this phenomena is so wide spread, I contend that this is a naturally occurring pattern arising from the equally natural phonetic phenomena of vowel-to-vowel (V-V) coarticulation. I will return to the relationship between SDH and V-V coarticulation in section 3, but first, in section 2, I will outline in detail a phonetically motivated Optimality Theoretic account of the SDH system that was present in Old Norwegian.

2 Phonological Analysis: Old Norwegian Height Harmony

2.1 Old Norwegian data

The language referred to as Old Norwegian was spoken roughly from 1050-1370. The vowel system of Old Norwegian, taken from Hagland (1978), is shown in (2).

(2) Vowel System of Old Norwegian

i y	u	i: y:	u:
e ø	o	e: ø:	o:
æ	a	æ:	a:

Norwegian inherited its stress pattern from ancestral Germanic. With the exception of loanwords and weakly accented prefixes, the word initial syllable carried the stress. Old Norwegian developed a vowel harmony similar to the more well known SDH system in the Pasiego Montañes dialect of Spanish (McCarthy 1984). In Old Norwegian, the non-low unstressed vowels agreed in height with the initial stressed vowels (Hagland 1978, Gordon 1957). Old Norwegian differs from Pasiego in that it had a phonemic vowel length distinction. This length distinction plays a role in the low vowels: long low vowels trigger a lowering of high vowels to mid, whereas short low vowels do not. The data in (3) below illustrates the harmony of the non-low vowels (Hagland 1978).

(3) Height Harmony in Old Norwegian

[+high] stressed vowel			[-high] stressed vowel		
'inni	'inside'	(*'inne)	'dømdo	'sentenced'	(*'dømdu)
'undir	'under'	(*'under)	'Þesser	'these'	(*'Þessir)
'pinur	'plagues'	(*'pinor)	'opet	'open'	(*'opit)
'sunir	'sons'	(*'suner)	'retto	'right'	(*'rettu)
'systur	'sister'	(*'systor)	'toko	'took'	(*'toku)

The forms in the left column all contain a high stressed vowel. Forms in which a high stressed vowel is followed by a mid vowel do not occur. The right column contains forms with a stressed mid vowel. In these cases, the following vowel may not be high.

(4) contains data illustrating that the short low vowels of Old Norwegian failed to trigger the height harmony.

(4)	'adrum	'other'	'hafde	'had'
	'ællu	'all, singular'	'aller	'all, m. plural'

The data in the first column contains forms in which a stressed short low vowel is followed by an unstressed high vowel, and in the second column, the stressed short low vowel is followed by an unstressed mid vowel. Thus, these short low vowels do not appear to trigger harmony. Unlike the short low vowels, long low vowels are always followed by mid vowels. The data in (5) illustrate this restriction.

(5)	'va:rer	'our'	(*'va:rir)	'læ:rder	'learned'	(*'læ:rdir)
	'a:re	'year'	(*'a:ri)	'væ:re	'were'	(*'væ:ri)
	'va:rom	'owned'	(*'va:rum)	'mæ:lto	'said'	(*'mæ:ltu)

Hagland analyzes this as vowel reduction rather than vowel harmony because a similar pattern is seen in final unstressed syllables of trisyllabic words. Regardless of the harmony, the final unstressed vowels of trisyllabic words are mid. Forms illustrating this generalization are shown in (6).

(6) 'kælingom 'woman'
'stukunne 'chapel'
'iattado 'affirmed'

There is some evidence that the forms in (6) above are not subject to a general final neutralization process. The forms *'adrum* and *'ællu* contain short low vowels followed by high vowels. There is no harmony acting in these forms, so the final vowels would be free to undergo the final neutralization to mid vowels, but they do not.

The form *'stukunne* in (6) above has the regular height harmony, but the final unstressed syllable is mid, in defiance of the harmony. One might take this as evidence that the harmony is bound to the stress foot. Given the patterns above, the generalization appears to be that final unstressed syllables that do not belong to a stress foot are the targets of final neutralization. I leave the analysis of the final neutralization for further study.

2.2 OT Analysis of Old Norwegian height harmony

To account for the SDH, I posit a family of constraints called Stress-Prominence, shown in (7).

(7) **Stress-Prom(inence)(F)**
Every instance of the feature [F] must be associated with a stressed vowel.

Stress-Prom(F) is satisfied when the harmonic feature is associated with the salient stressed vowel and is violated for every unstressed vowel that is associated with a feature [F] that is not also associated with a stressed vowel. Stress-Prom(F) is a family of constraints, and I assume that F can be filled by any vowel feature. SDH systems can have various harmonic features, as demonstrated in the table in (1). The relevant member of the Stress-Prom family for Old Norwegian is Stress-Prom(high) since it contains a height harmony. Stress-Prom(high) is defined in (8) below.

(8) **Stress-Prom(high)**
Every instance of the feature [high] must be associated with a stressed vowel.

Stress-Prom(high) accounts for the fact that stressed and unstressed vowels share the harmonic feature [high], but this constraint says nothing with regards to which [high] feature they share. The fact that unstressed vowels alternate in agreement with stressed vowels rather than the other way around can be accounted for using a positional faithfulness framework (Beckman 1998). The faithfulness constraints in (9) and (10) are used in this analysis of Old Norwegian.

(9) **Ident(high)**
An output segment in a stressed syllable and its corresponding input must be identical with respect to the feature [high].
(McCarthy and Prince 1995)

(10) **Ident-□(high)**

An output segment in a stressed syllable and its corresponding input must be identical with respect to the feature [high].

(Beckman 1998)

The constraint in (10) is a positional faithfulness constraint motivated by the fact that segments in prominent positions such as stressed syllables tend to maintain contrasts that are lost elsewhere. The constraint hierarchy given in (11) is the core SDH ranking.

(11) Ident-□(high), Stress-Prom(high) >> Ident(high)

Ident-□(high) is undominated, giving the result that stressed vowels will always be faithful to their input [high] specification. Since Stress-Prom(high) outranks the general faithfulness constraint Ident(high), unstressed vowels will be unfaithful to their input specification of [high] and share the [high] specification of the stressed vowel in order to satisfy the harmony requirement imposed by Stress-Prom(high). The tableau in (12) illustrates how this constraint hierarchy applies to the Old Norwegian form *'opet 'open'*.

(12)

/opit/	Ident-□ (high)	Stress-Prom(high)	Ident(high)
a. 'upit	*!		*
b. 'opit		*!	
Xc. 'opet			*

Candidate (a) violates the positional faithfulness constraint because the vowel in the stressed syllable in the output is specified as [+high], but its correspondent in the input contains a [-high] specification. Candidate (b), the faithful candidate, violates Stress-Prom(high) since the unstressed vowel does not share its [+high] specification with the stressed vowel. Candidate (c) emerges as the optimal candidate since the unstressed vowel shares the [-high] specification of the stressed vowel, satisfying both the positional faithfulness and Stress-Prom constraints.

Low vowels do not undergo the height harmony in Old Norwegian. The faithfulness constraint Ident(low), shown in (13), is undominated in this language.

(13) **Ident(low)**

Output segments and their input correspondents must have identical specifications for the feature [low].

The failure of the short low vowels to trigger a harmonic lowering of high vowels can be accounted for by a constraint, Uniform(low), adapted from Uniform(round) (Kaun 1995). This constraint is defined in (14) below.

(14) **Uniform(low)**
Two segments can only share a [high] specification if they share a [low] specification.

This constraint rules out a configuration in which a low vowel and a mid vowel share a [-high] specification. This constraint dominates Stress-Prom(high) in Old Norwegian, giving the result that unstressed high vowels do not lower to mid in order to share [-high] with a low vowel. The ranking thus far is given in (15) and demonstrated by the form *'adrum* in the tableau in (16).

(15) Ident- □(high), Ident(low), Uniform(low)>> Stress-Prom(high)

(16)

/adrum/	Ident-□ (high)	Ident (low)	Uniform (low)	Stress-Prom (high)	Ident (high)
a . 'idrum	*!	*			*
b. 'adram		*!			*
c. 'adrem			*!		*
Xd. 'adrum				*	

Candidate (a) is ruled out because it violates the positional faithfulness constraint since the stressed vowel contains a [+high] specification that its corresponding input did not. Candidate (b) is ruled out because the unstressed vowel contains a [+low] specification in the output but not in the corresponding input. Candidate (c) violates the uniformity requirement since the stressed and unstressed vowels share a [-high] feature, but not a [low] feature. Candidate (d) emerges as optimal despite its violation of Stress-Prom(high) since it fares better on the higher ranking constraints.

As discussed above, the stressed long low vowels of Old Norwegian conditioned a one-step lowering of high vowels to mid. The constraint on the height of the unstressed vowels following stressed, long low vowels may be due to an extra degree of influence exerted by the vowels which are both stressed and long. These vowels are prominent in that they are stressed, and also prominent in that they are long. The fact that length is a form of prominence is captured in the family of prominence constraints, Long-Prom(F), defined in (17) below.

(17) **Long-Prom(F)**
Every instance of the feature F must be associated with a long vowel.

Long vowels are prominent and as such, may trigger phonological alternations similar to SDH. An example of this type of phonological harmony exists in Tigre, a Semitic language spoken in Eritrea and Sudan, which possesses a palatal vowel harmony in which the only short vowels of the language, [χ] and [Ξ], agree in backness with a following long vowel. An analysis similar to the one developed here using Stress-Prom as the driving force behind SDH systems could be developed for Tigre using Long-Prom.

Since the harmony in Old Norwegian concerned the feature [high], the member of the Long-Prom family relevant to this analysis, Long-Prom(high), is defined in (18).

(18) **Long-Prom(high)**
Every instance of the feature [high] must be associated with a long vowel.

In Old Norwegian, the fact that long stressed vowels are prominent in two manners can be captured using constraint conjunction as outlined in Crowhurst & Hewitt (1998). In this form of constraint conjunction, a candidate passes a conjunction A^B if and only if this candidate passes Constraint A *and* Constraint B. Stated negatively, a candidate violates the conjuction A^B if it violates either Constraint A or Constraint B.

In Old Norwegian, the fact that stressed, long low vowels trigger a lowering of high vowels to mid can be captured by conjoining the two prominence constraints, Stress-Prom(high) and Long-Prom(high). The conjunction of Stress-Prom(high) and Long-Prom(high) is given in (19).

(19) **Stress-Prom(high) $^{\wedge[hi]}$ Long-Prom(high)**
Every instance of the feature [high] must be associated to a stressed long vowel.

Any candidate that violates either of the members of this conjunct will violate the entire constraint. This constraint conjunction allows for an unstressed vowel to share a [high] specification with the stressed long vowel. This constraint must by ranked above Uniform(low) so that it may override the restriction in which, if segments share a specification of [high], they must also share a specification of [low]. The ranking is given in (20) and illustrated in the tableau in (21).

(20) Stress-Prom(high) $^{\wedge[hi]}$ Long-Prom(high) >> Uniform(low)

(21)

/va:rir/	StressProm (high)	^[hi]	Long Prom (high)	Uniform(low)
a. 'va:rir	(*)	*!	(*)	
Xb. 'va:rer				*

Candidate (a) is ruled out because the unstressed vowel has a [+high] specification that is not associated with the stressed vowel or a long vowel. Although candidate (b) violates the Uniform(low) constraint, it satisfies the higher ranked conjunction because the [-high] specification is associated with the stressed long vowel.

Given a form in which the stressed vowel is a short low vowel such as *'aller*, the current constraint ranking would not rule out a candidate in which a mora is added to the stressed vowel to make it long, because it would then satisfy the constraint conjunction. However, in Old Norwegian, short vowels were never lengthened. The constraint that captures this fact is Weight-Ident, given in (22) below.

(22) **Weight-Ident**

An output segment and its corresponding input must be identical in weight. (McCarthy 1995)

Weight-Ident assigns violations if a vowel is short in the input and long in the output or vice versa. This constraint dominates the constraint conjunction, accounting for the fact that vowels are not lengthened in the output in Old Norwegian, in order to satisfy the prominence conjunction. This ranking is given in (23) below and the tableau in (24) illustrates how this applies to the Old Norwegian form *'adrum.*

(23) Weight-Ident >> Stress-Prom(high) ^[hi] Long-Prom(high)

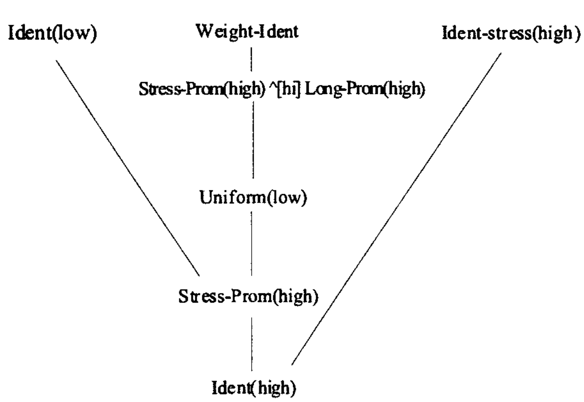
(24)

/adrum/	Weight-Ident	Stress Prom	^hi	Long Prom
[-high] / \ a. 'a:drem	*!			
X b. 'adrum		(*)	*	(*)

Candidate (a) satisfies the constraint conjunction since, by adding a mora to the stressed vowel, the [-high] specification of the unstressed vowel is shared with both a stressed and a long vowel. This candidate is ruled out though by the higher ranked constraint Weight-Ident so candidate (b) emerges as the optimal candidate.

The diagram in (25) shows the final ranking of constraints that accounts for the SDH pattern of Old Norwegian.

(25)



The fact that Stress-Prom(high) outranks Ident(high) yields a vowel harmony and since Ident (high) outranks Ident(high), only the unstressed vowels will undergo the harmony. Uniform(low) and Ident(low) outrank Stress-Prom(high), so low vowels will not trigger or undergo the harmony. The constraint conjunction Stress-Prom(high) ^ Long-Prom(high) outrank Uniform(low) accounting for the fact that long low vowels do trigger a harmony, but since Weight-Ident is unviolated, low vowels are never lengthened to satisfy the constraint conjunction.

3 Phonetic Support for Stress-Prom Analysis

The Stress-Prom family of constraints plays a crucial role in the analysis of Old Norwegian. Specifically, it is the driving force behind the harmony. Similar analyses of SDHs such as the color harmony in Eastern Cheremis or the nasal harmony in Chiriguano make use of other members of the Stress-Prom family, namely Stress-Prom(color) and Stress-Prom(nasal).

I argue that SDH has phonetic origins in V-V coarticulation (Majors 1998a, 1998b). I have conducted both acoustic and perceptual experiments that provide further phonetic grounding for the constraint family Stress-Prominence. In the remainder of section 3, I briefly summarize my findings from these experiments.

3.1 Stress-effects on V-V coarticulation in English

A few acoustic studies have reported that unstressed vowels are more likely to undergo coarticulation with surrounding vowels than stressed vowels are (Fowler 1981, Van Bergem 1994). Most studies of stress effects on V-V coarticulation have investigated the behavior of the vowel schwa, which has been argued to be either targetless (Van Bergem 1994), or represent a neutral tongue position (Browman & Goldstein 1992). In either case, schwa tends to be a heavily reduced vowel in many vowel systems, and thus much more likely to undergo coarticulation with surrounding sounds. I have chosen to investigate the effect of stress on V-V coarticulation observable on vowels that resist massive reduction when occurring in unstressed position.

3.1.1 Methods

I chose to use English for the phonetic studies for several reasons. I am investigating V-V coarticulation as a phonetic basis of SDH harmony. In order to do so, I must look to a non-harmony language to find the phonetic beginnings of a harmonic system. The dominant stress system of English also provides a robust difference in the stressed and unstressed vowels. I chose to investigate the vowels /i/ and /o/ because, of the English vowels, these are the two that best resist reduction in unstressed position.

My hypothesis was that unstressed vowels would undergo a greater amount of V-V coarticulation than vowels bearing primary stress. To test this hypothesis, I constructed reiterant CVCV speech data sets in which I varied the following: (i) the quality of the vowel (/i/ or /o/), (ii) level of stress (primary stress or no stress), (iii) the quality of the vowel in the adjacent syllable (/i/ or /o/), and (iv) the position of the vowel in the V_1CV_2 sequence (V_1 or V_2). Due to space considerations, I will discuss only the results that pertain to V_2 position. Similar results obtained for V_1 position, but to a lesser extent. Subjects were presented with actual words of English but were asked to replace all non-final consonants with the voiced bilabial [b], retaining the normal stress pattern of the original word. [b] was chosen to maximize the opportunity for V-V coarticulation. (26)

contains the carrier phrase used and (27) shows the reiterant tokens used for this experiment.

(26) Did you say you saw Fred's ___ before, or Ted's ___ before?
(27) 'bibi bi'bi 'bobo bo'bo 'bibo bi'bo 'bobi bo'bi

Four native speakers of American English (3M, 1F) provided the speech tokens for the acoustic experiment. Speakers were first trained on the consonant replacement task. Speakers were asked to speak at a self-selected fast rate of speech, producing ten repetitions of each token. Any tokens for which the target vowels were judged to be reduced to schwa or incorrectly stressed were not included in the study. Six formant measurements were made for each vowel: vowel onset, midpoint, and offset for both the first and second formant.

3.1.2 Results

V-V coarticulation occurs when a speaker anticipates or carries over one or more aspects of the articulation of one vowel to neighboring vowels. Acoustically, V-V coarticulation is evident when the formant values of the affected vowel are closer to the values of the vowel triggering the coarticulation. For example, in the sequence [bibo], the [o] vowel in the second syllable might be higher and more front than [o]s found in other contexts because the previous syllable contains a high, front vowel, [i].

Two of the four speakers exhibited significant stress effects on V-V coarticulation, supporting my hypothesis that unstressed vowels tend to undergo a greater amount of V-V coarticulation than stressed vowels. This was true particularly for the second formant, indicative of coarticulation in the front/back dimension. There were also vowel specific differences; the formant values of unstressed /i/ were affected more by the transconsonantal vowel than stressed /i/, but the formants of both stressed and unstressed /o/ were greatly influence by the transconsonantal vowel. The figure in (28) shows the mean formant values (speaker 2) of the unstressed vowel /i/ in the 'bi.bi and 'bo.bi contexts. The second formant values at onset and midpoint are visibly separated, indicating that the identity of the previous vowel has an affect on the quality of this unstressed /i/. ANOVA results confirm that these differences are significant at the .05 level.

(28)

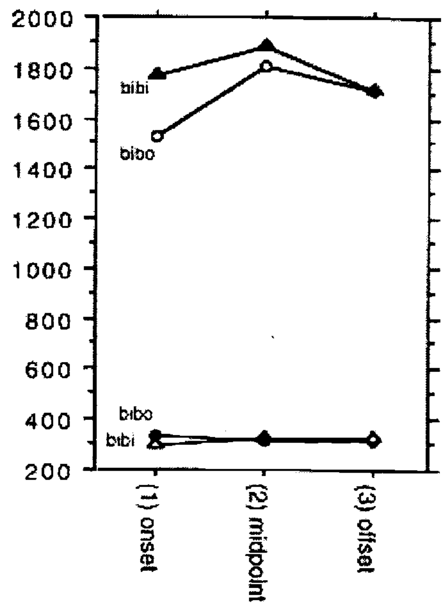
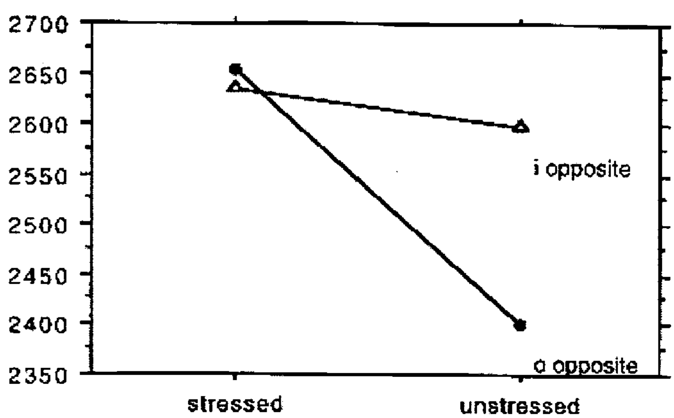


Figure (29) is an interaction diagram showing the effects of the transconsonantal vowel on F2 across stress level (subject 1). For the unstressed /i/, the difference in the ['bibi] and ['bobi] contexts is about 250 Hz., but for the stressed vowel /i/, the difference is negligible. The interpretation of this is that the stressed /i/ did not undergo V-V coarticulation while the unstressed vowel did.

(29)



The results of these acoustic experiments indicate that, at least for some speakers of English, unstressed vowels undergo a greater degree of V-V coarticulation than stressed vowels. While this supports my hypothesis that such stress asymmetries are plausible and likely phonetic origins of phonological SDH systems, in order for a sound change such as the one I am proposing to occur, the listeners in the speech community must be able to hear the differences in order for the asymmetry to influence the direction of the sound change. The perception experiment I describe in the next section was designed to test whether or not the stressed differences described above can be detected by naïve listeners of English.

3.2 The perception of V-V coarticulation on unstressed /i/

In order to test whether the differences in vowel quality of the unstressed vowels in the two coarticulatory contexts were great enough to be perceived, I constructed an ABX discrimination task in which the unstressed [bi] syllables were excised from their phonetic context and placed in triads of stimuli. The first and second member of the triad were always taken from the different coarticulatory contexts ([‘bi.bi] and [‘bo.bi]) and the third member matched one of the first two tokens in coarticulatory context, but was never token identical. Twelve native English speakers were asked to report which of the first two tokens the third token sounded most like. The test consisted of 80 triad, grouped into ten groups of eight triads each.

3.2.1 Results

Overall, subjects reported that the test token sounded more like the reference token 80% of the time. The table in (30) shows the number of times the actual token of [bi_i] and [bi_o] were judged to be most similar to the [bi_i] and [bi_o] reference tokens. If the subjects had performed at chance level (50%), each cell would contain the number 120. The percentage of the total is given in parentheses.

(30)

Similar to reference token:	Actual [bi_i]	Actual [bi_o]
[bi_i]	225 (94%)	45 (19%)
[bi_o]	15 (6%)	195 (81%)

The actual [bi_i] and [bi_o] tokens were identified with the reference token from the same context far more than the chance 120 times. The result of a two-way Chi-square test indicate that these four groups were significantly different from one another (χ^2 = 271.24, df=1, p <.05). A strength of association test indicated a very strong relationship between actual coarticulatory context and the coarticulatory context of the token to which it was judged to be most similar (ϕ= .75). These results suggest that, independent of vowel reduction, sufficient cues were present in the unstressed [bi] syllables such that listeners were able to perceive differences based on the identity of the transconsonantal vowel.

4 Conclusion

I have provided evidence that stress dependent harmony is a cross-linguistic pattern, and have posited a family of constraints, Stress-Prominence, which acts as the driving force behind the harmony. I have argued that this constraint family is motivated by acoustic and perceptual considerations, and have provided not only a grounded theoretical account of the pattern, but I have also conducted acoustic and perceptual experimentation that serves as further evidence for the phonetic plausibility of my account. Providing both theoretic modeling and empirical evidence of phonetic grounding of the SDH serves to triangulate the analysis, yielding a more robust understanding of the phenomenon. As such, I have provided not only an account of the synchronic pattern, but a window into the origins, and a plausible *explanation* for the existence of SDH in these languages.

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