Subphonemic Teamwork: A Typology and Theory of Cumulative Coarticulatory Effects in Phonology

by

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Abstract

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In this dissertation, I argue that phonology is —at least partly— grounded in phonetics, and that the phonetic information that is relevant to phonology must be given dedicated scalar representations. I lay out the foundations of a theory of such representations, which I call SUBFEATURES. A typology and case-study of SUBPHONEMIC TEAMWORK, a kind of multiple-trigger assimilation driven by partial coarticulatory effects, serves as the empirical basis of this proposal. I argue, on the basis of instrumental evidence, that such partial coarticulatory effects are relevant to the phonological grammar, and must accordingly be represented in it.

In doing so, I take a stand in several debates that have shaped phonology. First, the debate surrounding *phonological substance*: I argue against a substance-free approach (cf. Blaho 2008 and references therein) by showing that some phonological phenomena (here, subphonemic teamwork) require a phonetically grounded, or "natural", approach. Furthermore, within the field of phonetically based phonology, I argue in favor of maintaining a separation between phonology and phonetics, which are conceived of as distinct components of the grammar that communicate through the mediation of abstract phonetic knowledge. Finally, the theory I propose is *representational*: phonetic knowledge, which is what allows phonology access to some phonetic information, is reified into subfeatural representations that can be manipulated by the phonological grammar.

À a me minnana, Raymonde Hecq

Good training in theory, and acquaintance with its latest results, is not identical with being burdened with "preconceived ideas." If a man sets out on an expedition, determined to prove certain hypotheses, if he is incapable of changing his views constantly and casting them off ungrudgingly under the pressure of evidence, needless to say his work will be worthless. But the more problems he brings with him into the field, the more he is in the habit of moulding his theories according to facts, and of seeing facts in their bearing upon theory, the better he is equipped for the work. Preconceived ideas are pernicious in any scientific work, but foreshadowed problems are the main endowment of a scientific thinker, and these problems are first revealed to the observer by his theoretical studies.

Bronisław Malinowski, *Argonauts of the Western Pacific: An Account of Native Enterprise and Adventure in the Archipelagoes of Melanesian New Guinea.*, 1922. (Introduction, division V)

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Chapter 1

Introduction

1.1 Phonetic substance and phonology

Linguists studying speech sounds have for a long time wrestled with the paradox that "speech is both discrete and continuous" (Cohn 1998: 25). The response to this paradox has been to develop two separate but connected fields of research, one —phonology— dealing with the abstract, discrete, categorical aspects of speech, embodied in mental representations and computational processes, while the other —phonetics— focuses on the concrete, continuous, gradient aspects of realized speech.

However, this clearcut division between abstract categorical phonology and concrete gradient phonetics is by no means uncontroversial. The field of phonological theory has indeed been shaped by a long debate about the role of phonetic substance in phonology, schematically opposing two types of approaches: SUBSTANCE-FREE VS. PHONETICALLY GROUNDED phonology.

Substance-free approaches hold that "patterns of phonetic substance are not relevant to phonological theory strictly defined" (Hale and Reiss 2000: 158). Blaho (2008) presents a review of recent developments in substance-free phonology, and summarizes as follows the basic tenets of this type of approach: phonology is a "symbolic computational system" manipulating purely abstract mental representations. It is strictly independent from phonetics, in the sense that the phonetic realization of abstract phonological representations is invisible to the system and has therefore no role to play in the phonological computation. According to this view, "markedness and typological tendencies are not part of phonological competence, but rather an epiphenomenon of how extra-phonological systems such as perception and articulation work" (Blaho 2008: 3).[1]

Opposing this view, a long tradition of phonetically grounded phonology, rooted in observations and intuitions going back to the very beginnings of the field,[2] has defended the idea that (at least some) phonological phenomena are rooted in natural phonetic processes, i.e. that phonology is (at least in part) natural. Naturalness —the origin of markedness and typological tendencies—, is thus construed as being part of the phonological grammar. After a period of dormancy, this approach was revived in the 1970's by research in Natural Phonology (Stampe 1973; Donegan and Stampe 1979). More recently, the advent of Optimality Theory (OT, Prince and Smolensky

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[1] The last point of Blaho's (2008: 3) definition, namely that phonology is innate, will not concern us here.

[2] See, among others, Sievers (1876), Kruzsewski (1881), Passy (1890), Baudoin de Courtenay (1895), Jespersen (1904), Sapir (1921, 1933), Fouché (1927), Grammont (1933).

1993), particularly suited to functionalist approaches (cf. Myers 1997, Boersma 1998: 4, Hayes and Steriade 2004: 2), has given rise to an important body of work in phonetically grounded phonology,[3] based on earlier research suggesting that articulatory and perceptual factors have a role to play in accounting for cross-linguistic sound patterns.[4]

In this dissertation, I show that phonology is in part phonetically grounded. I propose a theory accounting for this phonetic grounding, through the direct incorporation of phonetic information into phonological representations.

1.2 Phonetic representations in phonology

The debate about the role of substance in phonology is cross-cut by a debate about phonological representations: what and how many representations should be allowed in phonology? This debate roughly opposes approaches that tend to favor grammatical complexity and representational economy, i.e. account for as many phonological patterns as possible through purely grammatical means (e.g. rules, constraint interaction), using only traditional phonological representations such as binary features, moras, syllables, etc. —to approaches that rely on richer representations to alleviate the onus of grammar in explaining phonological patterns. I will schematically label these two types of approaches "grammar-driven" vs. "representational". These labels should be understood in a relative sense. First, it is clear that phonology always needs both representations and grammatical computation; a grammar-driven approach simply gives more importance to grammar and limits the types an number of representations it uses, while a representational one uses detailed appropriate representations as the basis of explanation. Second, these two types of approaches do not necessarily define general opposing theories, and can even coexist within one and the same theoretical framework. One and the same phonologist, working within one and the same theory, may choose a grammar-driven account for one phenomenon, and a representational one for another one, so long as this representational account does not add to the minimal inventory of representations allowed in their theory.

Let us note that the debate about representations is orthogonal to the debate about substance. For example, arguing that phonology is phonetically based does not necessarily entail including phonetic representations in phonological theory. As a matter of fact, many recent phonetically grounded approaches can be defined as grammar-driven, in the sense that they derive phonetically natural processes, not through the manipulation of phonetic representations, but through phonetically grounded grammatical processes, such as constraint interaction (see, for example, Steriade's (2009) P-map in § 5.4.1). As we will see, the theory I propose in this dissertation is both phonetically grounded, and representational.

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[3] See, e.g. Archangeli and Pulleyblank (1994); Jun (1995), Flemming (1995, 2001, 2002); Hayes (1996); Boersma (1998); Hume (1998); Pierrehumbert (2000); Kirchner (1998); Steriade (1997, 2001, 2009); and papers in Hayes, Kirchner, et al. (2004).

[4] See, e.g., Jakobson et al. (1952); Liljencrants and Lindblom (1972); Lindblom (1983, 1986, 1990); Kingston (1985); Browman and Goldstein (1986, 1989, 1990); Ohala (1990, 1993); papers in Hume and Johnson (2001).

1.3 Cumulative effects in phonology: subphonemic teamwork

Categorical phonological processes (e.g. assimilation) that are driven by gradient, subphonemic effects traditionally considered to fall within the domain of phonetics (e.g. coarticulation) constitute a serious challenge for substance-free phonology and a strong argument in favor of phonetic grounding. One such type of process is what I call SUBPHONEMIC TEAMWORK, the topic of this dissertation. Subphonemic teamwork is a type of multiple-trigger process which obtains when two segments exerting the same coarticulatory effect on a target segment trigger a categorical assimilation only if they "team up" and add their coarticulatory strengths in order to pass the threshold necessary for that process to occur.

Woleaian *a*-raising (Sohn 1971; 1975: 29-31)), illustrated in (1) below, is an interesting case in point, since it has been given both substance-free / grammar-driven (e.g. Nevins 2010: 39–45, Suzuki 1997) and phonetically grounded accounts (e.g. Flemming 1997).[5]

(1) /ʉwal-i/ [ʉwe̱li̥] 'neck of'
/ita-i/ [ite̱i] 'my name'

As seen, the low vowel /a/ is raised to [e] between two high vowels. Both triggers are necessary, as shown in (2) by the fact that *a*-raising does not occur when only one of the flanking syllables has a high vowel.

(2) a. /mafili/ [mafili̥] 'to listen'
a. /nʉ-tage/ [nʉtage̥] 'to sail with the sail narrowed'
b. /libbeja-i/ [libbejai] 'my twins'

Flemming (2002: 77) points out the difficulty in accounting for multiple-trigger processes using standard autosegmental representations: "spreading a feature from two sources onto a target achieves the same as spreading the feature from one source, so the role of the second source is unexplained." Classic Optimality Theory (OT, Prince and Smolensky 1993), based on strict ranking, also faces a challenge, since it cannot model cumulative effects: a structure is either marked and needs to be repaired through a phonological process (M[arkedness] $\gg$ F[aithfulness]), or it is unmarked and no repair is needed (F $\gg$ M); but it cannot be weakly marked, triggering a repair strategy only if a certain threshold of markedness is reached, since no amount of violations of M will ever make up for a violation of F if F $\gg$ M, and vice-versa.

1.4 Modeling cumulativity

Both substance-free and phonetically grounded, grammar-driven and representational solutions to these problems have been, or can be proposed, as we will see in detail in chapter 5.

A possible, entirely grammar-driven solution to the constraint ranking problem mentioned above is to allow two or more weak constraints, each militating for a categorical change, to gang up in order to overcome strong faithfulness. This can be done through Local Constraint Conjunction (Smolensky 1993, 1995) as in Suzuki's (1997) account of the Woleaian data above: two

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[5] Woleaian *a*-raising is described in more detail in § 4.2.3, and the analyses mentioned above are discussed in chapter 5

markedness constraints penalizing high-low and low-high vowel sequences respectively are ranked lower than faithfulness to vowel height, and are thus inactive. Only their conjunction (i.e. *high-low & *low-high) is ranked higher than faithfulness, which explains why the height assimilation obtains only when there are two triggers (cf. § 5.2.1). The same mechanism can be modeled in Harmonic Grammar (Legendre et al. 1990, Smolensky and Legendre 2006), as we will see more in detail in § 5.2.2.[6] Crucially, no reference to phonetic information is necessary.

A different (and not OT-specific) approach is to ground teamwork phonetically, by allowing phonology to refer to fine-grained phonetic information. In such an approach, teamwork can be analyzed as resulting from cumulative coarticulatory effects, e.g. every high vowel in Woleaian has a slight raising coarticulatory effect on a neighboring [a] (i...^{i}a, a^{i}...i) and the cumulative effect of two high vowels breaks the threshold of coarticulatory raising and triggers categorical raising (i...^{i}a^{i}....i → i...e̱...i) (cf. Flemming 1997).[7]

These two types of accounts are not only different in their approach to phonetic naturalness, they also make different predictions. While both successfully account for the categorical assimilation in the presence of the two necessary triggers, as we will see in chapters 3 and 5, they make different predictions in cases where only one trigger is present.

The constraint gang-up effects modeled by Local Constraint Conjunction or Harmonic Grammar are categorical: the full phonological process occurs only if both weak constraints are violated at once; if it isn't the case, nothing happens. In particular, if only one of the weak constraints is violated, no effect is predicted. On the other hand, a phonetically grounded approach predicts that each trigger should independently have a partial coarticulatory effect on the target, the full assimilation being obtained by the addition of the partial effects contributed by both triggers.

In other words, in a grammar-driven, substance-free approach, teamwork is viewed as a categorical effect, while in a phonetically grounded approach, it is cumulative. This is summarized in Table 1.1.

	Substance-free Grammar-driven	**Phonetically grounded**
One trigger:	No effect	Partial effect (i...^{i}a, a^{i}...i)
Two triggers:	Full effect (i...a....i → i...e̱...i)	Full effect (= partial effect x2) (i...^{i}a^{i}....i → i...e̱...i)
Type of effect:	**Categorical**	**Cumulative**

Table 1.1: Predictions of substance-free vs. phonetically grounded accounts of teamwork

To evaluate and compare the descriptive and explanatory power of both approaches, one can test whether the presence of only one trigger has a partial effect on the target or not. The presence of such a partial effect constitutes a solid argument in favor of phonetic grounding, while its absence tilts the scale in favor of a substance-free approach.

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[6] See also Nevins's (2010: 39–45) analysis of Woleaian *a*-raising in § 5.1 for a different grammar-driven, substance-free approach.

[7] This is only a hypothesis, already proposed by Flemming (1997), to be tested against instrumental data.

In this dissertation, I provide instrumental evidence that subphonemic teamwork involves partial, cumulative effects, necessitating a phonetically grounded approach.

1.5 The solution: subfeatural representations

Based on this instrumental evidence, I propose to enrich phonology with a new set of fine-grained, scalar representations capturing the partial effects driving in subphonemic teamwork. Specifically, I propose that the partial coarticulatory effect of an individual trigger on the target in a case of subphonemic teamwork be given a representation visible to the phonology. I term these representations subfeatures, because they capture subphonemic, perceptually distinct categories below the featural level. For example, in Woleaian, I argue that a high vowel exerts a partial raising effect on an adjacent low vowel [a]. This results in a partially raised [a], which is phonologically characterized as low, like any other [a] (i.e. featurally [+low, –high], or [0 high] in a ternary feature system opposing [0 high] /a/ vs. [1 high] /e, o/ vs. [2 high] /i, u/) —but subfeaturally ⟦x high⟧, with $0<x<1$ (for the evaluation of the intermediate subfeatural value x, see § 3.2.1). This ⟦x high⟧ [a] is known by the speaker to belong to the phonological category of low vowels (i.e. it does not contrast with other low vowels), but it is perceived as distinctly higher than low vowels that are not surrounded by any high vowels, i.e. ⟦0 high⟧ [a].

Features are thus organized in a two-tier system, where phonologically contrastive categories (phonemes), defined by classic features (binary, or privative, or possibly even multivalued as in the case vowel height), can be subdivided into perceptually distinct subcategories, defined by subfeatures. In the case of Woleaian, the phonological category "low vowel", defined as [+low, –high] or [0 high], subsumes two non-contrastive, but distinct subfeatural categories corresponding to two different contextual realizations: ⟦x high⟧ in the vicinity of a high vowel, ⟦0 high⟧ elsewhere, as schematized in (3).

(3) Featural Subfeatural

/a/ [+lo, –hi] ~ [0 high] < ⟦x high⟧ [a] / V_{hi}__, __V_{hi}
⟦0 high⟧ [a] elsewhere

Subfeatures capture perceptually distinct contextual realizations of phonemes, resulting from language-specific coarticulation. I claim that such coarticulatory effects are part of phonetic knowledge (Kingston and Diehl 1994), a building block of phonetically grounded approaches to phonology, defined by Hayes and Steriade (2004: 1) as "the speaker's partial understanding of the conditions under which speech is produced and perceived." I also claim that this abstract knowledge of the effect of segmental context on the realization of concatenated segments is available to phonological computation, i.e. phonology has access to subfeatural representations of phonetic knowledge.

Once one adopts subfeatural representations, the different types of subphonemic teamwork can be given straightforward analyses, as I will show (cf. §§ 3.3 and 3.5 and chapter 4).

The theory of subfeatural representations proposed here builds on previous research in phonetically grounded phonology. It rests on the idea that phonology is (in part) synchronically grounded in phonetics. In that sense it departs from approaches where phonetic naturalness is understood to play a role only in diachronic change (e.g. Ohala 1981 and subsequent work; Hyman 1976, 2001; Blevins 2004; Blevins and Garrett 2004). However, it does not question the separation of phonology and phonetics, contrary to theories that conflate phonetics and phonology into a unified model (e.g. Flemming 1995, 2001, 2002; Kirchner 1998, 2001). In the theory of subfeatural representations, phonology and phonetics are kept separate, but they communicate: abstract phonetic knowledge acts as a mediator between gradient/variable phonetics and categorical phonology. Subfeatures are representations of this implicit knowledge. Finally, the theory of subfeatural representations is a representational approach to phonetically grounded phonology: it introduces new, specific representations to tackle problematic data.

1.6 Structure of the dissertation

This dissertation derives the phonetically grounded, representational theory of subphonemic teamwork summarized above from a particular case study, before enlarging the scope to other cases of subphonemic teamwork which confirm the predictions of the theory, and comparing it to alternative approaches.

Chapter 2 presents the case of the Laal doubly-triggered rounding harmony, which constitutes the main descriptive contribution of this dissertation, as well as the strongest empirical support for the theory of subfeatural representations. I first describe this typologically unusual harmony, showing that it obligatorily involves two triggers and has uncontroversial phonological status. I then provide acoustic measurements showing that it is driven by partial coarticulatory effects, giving credence to a phonetically grounded approach.

On the basis of this instrumental evidence, chapter 3 develops the theory of subfeatural representations briefly sketched above, both phonetically grounded and representational. Illustrative analyses, couched in Optimality Theory, of both the Laal and Woleaian alternations are proposed, showing that adding subfeatural representations to the regular arsenal of phonological theory facilitates the analysis of subphonemic teamwork.

Chapter 4 enlarges the empirical scope of the theory by looking at other cases of subphonemic teamwork attested worldwide. It presents a tentative typology based on 52 cases identified in 42 typologically, geographically, and genetically diverse languages. 16 cases are described in detail and shown to be easily accounted for by the theory.

Chapter 5 compares the phonetically grounded, representational theory of subfeatural representations with alternative approaches, and shows its strengths over both grammar-driven and representational, substance-free and other phonetically grounded approaches.

Finally chapter 6 concludes with a summary of the findings and the main points of the theory proposed here, and discusses a few directions of future research.

Chapter 2

The Laal doubly triggered rounding harmony

In this chapter, I describe a very intriguing case of subphonemic teamwork: the doubly triggered rounding harmony of Laal. I first give some background information about the phonology of the language (§ 2.1). I then describe the doubly triggered rounding harmony (§ 2.2), its phonological nature (§ 2.3), and its phonetic basis (§ 2.4). I conclude that the harmony is driven by partial subphonemic effects, and constitutes a strong argument in favor of phonetic grounding.

2.1 Introductory remarks on Laal phonology

Laal is a language isolate spoken by ca. 800 people, residing mainly in the two villages of Gori and Damtar along the banks of the Chari river in southern Chad. The language was first brought to the attention of the scientific community in the 1970's by Pascal Boyeldieu, who described its phonology (Boyeldieu 1977), as well as its nominal and verbal systems (Boyeldieu 1982, Boyeldieu 1987). All the data presented here come from my own fieldwork on the language (twelve months between 2010 and 2015). The phonological sketch below is based on my own analysis, which is mostly congruent with Boyeldieu's.

As can be seen in Table 2.1, Laal has twelve phonemic vowels, characterized by three degrees of aperture and an opposition between [+ front] and [–front] vowels, coupled with a rounding contrast among both [+ front] and [–front] vowels.

V$_1$ (and Vː$_1$)			
+front		*–front*	
i	y	ɨ	u
e	yo	ə	o
ia	ya	a	ua
–rd	*+rd*	*–rd*	*+rd*

V$_2$ (*Vː$_2$)		
+front	*–front*	
i	ɨ	u
e	ə	o
	a	
–rd	*–rd*	*+rd*

Table 2.1: Laal vowel inventory

The relevance of the [+ front] vs. [–front] opposition (as opposed to [+ back] vs. [–back], or [+ front,–back] vs. [–front,–back] vs. [–front, + back]) is revealed by the simple rounding harmony process that will be discussed in § 2.3: front vowels are rounded into front rounded vowels (/i, e, ia/ → /y, yo, ya/), and central vowels into back rounded vowels (/ɨ, ə, a/ → /u, o, ua/), i.e. central and back vowels form a natural class.

The four vowels /ia, ua, yo, ya/ are analyzed as diphthongized monophthongs. They pattern phonologically as would /ɛ, ɔ, ø, œ/, as demonstrated by their monomoraicity and their behavior in vowel harmony,[1] but are most of the time realized as diphthongs, hence my choice to transcribe them as such: /ia/ = [ɛ∼e̯a∼ja], /ua/ [ɔ∼o̯a∼wa], /yo/ = [ɥø∼ɥo], /ya/ = [œ̯a∼ɥa].

Length is distinctive for all twelve vowels.[2] Outside of the stem-initial syllable (V_1), only seven of these twelve vowels are attested, viz. all but the three front rounded vowels and the two low peripheral vowels. The length contrast is also neutralized in that position, where all vowels are short.

Table 2.2 presents the consonant inventory of Laal. /ʔ/ is attested only in word-initial position, where it acts as a default epenthetic consonant inserted to avoid vowel-initial words, strictly forbidden in Laal. Additionally, the laryngeal and prenasalization contrasts among plosives are neutralized in non-stem-initial position. Word-internal (intervocalic as well as preconsonantal) plosives are always voiced, word-final ones voiceless, as briefly illustrated in (4).

	C_1 (stem-initial)					Elsewhere			
Plosives	p	t	c	k	(ʔ)				
	b	d	ɟ	g		p∼b	t∼d	c∼ɟ	k∼g
	mb	nd	ɲɟ	ŋg					
	ɓ	ɗ	’j						
Non-plosives	m	n	ɲ			m	n	ɲ	ŋ
		l					l		
		r					r		
	w		j			w		j	
		s		h			s		

Table 2.2: Laal consonant inventory

(4)	ɗɨ́b	[ɗɨ́p]	’to hit’	*vs.*	ɗɨ̀bɨ̀	[ɗɨ̀bɨ̀]	id. (gerund)
	cíd	[cít]	’to eat meal without sauce’	*vs.*	cìdì	[cìdì]	id. (gerund)
	ɓə̀j	[ɓə̀c]	’to fool’	*vs.*	ɓàjà	[ɓàjà]	id. (gerund)
	lūg	[lūk]	’to unearth’	*vs.*	lùgù	[lùgù]	id. (gerund)
	lóóg	[ló:k]	’pigeon’	*vs.*	luágmí	[luágmí]	’pigeons’

Finally, vowel harmony is pervasive in Laal morpho-phonology, where no less than four har-

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[1] /ia, a, ua/ are the low counterparts of /e, ə, o/ respectively as shown by their alternation in low harmony illustrated in (6)), while /u, o, ua/ and /y, yo, ya/ are the rounded counterparts of /i, e, ia/ and /ɨ, ə, a/ respectively in the simple rounding harmony illustrated in (16). These Laal vowels are already analyzed as complex realizations of underlying monomoraic, monophothongal vowels by (Boyeldieu 1982: 5-6). See also (Lafarge 1978: 126-124) and (Boyeldieu 1985: 129-134) for a similar analysis for Kosop and Lua /ia, ua/.

[2] Vowel length is indicated in transcription by doubling the (last) vowel symbol, e.g. *aa*, *iaa*, etc. This convention is not a reflection of the realization of diphtongized vowels, whose phonological lengthening is not always manifested through lengthening of the final V element, but often through strong diaeresis, in particular in monosyllabic words, e.g. *diáágál* [diá:gál], but *miààm* [mìʲàm].

mony processes are attested. Additionally to the doubly triggered rounding harmony that is the focus of this paper, a simpler rounding harmony also exists (cf. § 2.3), as well as two height harmonies: a perseverative [+high] harmony and an anticipatory [±low] harmony, illustrated in (5) and (6) respectively.

(5) [+high] harmony: $V_{\mathrm{mid}} \rightarrow V_{\mathrm{hi}}$ / $V(C)_{\mathrm{hi}\_}$

		+ -*ə̀r* 'my' → -*ɨ̀r*	+ -*ò* 'her' → -*ù*
mīīw	'liver'	mììw-ɨ̱̀r	mììw-ù̱
mɨ̄lā	'eye'	mɨ̀l-ɨ̱̀l	mɨ̀l-ù̱
mbūl	'navel'	mbùl-ɨ̱̀l	mbùl-ù̱

(6) [±low] harmony: [–hi, αlo] → [βlo] / _(C)[βlo]

a. [+lo] suffix *-àr/-àn* 'it' (obj)': mid → low

e → ia	léérí	'roll'	→	li̱á̱á̱r-àn	'roll it'[3]
ə → a	cə̄r	'want'	→	cà̱r-àr	'want it'
o → ua	sór	'find'	→	su̱á̱r-àr	'find it'

b. [–lo] medio-passive suffix *-ɨ́ny* : low → mid

ia → e	ʔiáár	'choose'	→	ʔé̱é̱r-ɨ́ny	'be chosen'
a → ə	màŋà	'gather'	→	mə̱̀ŋ-ɨ́ny	'be gathered'
ua → o	juāŋ	'buy, sell'	→	jò̱ŋ-ɨ́ny	'buy from one another'

In each example in this chapter, the surface form are given alongside the underlying form and, when necessary, an intermediate form where all the phonological processes but the doubly triggered rounding harmony have already applied.

2.2 The doubly triggered rounding harmony

2.2.1 The basic pattern

One of the most complex and intriguing features of Laal is its doubly triggered rounding harmony: a non-round vowel is rounded by a following round vowel only if it is preceded or followed by a labial consonant (with an optional consonant in between). Additionally, the rounding harmony is parasitic: the trigger and target vowels need to be of equal height (αHeight condition) and backness (βFront condition). What makes this case of doubly triggered harmony particularly interesting is that it does not necessarily involve a double-sided effect: the two co-triggers —the labial consonant and the round vowel—, may surround target vowel as in (7b-c), or they may be both on the same side (i.e. to the right), as in (7b-c). Examples (7d-e) illustrate cases with not one, but two labial co-triggers. The harmony is illustrated in (7) below with plural nouns formed with the suffixes *-u* or *-o* (I come back to these suffixes in § 2.2.3).

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[3] Given their phonological patterning, the diphthongized vowels /ia/ and /ua/ are analyzed as phonologically [-high, +low]. Phonetically, they are of course not uniformly low, but formed of a high (or mid depending on the realization, subject to variation) onglide and a low nucleus. In view of the fine-grained phonetic gradations that I propose to capture phonologically in the theory of subfeatural representations I propose in chapter 3, this very abstract phonological characterization may seem confusing. Since diphthongized vowels play no role in the doubly triggered rounding harmony, I will leave the issue of their correct representation in subfeature theory aside.

(7) V2[rd], Lab, αHeight, βFront $\rightarrow$rounding

	Singular	*Plural suffix* -u/-o			
a.	ɓɨ̀r-à	/ɓɨ́r-ú/	ɓù̱r-ú	‘fish hook’	$(C_{lab} = C_1)$
b.	tàb	/tə̀b-ó/	tò̱b-ó	‘fish sp.’	$(C_{lab} = C_2)$
c.	dɨ̀làm	/dɨ̀lm-ú/	dù̱lm-ú	‘type of house’	$(C_{lab} = C_3)$
d.	páb	/pə́b-ó/	pó̱b-ó	‘cobra’	$(C_{lab} = C_1$ and $C_2)$
e.	málɨ̀m	/mə̂lm-ó/	mô̱lm-ó	‘Koranic school teacher’	$(C_{lab} = C_1$ and $C_3)$

General phonotactic restrictions limit the number and type of potential triggers and targets of the harmony. First, since words in Laal are maximally disyllabic[4], it is impossible to derive forms that would show harmony across more than one syllable. The harmony thus involves only one target: the stem-initial vowel V_1.[5] The trigger is always the nucleus of the second and last syllable (V_2), which may be part of a disyllabic stem, or of a suffix as in the examples in (7). Furthermore, given the reduced V_2 inventory (cf. table 2.1), the number of potential triggers of the harmony is restricted to /u/ and /o/ —the only two [+round] vowels attested in V_2— each of which, by virtue of the αHeight and βFront conditions, can only target one vowel: V_2 /u/ rounds V_1 /ɨ/ into [u], while V_2 /o/ rounds V_1 /ə/ into [o]. This is schematized in Figure 2.1.[6]

As can be seen from the examples in (8) below, all four conditions (the two triggers V_2[rd] and LabC, and the two additional conditions αHeight and βFront) must be met in order for rounding of V_1 to occur. If any one of the four conditions is missing, as in (8a), the harmony fails to apply. Examples (8b-c) show that, as expected, the harmony does not apply either when more than one condition is missing.

Words like *gōbə̄r* ‘cloud’ or *gúmlɨ́l* ‘round’ further show that the harmony is strictly anticipatory. Additionally, the teamwork effect is necessarily driven by the association of a labial consonant and a round vowel. Two labial consonants may not team up to co-trigger rounding, as shown in (9) below.

(9)	/mə̀ə̀m-ə̄r/	mə̀ə̀mə̄r	(*not* mòòmə̄r)	‘my grandmother’
	/bə̀brə̀/	bə̀brə̀	(*not* bòbrə̀)	‘lizard sp.’
	/pɨ́rmɨ́n/	pɨ́rmɨ́n	(*not* púrmɨ́n)	‘dust’
	/bɨ̀rmɨ́n/	bɨ̀rmɨ́n	(*not* búrmɨ́n)	‘savannah’

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[4] With only a few exceptions, mostly ideophones, frozen compounds, reduplicative forms and/or loanwords, ignored here.

[5] There are no prefixes in Laal, so the target is systematically both stem- and word-initial.

[6] Two noun plural forms in the language suggest that the doubly triggered rounding harmony used to apply between low [–front] vowels as well in an earlier stage of the language, when presumably the low peripheral vowels /ɛ∼ia/ and /ɔ∼ua/ were still attested in V_2: *huāā-r-ā*, the plural of *pə̄ə̄-l* ’village’, and *muág-r-á*, the plural form of *mə́g-ə́l* ’mouse’ (alternate pl. *móg-ór*). The historical derivation of these two plural forms is given below.

	/pə̄ə̄ + -r + ɔ/	/mə́g + -r + -ɔ/
[±low] harmony	pāārɔ̄	mágrɔ́
D.-tr. rounding harmony	pɔ̄ɔ̄rɔ̄	mɔ́grɔ́
*p > h / $\_V_{[+rd]}$	hɔ̄ɔ̄rɔ̄	–
*ɔ > {ua/V_1, a/V_2}	**huāārā**	**muágrá**

This diachronic change also shows that the doubly triggered rounding harmony must have already been an active alternation in the language prior to the (regular) *p > h / $\_V_{[+rd]}$ sound change (presumably $p^h > p^\phi / \_V_{[+rd]} > \phi > h$).

(8) Non-application of the harmony (✔ = condition met; * = condition not met)

			V_2 [rd]	**LabC**	**αHeight**	**βFront**
a. Only three conditions are met						
/kààm-ə́/	kə̀ə̀m-ə́	‘tree sp.-pl’	*	✔	✔	✔
/gɨ́n-ù/	gɨ́n-ù	‘net-pl’	✔	*	✔	✔
/sàg-ó/	sə̀g-ó	‘bag-pl’				
/mààg-ú/	mə̀ə̀g-ú	‘tree sp.-pl’	✔	✔	*	✔
/ɓàr-ú/	ɓə̀r-ú	‘plants sp.-pl’				
/píl-ù/	píl-ù	‘mat-pl’	✔	✔	✔	*
/bìrú/	bìrú	‘burn’				
b. Only two conditions are met (incl. at least V_2[rd] or LabC)						
/miàn-ú/	mèn-ú	‘road-pl’	✔	✔	*	*
/miààg-ú/	mèèg-ú	‘kaolin-pl’				
/ɟíŋ-ù/	ɟíŋ-ù	‘harpoon-pl’	✔	*	✔	*
/tíl-ù/	tíl-ù	‘sand-pl’				
/dán-ú/	də́n-ú	‘tree sp.-pl’	✔	*	*	✔
/ɟág-ú/	ɟə̀g-ù	‘knife-pl’				
/mɨ́n-í/	mɨ́n-í	‘eye-pl’	*	✔	✔	*
/tɨ́m-í/	tɨ́m-í	‘hand-pl’				
/ɓɨ̀r-à/	ɓɨ̀r-à	‘fish hook-sg’	*	✔	*	✔
/sɨ́m-á/	sɨ́m-á	‘fishing net-pl’				
c. Only one condition is met (incl. at least V_2[rd] or LabC)						
/niàn-ù/	nèn-ù	‘pus-pl’	✔	*	*	*
/tiààr-ú/	tèèr-ú	‘grass sp.-pl’				
/màl-í/	mə̀l-í	‘tongue-pl’	*	✔	*	*
/sám-ì/	sə́m-ì	‘(be) acidic-pl’				

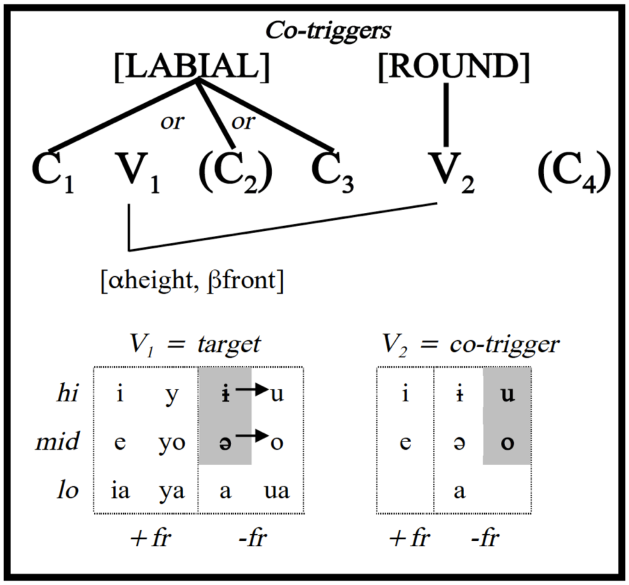

Figure 2.1: Laal doubly triggered rounding harmony

2.2.2 The blocking effect of intervening /w/

The only nine (regular) exceptions to the doubly triggered rounding harmony are listed in (10a-b) below, and illustrate another intriguing property of the doubly triggered rounding harmony: the blocking effect of /w/ when it intervenes between V$_1$ and V$_2$.

(10)		*Singular*		*Plural suffix* -o *(triggering [±[±low] harmony)*		
	a.	gâw	'hunter'	/gə́w-ó/	gə́w-ó	
		gàw	'elephant trap'	/gə̄w-ō/	gə̄w-ō	
		ɟàw	'cheetah'	/ɟə̀w-ó/	ɟə̀w-ó	
		sàw	'fish sp.'	/sə̄w-ō/	sə̄w-ō	
		sáw	'warthog'	/sə́w-ò/	sə́w-ò	
		táw-ál	'shield'	/tə́w-ò/	tə́w-ò	
		tāw-āl	'beeswax'	/tə̄w-ō/	tə̄w-ō	
		ɟāgw-ā	'hat'	/ɟə́gw-ó/	ɟə́gw-ó	
	b.	māw	'scorpion'	/mə́w-ó/	mə́w-ó	
	c.	wàár	'genet'	/wə̀ə̀r-ó/	wò̱ò̱r-ó	(cf. (12a) below)

Not only does an intervening /w/ not co-trigger the harmony (10a), it even blocks it, as clearly shown by *mə́w-ó* in (10b), where the word-initial /m/ fails to act as a co-trigger. Word-initial /w/, on the other hand, co-triggers the harmony like any other labial consonant, as shown in (10c).[7] This blocking effect of intervening /w/ is rooted in an exceptionless phonotactic constraint that bans sequences of a round vowel followed by /w/ (with an optional intervening consonant):

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[7] Only cases with mid vowels (i.e. ə(C)wo) are attested. The ɨ(C)w sequence is extremely rare in Laal: it is unattested in nouns, and found in only six verbs, all of which are plural forms derived from their singular counterpart through regular a → ɨ raising: Ca(a)w → Cɨ(ɨ)w, e.g. *kāw* → *kɨ̄w* 'eat (sg/pl)'.

*U(C)w. This constraint is enforced without exception, both in the lexicon and in morphologically derived environments (cf. ex. (17) below).

2.2.3 Morphological conditioning

The harmony is only actively enforced between roots and number-marking suffixes (other types of suffixes and their effects will be presented in § 2.3). Laal has 29 number-marking suffixes (10 singular, 19 plural). These suffixes all combine arbitrarily with a restricted set of nouns and verbs. Out of 1050 monomorphemic nouns in my corpus, 384 combine with at least one such suffix. The most frequent (*-u*) is attested with 73 nouns, while eleven of these suffixes are attested with less than five nouns each. Additionally, some of these suffixes are used to derive either the plural- or the singular subject form of 38 intransitive verbs. e.g. *ɲún* ‘go (sg subject)’ vs. *ɲún-ì* ‘go (pl. subject)’, or *lūr* ‘be short (sg. subject)’ vs. *lūr-ā* ‘be short (pl. subject)’.

Four number-marking suffixes contain a round vowel (henceforth “round suffixes”): the three plural suffixes *-u* (73 occurrences), *-o* (46), and *-or*∼*-ur* (14), and the singular suffix *-o* (7). The suffix *-or*∼*-ur* varies between a mid and a high realization, subject to [+high] harmony (cf. (5) above): *-ur* if the root vowel is high, *-or* otherwise. All three are used only on nouns in my corpus. The doubly triggered rounding harmony is thus attested as an active process only with nouns, but that is most probably accidental.[8]

140 out of the 1150 monomorphemic nouns in the lexicon are compatible with one of the four round suffixes above. Of these 140 nouns, only 89 have an underlying non-round V_1. 34 of these 89 nouns meet the conditions for the doubly triggered rounding harmony, i.e. their plural form has both a labial consonant (C_1, C_2, or C_3), and two vowels of identical height and frontness. All these nouns obey the doubly triggered rounding harmony, with only nine (regular) exceptions: the nine nouns featuring an intervening /w/, listed in (10a-b) above. This leaves 25 attested cases of active doubly triggered rounding harmony, all listed in examples (11) and (12), where V_1 an V_2 are both high and both mid respectively.

(11)	*Singular*		*Plural suffix* -u, -ur	
	bɨ́nàn	‘okra’	/bɨ̂nn-ú/	bû̱nn-ú
	bɨ̀g-ál	‘bark’	/bɨ̄g-ū/	bū̱g-ū
	ɓɨ̀r-à	‘fish hook’	/ɓɨ̀r-ú/	ɓù̱r-ú
	ɓɨ̄g-āl	‘tree sp.’	/ɓɨ̄g-ùr/	ɓù̱g-ùr
	cɨ́rám	‘tree (sp.)	/cɨ́rm-ú/	cú̱rm-ú
	dɨ̄lām	‘type of house’	/dɨ̀lm-ú/	dù̱lm-ú
	màl	‘skilled artisan’	/mɨ̀l-ù/	mù̱l-ù[9]
	sɨ́b-l-ál	‘lie’	/sɨ́b-ùr/	sú̱b-ùr
	sɨ̀m-à	‘fishing net’	/sɨ̀m-ú/	sù̱m-ú

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[8] A trace of the doubly triggered rounding harmony can however be found in the verb *wóóró* ‘to boil (intr.)’, historically derived from *wáá* ‘to boil (tr.)’ (/wáá-ó/ → *wɔ́ɔ́-r-ó* → *wóóró*, with regular epenthetic *r*). This is, however, an isolated case, possibly the only remain of an old detransitivising suffix, which would have been on a par with number marking suffixes in triggering the doubly triggered rounding harmony.

[9] The noun *màl* ‘skilled artisan’ has two plural forms, one obtained through a → ɨ umlaut, the other through suffixation of *-u* to the latter.

(12)	a.	*Singular*		*Plural suffix* -o, -or[10]	
		bàg-à	‘antelope sp.’	/bə̀g-r-ó/	bò̲g-r-ó
		báág	‘ostrich’	/bə́ə́g-ó/	bó̲ó̲g-ó
		ɓàg-ál	‘head’	/ɓə̀g-ór/	ɓò̲g-ór
		bǎl	‘fish sp.’	/bə̀l-ó/	bò̲l-ó
		málɨ̀m	‘Koranic teacher’	/mâlm-ó/	mô̲lm-ó
		màm-ál	‘grand-child’	/mə̀m-ór/	mò̲m-ór
		mààm-ál wīī	‘fish sp.’	/mə̀ə̀m-ór wījā/	mò̲ò̲m-ór wīyā
		mə́g-əl	‘mouse’	/mə́g-ór/	mó̲g-ór (alt. *muágrá*, cf. footnote 4)
		ɲàm ʄàm	‘antelope sp.’	/ɲə̀m ʄə̀m-ó/	ɲə̀m ʄò̲m-ó
		pàb	‘cobra’	/pə̀b-ó/	pò̲b-ó
		sààb	‘fabric, garment’	/sə̀ə̀b-ó/	sò̲ò̲b-ó
		sám	‘boa’	/sə́m-ò/	só̲m-ò
		sāām	‘skin’	/sə́ə́m-ó/	só̲ó̲m-ó
		tàb	‘fish sp.’	/tə̀b-ó/	tò̲b-ó
		wàár	‘genet’	/wə̀ə̀r-ó/	wò̲ò̲r-ó
	b.	*Plural*		*Singular suffix* -o	
		ndààm-à	‘Ndam people’	/ndə̀ə̀m-ó/	ndò̲ò̲m-ó

A few nouns have more than one possible plural form. Interestingly, three such nouns, shown in (13) below, make use of two alternate round suffixes. As expected, rounding harmony applies only in (13a), where both vowels are of equal height before application of the harmony, but not in (13b), where αHeight is violated.

(13)		*Singular*		*Plural suffix* -u			*Plural suffix*-o	
	a.	báág	‘ostrich’	/bə́ə́g-ú/	→ bə́ə́gú	∼	/bə́ə́g-ó/	→ bó̲ó̲gó
		tàb	‘fish sp.’	/tə̀b-ú/	→ tə̀bú	∼	/tə̀b-ó/	→ tò̲bó
	b.	sàg	‘tree sp.’	/sə́g-ú/	→ sə́gú	∼	/sə́g-ó/	→ sə́gó

The limited productivity of the doubly triggered rounding harmony is due to the limited productivity of the number-marking suffixes, which seem to be in the process of becoming lexicalised. In this respect, it is not different from other morpho-phonological alternations that phonologists regularly choose to model. However, number marking morphology cannot be said to be entirely fossilised, since plural suffixes (including the round suffixes *-o* and *-u*) are sometimes used on more or less recent loanwords, as shown in (14) below. Note that the first two examples illustrate the application of the doubly triggered rounding harmony to words of foreign origin (14a-b). Loanwords from Bagirmi and Arabic are most probably not older than 200 to 300 years, and loanwords from French (14e) are definitely less than a century old.

(14)		*Singular*	*Plural*			
	a.	málɨ̀m	/mə̂lm-ó/	mô̲lm-ó	‘Koranic school teacher’	< Arabic
	b.	dīlām	/dɨ̀lm-ú/	dù̲lm-ú	‘(type of) house’	< Bagirmi
	c.	mòɲ	/muāɲ-ā/	muāɲ-ā	‘disease’	< Bagirmi
	d.	gâw	/gə́w-ó/	gə́wó	‘hunter’	< Bagirmi
	e.	ság	/sə́g-ú/	sə́g-ú	‘bag’	< French *sac*

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[10] The plural suffixes *-o* and *-or* trigger both [low] and rounding harmony, i.e. a→ə→o (or a→ua→o).

The doubly-triggered rounding harmony is also a morpheme structure constraint: there is no word in the lexicon that does not conform to its requirements.

Finally, both the harmony and the *U(C)w phonotactic constraint apply only within words, and never across a word boundary, as shown by the examples in (15a) and (15b) respectively.

(15)	a.	mɨ̀l	ɓúúrá	(*not* mù̱l ɓúúrá; cf. (11f)) /mɨ̀l-ú/ → mù̱lú)
		good.artisans	be.fearful	
		‘The good artisans are fearful.’		
	b.	mòòmór wīj̄ā	‘fish (sp.)’	(*not* mòòmə̱̀r wīj̄ā; cf. (12g))

2.3 A phonological alternation

There is abundant evidence that the doubly triggered rounding harmony described above is a phonological process, rather than a superficial phonetic effect. Firstly, the harmony is exceptionless and not subject to any variation: it systematically applies whenever the conditions are met. The only exceptions are entirely regular and result from an independent phonotactic restriction of the language (*U(C)w). I have not encountered any sign of intra- or inter-speaker variation over the 12 months of fieldwork I have conducted on Laal over a period of five years, neither in my daily interactions with many speakers in Gori, nor with the five main consultants I have worked with. Furthermore, it is not sensitive to speech rate: when asked to speak slowly, or even to mark a pause between the two syllables of a word where the harmony should apply, speakers never “undo” the harmony.

The most solid argument in favor of the phonological status of the doubly triggered rounding harmony is the fact that it is morphologically conditioned. We saw earlier that the doubly triggered harmony applies as a morpheme structure constraint and between roots and number marking suffixes. With pronominal suffixes (object pronoun suffixes on verbs and inalienable possessive suffixes on nouns), on the other hand, anticipatory rounding harmony is systematic and unconditional, as illustrated in (16a) below, with the object suffixes *-nǔ* ‘us (excl.)’ and *-ò(n)* ‘her’ (raised to *-ù(n)* when V1 is a high vowel, as per regular [+high] harmony, cf. (5) above).[11] (16b) shows segmentally similar examples in the environment where the doubly triggered harmony applies. As can be seen, the conditions for the doubly triggered rounding harmony (LabC, αHeight and βFront) are irrelevant to the simple rounding harmony, which applies systematically.

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[11] The third person feminine singular object suffix has two allomorphs: *-ò* and *-òn*, each with a high vowel allophone (*-ù*, *-ùn*) when subject to high harmony. The distribution of these two allomorphs is arbitrarily determined on a verb by verb basis.

(16) The two harmonies compared (✔ = condition met; * = condition not met)

				LabC	α**Height**	β**Front**
a. Simple rounding harmony						
pɨ́r + -ò	/pɨ́r-ù/	pú̲r-ù	‘catch her’	✔	✔	✔
kɨ́r + -òn	/kɨ́r-ùn/	kú̲r-ùn	‘place her’	*	✔	✔
dāg + -òn	/dəg-òn/	dò̲g-òn	‘drag her’	*	✔	✔
dāg + -nǔ	/dəg-nǔ/	dò̲g-nǔ	‘drag us (ex.)’	*	*	✔
léér + -nǔ	/léér-nǔ/	ly̲ó̲ó̲r-nǔ	‘wrap us’	*	*	*
b. Doubly triggered rounding harmony (cf. (7)-(8))						
ɓɨ̀r- + -ù	/ɓɨ̀r-ú/	ɓù̲r-ú	‘fish hook-pl.’	✔	✔	✔
gɨ́n- + -ù	/gɨ́n-ù/	gɨ́n-ù	‘net-pl	*	✔	✔
sàg + -ó	/səg-ó/	səg-ó	‘bag-pl’	*	✔	✔
dán + -ú	/də́n-ú/	də́n-ú	‘tree sp.-pl’	*	*	✔
tiààrr + -ú	/tèèr-ú/	tèèr-ú	‘grass sp.-pl’	*	*	*

Simple rounding harmony also fails to apply in contexts where it would violate the general ban on U(C)w sequences, as seen in (17) below.

(17) a. /káw-ò/ kə́w-ò (*kówò) ‘be insufficient for her’
b. /káw-nǔ/ kə́w-nǔ (*kównǔ) ‘be insufficient for us (excl.)’

The two rounding harmonies of the language are thus specific to two exclusive sets of morphological environments. Given the requirement that words be maximally disyllabic in Laal, the segmental and prosodic domains of application of both rounding harmonies in disyllabic words is exactly the same. For all of the above reasons we can safely conclude that the doubly triggered rounding harmony is a phonological process, and whatever drives it should consequently be accounted for in phonology.

As mentioned in chapter 1, what makes multiple-trigger assimilatory processes such as the doubly triggered rounding harmony of Laal particularly interesting is their relevance in the debate between substance-free and phonetically grounded approaches to phonology. More precisely whether they constitute an argument in favor of phonetic grounding or not depends on whether they involve partial assimilatory effects or not. To test this, I conducted an acoustic analysis, which I present in the next section. This analysis shows that the doubly triggered rounding harmony involves partial assimilatory effects, an thus constitutes empirical support for a phonetically grounded approach.

2.4 The phonetic underpinnings of the Laal doubly triggered rounding harmony

While the doubly triggered rounding harmony described above is, as far as I know, unique, its phonetic basis is unsurprising: labiality, rounding, height, and backness are all factors that are known to contribute to the rounding of a vowel (Terbeek 1977; Linker 1982; Kaun 1995, 2004). In this section, I present instrumental evidence showing that a labial consonant greatly affects the non-low central vowels [ɨ, ə], by significantly lowering their F_2. This supports the analysis of labialized [$ɨ^b$, $ə^b$] as a separate category in Laal.

To test this, acoustic measurements were extracted from recordings made in Gori (one of the two Laal-speaking villages), Chad, in March 2014 and January 2015. Two native Laal speakers, both male, were recorded: KD, in his mid-fifties, and his 27-year old son AK. Both are also fluent in Lua (Adamawa), Ba (Adamawa), and Chadian Arabic. KD also speaks intermediate French, while AK's command of that language is limited. The recorded sessions consisted mainly in wordlists, elicited in French.

The recordings were made using a Zoom H4n recorder set at a sample rate of 44.1 kHz and 16-bit sample size, and a mono Røde NTG2 condenser shotgun microphone. Vowel formants were extracted in Praat (Boersma and Weenink 2014): the first three formants of the stem-initial vowel were automatically extracted from 546 tokens at the midpoint of the total vowel interval (defined manually), i.e. as far as possible from formant transitions. To better describe auditory frequency resolution, formant frequency values in Hertz were converted into ERB (Equivalent Rectangular Bandwidth), using Moore and Glasberg's (1983) equation. Both Hz and ERB values are provided, but the statistics and vowel plots are all based on the latter.

Since the recording sessions could only take place in a relatively noisy environment, some recordings had to be excluded from the sample due to excessive background noise. This explains why the number of tokens per word considered for each speaker is not always identical, and the words used for both speakers are not always the same. The number of words and tokens are however sufficiently overlapping to make the data presented here representative.

The abbreviations and codes used in the charts and plots are explained in (18) and (19) below. Ellipses on vowel plots indicate two standard deviations. Statistical significance is assessed using a Welch two-sample two-sided t-test at the 5% significance level ($p < 0.05$).

(18) Abbreviations and codes:

ɨ-word	Word whose V_1 is /ɨ(ɨ)/
ə-word	Word whose V_1 is /ə(ə)/
C	Non-labial, non-palatal consonant (i.e. velar and dental-alveolar)
B	Labial consonant (except w), i.e. p, b, ɓ, mb, m
U	Round V_2, i.e. u, o
ɨ, ə	[ɨ, ə] not surrounded by a labial C, not followed by a round V_2
$ɨ^{b}$, $ə^{b}$	Labialized [ɨ, ə] , i.e. surrounded by at least one velar consonant

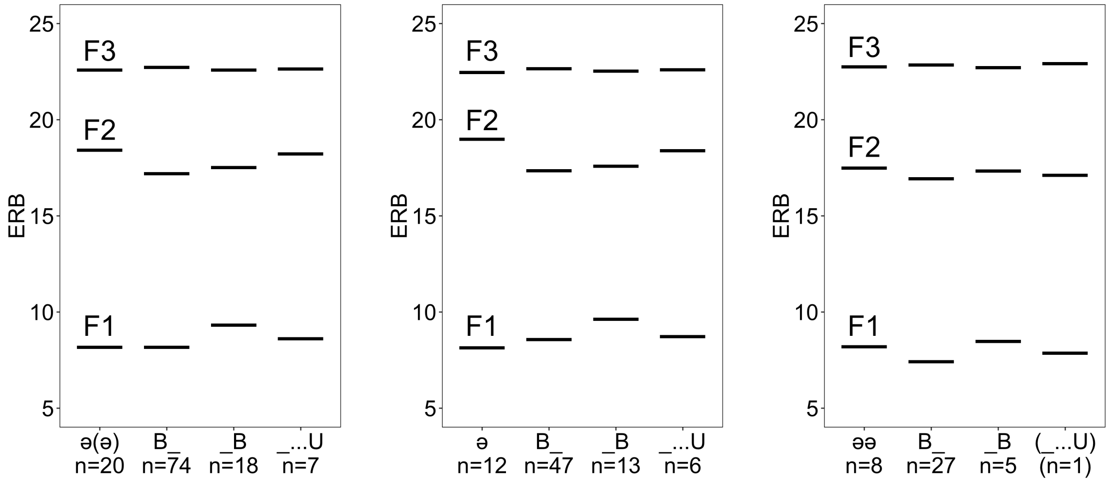
(19) Conditions:

B-condition	V_1 [ɨ, ə] surrounded by at least one labial consonant
U-condition	V_1 [ɨ, ə] followed by a round V_2
W-condition	V_1 [ɨ, ə] preceded or followed by a [w]
Multiple conditions	BU, BW, WU, BWU

Note that words where [ɨ, ə] are adjacent to a palatal consonant (e.g. cɨ, əj etc.) were excluded from the sample because the contrast between front and back vowels is partially neutralized in this environment.

2.4.1 Effects of the B condition

Acoustic measurements clearly show that a labial consonant has a very significant F_2 lowering effect on a (near-)adjacent non-low central vowel [ə] or [ɨ].



(a) [ə(ə)] = [ə] + [əə]

(b) [ə]

(c) [əə]

Figure 2.2: Effect of B and U conditions on [ə(ə)] (AK)

2.4.1.1 Effect of the B condition on [ə]

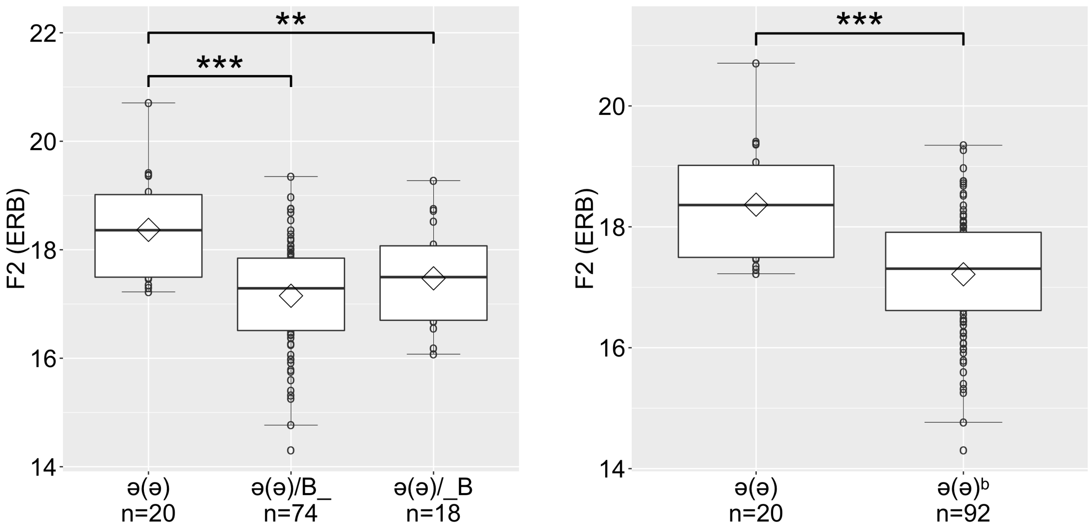
The only speaker for which the data on [ə] are complete (i.e. illustrates all possible conditions) is AK. I will thus first focus on AK's data, and present KD's more limited data in § 2.4.1.1.2.

The [ə]-words included in the sample for AK are summarised in Table 2.15 (the full list can be found in Appendix A). The total number of tokens within each condition includes repetitions, e.g. three separate productions of the word *pə́d* 'pass' and one production of the word *mə̄l* 'be straight' constitute a total of four Bə tokens.

Conditions	#words	#tokens	Example	
ə(ə)	**8**	**20**		
ə	5	12	gə̄rī	'tree sp. (pl)'
əə	3	8	ndə́ə́r	'skulls'
B	**34**	**98**		
Bə	18	47	pə́d	'pass'
Bəə	6	27	pə̄ə̄l	'village'
əB	5	13	kə́m	'fish sp. (pl)'
əəB	2	5	tə́ə́mə̀r	'my cheek'
U	**3**	**7**		
ə-U	2	6	də́nú	'tree sp. (pl)'
əə-U	1	1	ʔə́ə́rú	'sauces'

Table 2.3: ə-words sample, B and U conditions (AK)

Figure 2.2 shows the mean F_1, F_2 and F_3 values of AK's stem-initial [ə(ə)] in each of the B and U conditions. Note that there is only one token of [əə] in the U condition; the values reported for this token on Figure 2.2c are thus not mean values, and they are shown for reference only.



(a) Effect of /B_ and _B conditions

(b) Overall effect of B condition

Figure 2.3: Effect of B condition on F_2 of [ə(ə)] (AK)

As can be seen, the two B conditions appear to have a strong lowering effect on F_2, stronger on short [ə] than on long [əə] vowels. The U condition also seems to lower F_2 somewhat, but to a lesser extent. F_1 and F_3 appear to be unaffected. In the remainder of this section, I will concentrate on the F_2 lowering effect of the B and U conditions.

2.4.1.1.1 Effect of the B condition on [ə(ə)] (AK) Figure 2.3a shows the distribution of the F_2 values of non-labialized [ə(ə)] vs. [ə(ə)]/B_ and [ə(ə)]/_B. In Figure 2.3b, [ə(ə)]/B_ and [ə(ə)]/_B are collapsed into one category [ə(ə)^b]. As can be seen from these figures and from Table 2.4, a neighboring labial consonant has a strong, consistent, and highly statistically significant F_2 lowering effect [ə(ə)]: [ə(ə)]/B_ is on average 1.22 ERB (205 Hz) lower than [ə(ə)] (t(30.3) = 4.9, p = 3.21e^{-5}), while [ə(ə)]/_B is 0.89 ERB (154 Hz) lower (t(35.8) = 2.9, p = 0.007). Overall, labialized [ə(ə)^b] is 1.15 ERB (195 Hz) lower than non-labialized [ə(ə)] (t(27.9) = 4.7, p = 5.79^{-5}).

	F_2 (Hz)	$\Delta_{F_2\text{ (Hz)}}$	F_2 (ERB)	$\Delta_{F_2\text{ (ERB)}}$	t	df	p-value	
ə(ə)	1477		18.37					
∼ ə(ə)/B_	1272	–205	17.15	–1.22	–4.9	30.3	3.21 e^{-5}	***
∼ ə(ə)/_B	1322	–154	17.47	–0.89	2.9	35.8	0.007	**
∼ ə(ə)^b	1282	–195	17.22	–1.15	4.7	27.9	5.79 e^{-5}	***

Table 2.4: Statistical significance of the effect of the B condition on the F_2 of [ə(ə)] (AK)

Interestingly, vowel length also seems to have a lowering effect on F_2. This is visible in Figure 2.2, where the mean F_2 value of [əə] is clearly lower than that of [ə], and about the same as labialized [ə^b]. As shown in Figure 2.4, this difference is important, and clearly significant: [əə] is on average 1.47 ERB (266 Hz) lower in F_2 than [ə] (t(13.7) = 5.7, p = 5.79e^{-5}).

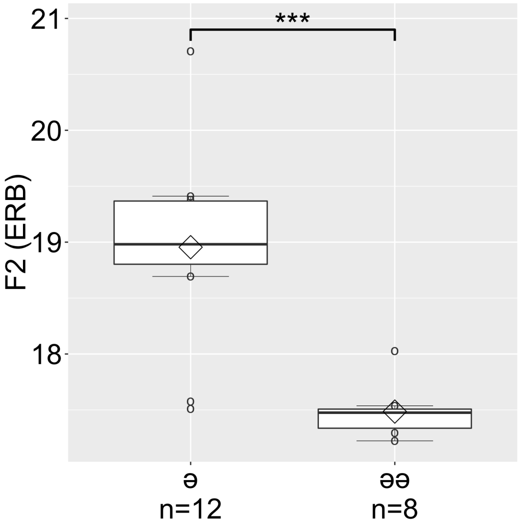


Figure 2.4: F_2 of [ə] vs. [əə] (AK)

At first sight, this fact seems to question the significance of the effect of adjacent labials on [ə(ə)]. However, when teasing short and long vowels apart, one notices the same trend in both sets: while the mean F_2 values of [ə] and [əə] are, for reasons unknown, intrinsically different, both undergo F_2 lowering when (near-)adjacent to a labial consonant. As shown in Figure 2.5 and Table 2.6, [ə]/B_ is on average 1.66 ERB (288 Hz) lower in F_2 than [ə] (t(20) = –5.6, p = 9.96e^{-6}), while [ə]/_B is 1.42 ERB (250 Hz) lower (t(22.8) = 3.9, p = 7.79e^{-4}). In general, [ə^b] is 1.61 ERB (279 Hz) lower in F_2 than [ə] (t(18) = 5.9, p = 1.54e^{-5}).

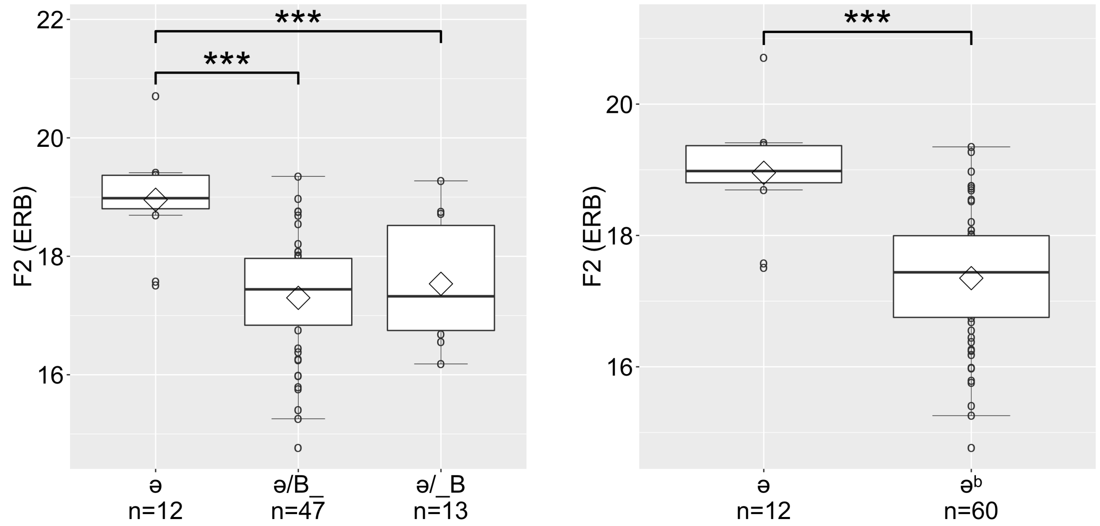
	F_2 (Hz)	$\Delta_{F_2\ (Hz)}$	F_2 (ERB)	$\Delta_{F_2\ (ERB)}$	t	df	p-value	
ə	1583		18.96					
∼ əə	1317	–266	17.49	–1.47	5.7	13.7	5.79e^{-5}	***

Table 2.5: Statistical significance of the F_2 difference between [ə] and [əə] (AK)

	F_2 (Hz)	$\Delta_{F_2\ (Hz)}$	F_2 (ERB)	$\Delta_{F_2\ (ERB)}$	t	df	p-value	
ə	1583		18.96					
∼ ə/B_	1295	288	17.30	1.66	–5.6	20.0	9.96e^{-6}	***
∼ ə/_B	1333	250	17.54	1.42	3.9	22.8	7.79e^{-4}	***
∼ ə^b	1304	279	17.35	1.61	5.9	18.0	1.54e^{-5}	***
əə	1317		17.49					
∼ əə/B_	1231	86	16.90	0,59	–3.0	32.9	0.006	**
∼ əə/_B	1294	23	17.31	0.17	0.4	4.4	0.69	ns
∼ əə^b	1241	76	16.91	0.52	2.8	37.7	0.007	**

Table 2.6: Statistical significance of the effect of the B condition on the F_2 of [ə] and [əə] (AK)

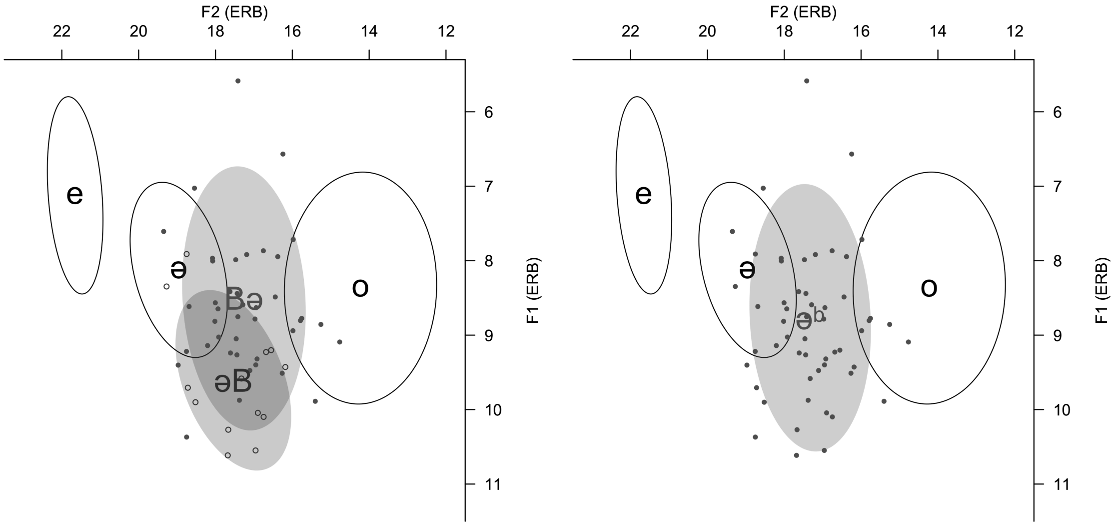
The vowel plot in Figure 2.6, illustrating only short vowels, very clearly shows that the distribution of [Bə] and [əB] mostly overlap, and that they are distinct from both [ə] and [o]: both Bə



(a) Effect of /B_ and _B conditions

(b) Overall effect of B condition

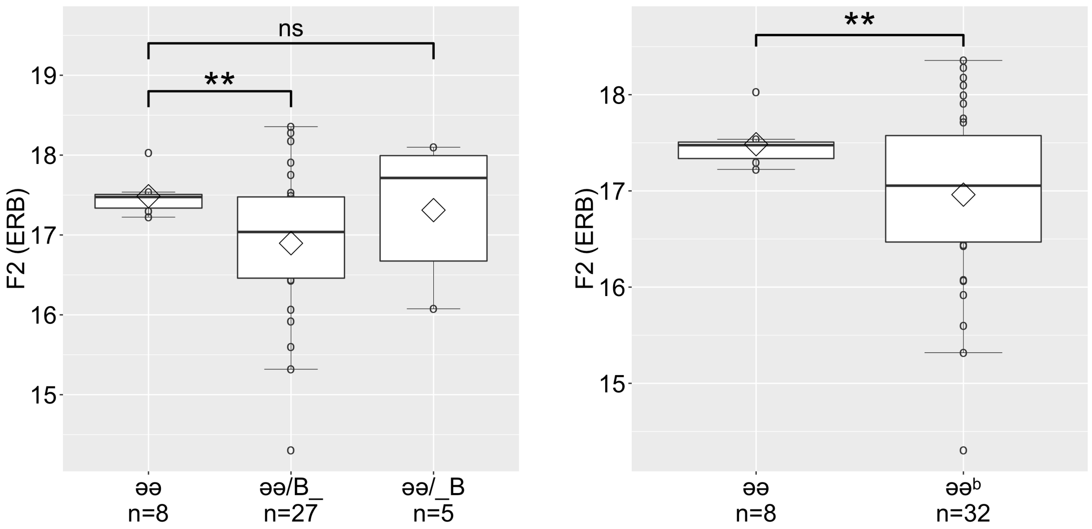
Figure 2.5: Effect of B condition on F_2 of [ə] (AK)



(a) [ə]/B_ and [ə]/_B

(b) [ə^{b}] = [ə]/B_ + [ə]/_B

Figure 2.6: [ə]/B_, [ə]/_B, and [ə^{b}] plotted against [e], [ə], and [o] (AK)



(a) Effect of /B_ and _B conditions

(b) Overall effect of B condition

Figure 2.7: Effect of B condition on F_2 of [əə] (AK)

+ əB (= $ə^b$) are exactly between [ə] and [o] in terms of F_2.

As seen in Figure 2.7 and Table 2.6, the overall difference between [əə] and [$əə^b$] is also significant, although it is noticeably less strong: [$əə^b$] is only 0.52 ERB (76 Hz) lower in F_2 than [əə] on average (t(37.7) = 2.8, p = 0.007). However, taken separately, [əə]/B_ and [əə]/_B do not display the same effect: while a preceding labial consonant does have a significant F_2 lowering effect on [əə] (Δ_{F_2} = –0.59 ERB (–86 Hz), t(32.9) = 3.0, p = 0.006), a following labial consonant does not seem to incur the same effect (Δ_{F_2} = –0.17 ERB (–23 Hz), t(4.4) = 0.4), p = 0.69). This might be due to the small size of the sample: only two words (five tokens total) illustrate the [əə]/_B condition for AK.

2.4.1.1.2 Effect of the B condition on [ə] (KD) The ə-words recorded from KD are listed in Appendix B. A summary of the relevant words and conditions for this section is given in Table 2.7 below. As can be seen, KD's data illustrate less conditions than AK's, in particular no usable token of [əə] and [əəB] could be included in the corpus. As a consequence, the effect of vowel length cannot be tested, and I will focus exclusively on short [ə] here.

The chart in Figure 2.8 shows the mean values of the first three formants of KD's [ə] in the B and U conditions. As in AK's speech, F_2 is clearly lowered in the two B conditions, less so in the U condition, and F_1 does not seem to vary much.

As shown in Figure 2.9 and Table 2.8, as wellas on the vowel plot in Figure 2.10, the overall F_2 lowering effect of a neighboring labial consonant on [ə] in KD's speech is comparable to what we saw for AK: [$ə^b$] is on average 1.43 ERB (256 Hz) lower in F_2 than [ə] (t(21.5) = 3.4, p = 0.003), the effect of a preceding B being stronger (Δ_{F_2} = –1.76 ERB (–311 Hz), t(24.5) = –3.7, p = 0.001) than that of a following B (Δ_{F_2} = –0.95 ERB (–181 Hz), t(19.9) = 2.1, p = 0.049).

Conditions	#words	#tokens	Example	
ə(ə)	**4**	**10**		
ə	4	10	gə̄rī	'tree sp. (pl)'
əə	0	0	ndə́ə́r	'skulls'
B	**14**	**42**		
Bə	4	14	pə́d	'pass'
Bəə	6	17	pə̄ə̄l	'village'
əB	3	10	kə́m	'fish sp. (pl)'
əəB	0	0	tə́ə́mə̀r	'my cheek'
U	**3**	**13**		
ə-U	2	8	də́nú	'tree sp. (pl)'
əə-U	1	4	ʔə́ə́rú	'sauces'

Table 2.7: ə-words sample, B and U conditions (KD)

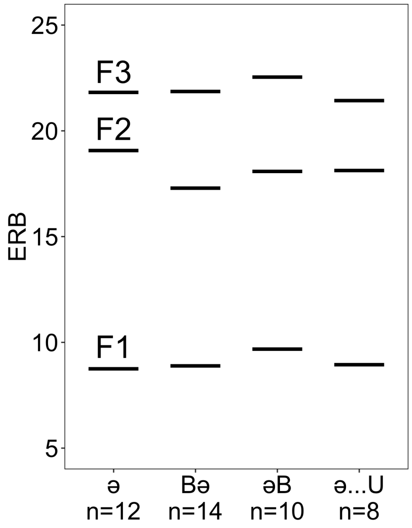
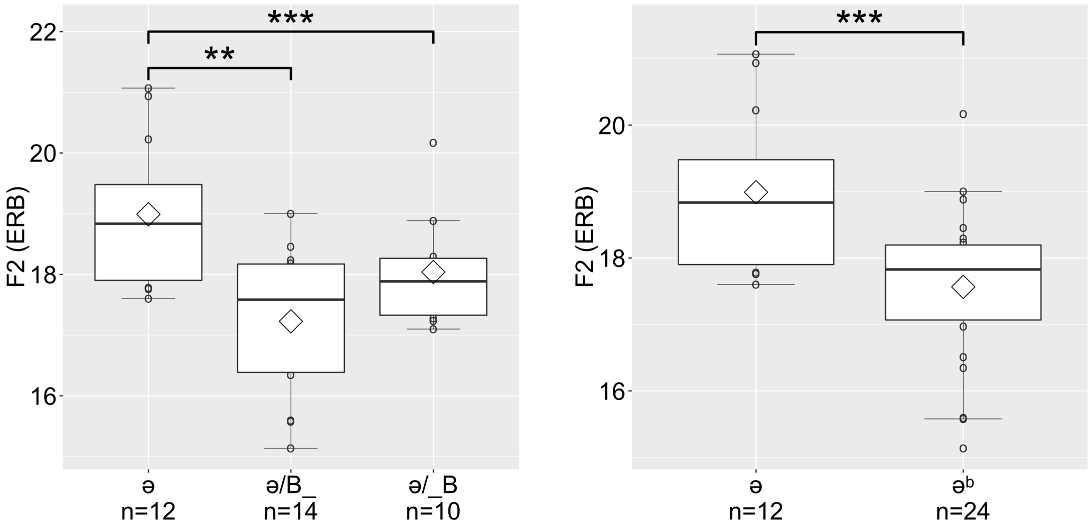


Figure 2.8: Effect of B and U conditions on [ə] (KD)

	F_2 (Hz)	$\Delta_{F_2\ \text{(Hz)}}$	F_2 (ERB)	$\Delta_{F_2\ \text{(ERB)}}$	t	df	p-value	
ə	1598		18.99					
$\sim$ ə/B_	1287	–311	17.23	–1.76	–3.7	24.5	0.001	**
$\sim$ ə/_B	1417	–181	18.04	–0.95	2.1	19.9	0.049	*
$\sim$ ə^{b}	1342	–256	17.57	–1.43	3.4	21.5	0.003	**

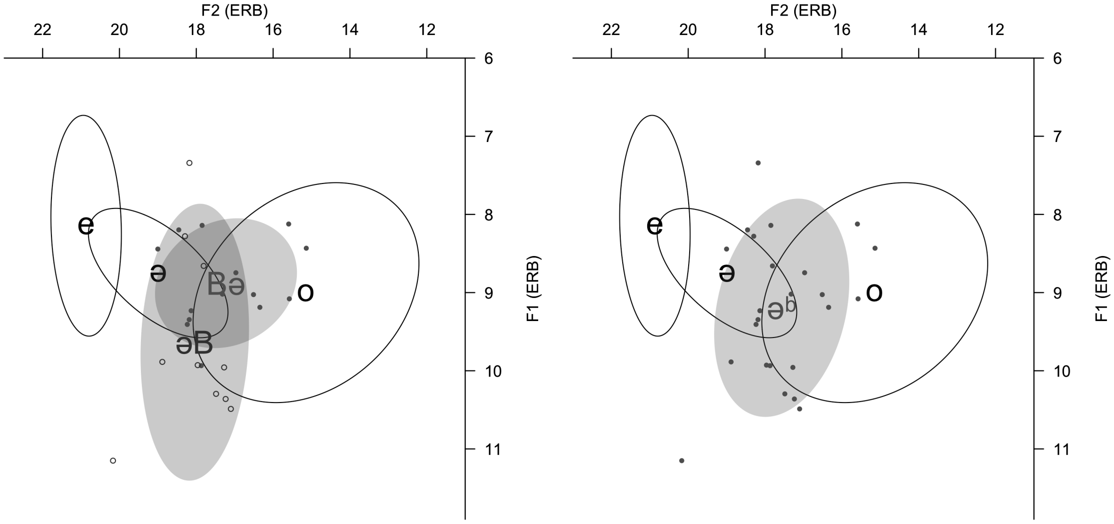
Table 2.8: Statistical significance of the effect of the B condition on the F_2 of [ə] (KD)



(a) Effect of /B_ and _B conditions

(b) Overall effect of B condition

Figure 2.10: Effect of B condition on F_2 of [ə] (KD)



(a) [ə]/B_ and [ə]/_B

(b) [əᵇ] = [ə]/B_ + [ə]/_B

Figure 2.10: [ə]/B_, [ə]/_B, and [əᵇ] plotted against [e], [ə], and [o] (KD)

2.4.1.2 Effect of the B condition on [ɨ]

The coarticulatory effects on [ɨ] are congruent with, and stronger than the effects on [ə], for both speakers, and across the two conditions B and U. The list of ɨ-words included in the sample are listed in Appendices C and D, and summarized in Table 2.9 below.[12]

Conditions	AK		KD		Example	
	#w	#t	#w	#t		
ɨ(ɨ)	**24**	**41**	**9**	**23**	dɨ̄gā	‘be bad’
B	**38**	**99**	**40**	**73**		
Bɨ	17	46	29	53	ɓɨ̀rà	‘fish hook’
Bɨɨ	3	3	2	4	mɨ̀ɨ̀r	‘curse (pl)’
ɨB	17	49	6	12	lɨ̀bár	‘immerse’
ɨCB	0	0	1	1	lɨ̀gmà	‘horses’
U	**1**	**1**	**0**	**0**	gɨ́nù	‘nets’

Table 2.9: ə-words sample, B and U conditions (AK)

A few notes on this sample are in order before we move on to the acoustic measurements and discussion. First, the non-labialized ɨ condition illustrates only short [ɨ]. The reason for this is that none of the recordings of the only four ɨɨ-words in the language whose V_1 is not surrounded by any labial or palatal consonant could be used, due to excessive background noise. Additionally, two of the above conditions (U in *gɨ́nù* ‘nets’, and ɨCB in *lɨ̀gmà* ‘horses’) are attested in only one word each. Each one was recorded only once, from one speaker only (*gɨ́nù*: AK; *lɨ̀gmà*: KD). I will come back to these two words at the end of this section.

Figure 2.11 presents the mean F_1, F_2 and F_3 values of stem-initial [ɨ] in both B_ and _B conditions environments, for both speakers. This chart invites the same observation as Figure 2.2b and Figure 2.8 for short [ə]: only F_2 seems to be affected by a preceding or following labial consonant, and it is strongly affected, for both speakers.

As shown in Figure 2.12 and Figure 2.14, the F_2 lowering effect of the B condition on [ɨ] are drastic and very highly significant for both speakers. In AK’s speech, F_2 is on average 2.25 ERB (407 Hz) lower in [ɨ]/B_ than [ɨ] ($t(79.7) = –14.6$, $p = 2.20e^{-16}$), 2.20 ERB (396 Hz) lower in [ɨ]/_B ($t(87.7) = 12.5$, $p = 2.20e^{-16}$), and overall 2.22 ERB (402 Hz) lower for labialized [$ɨ^b$] than for [ɨ] ($t(75) = 15.4$, $p = 2.20e^{-16}$). For KD, the findings are extremely similar: 1.96 ERB (343 Hz) lower in [ɨ]/B_ ($t(59.9) = –8.6$, $p = 5.40e^{-12}$), 1.42 (257 Hz) lower in [ɨ]/_B ($t(18.1) = 4.1$, $p = 6.67e^{-4}$), and 1.87 ERB (328 Hz) lower overall ($t(56) = 8.5$, $p = 1.10e^{-11}$).

The vowel plots in Figures 2.13 and 2.15 show that the distribution of labialized [$ɨ^b$] with respect to [ɨ] and [u] is similar to that of [$ə^b$] with respect to [ə] and [o]: [ɨ] and [$ɨ^b$] have virtually non-overlapping distributions, and [$ɨ^b$] seems to be exactly between [ɨ] and [u], for both speakers.

As mentioned earlier, only one token illustrating the ɨCB condition could be included in the sample: the plural noun *lɨ̀gmà* ‘horses’ (KD). With only one token, it is impossible to draw any generalization. However, it is noteworthy that the mean F_2 of [ɨ] in *lɨ̀gmà* 18.02 ERB (1407 Hz) is

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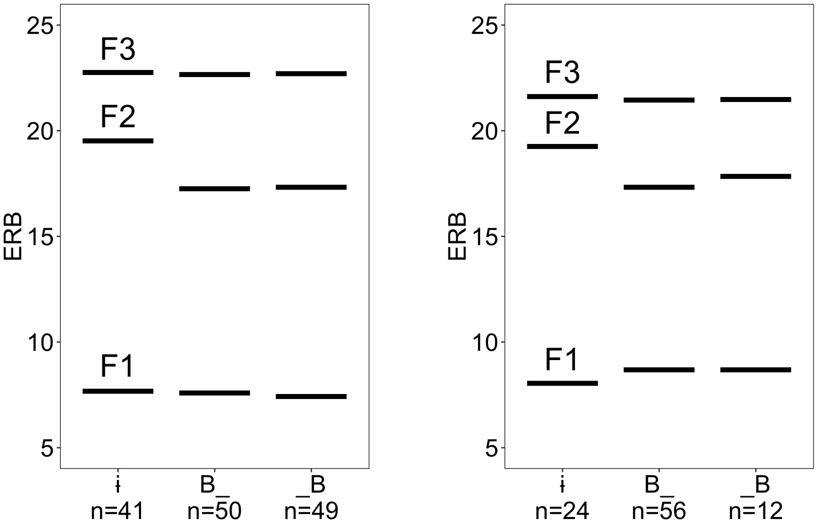
[12] There are 220 ɨ-words in the lexicon, including 199 in which V_1 /ɨ/ is neither preceded nor followed by a palatal consonant.



(a) AK (b) KD

Figure 2.11: Effect of B conditions on [ɨ]

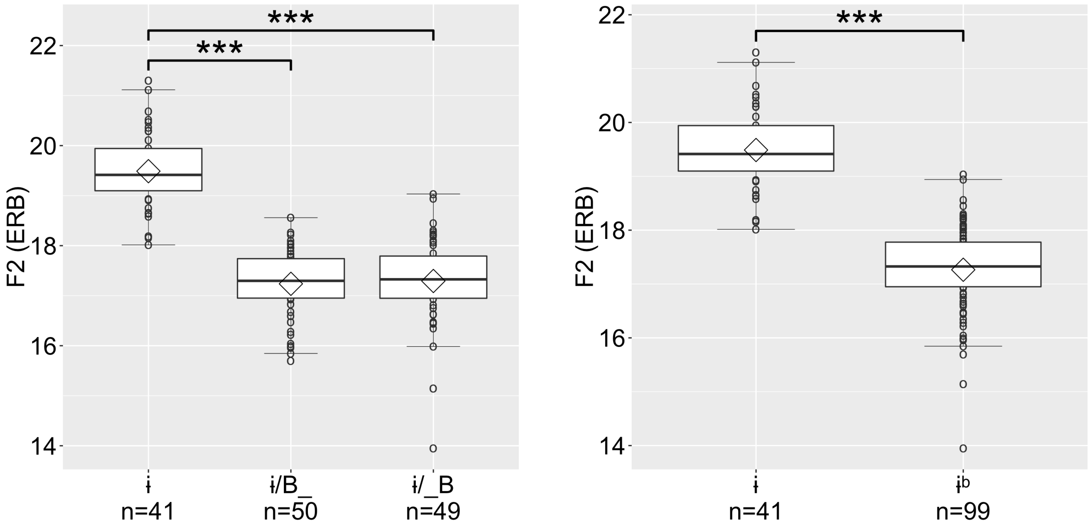
Speaker	Condition	F_2 (Hz)	$\Delta_{F_2\,(Hz)}$	F_2 (ERB)	$\Delta_{F_2\,(ERB)}$	t	df	p-value	
AK	ɨ	1688		19.49					
	$\sim$ ɨ/B_	1281	–407	17.24	–2.25	–14.6	79.7	$2.20e^{-16}$	***
	$\sim$ ɨ/_B	1292	–396	17.29	–2.20	12.5	87.7	$2.20e^{-16}$	***
	$\sim$ ɨ^{b}	1287	–402	17.27	–2.22	15.4	75.0	$2.20e^{-16}$	***
KD	ɨ	1635		19.22					
	$\sim$ ɨ/B_	1291	–343	17.25	–1.96	–8.6	59.9	$5.40e^{-12}$	***
	$\sim$ ɨ/_B	1378	–257	17.80	–1.42	4.1	18.1	$6.67e^{-4}$	***
	$\sim$ ɨ^{b}	1306	–328	17.35	–1.87	8.5	56.0	$1.10e^{-11}$	***

Table 2.10: Statistical significance of the effect of the B condition on the F_2 of [ɨ]

	F_2 (Hz)	$\Delta_{F_2\,(Hz)}$	F_2 (ERB)	$\Delta_{F_2\,(ERB)}$
[ɨ]	1635		19.22	
$\sim$ [ɨ]/_B	1378	–257	17.80	–1.42
$\sim$ l[ɨ̀]gmà	1407	–228	18.02	–1.20

Table 2.11: F_2 values of [ɨ] in *lɨ̀gmà* compared to [ɨ] and [ɨ]/_B (KD)

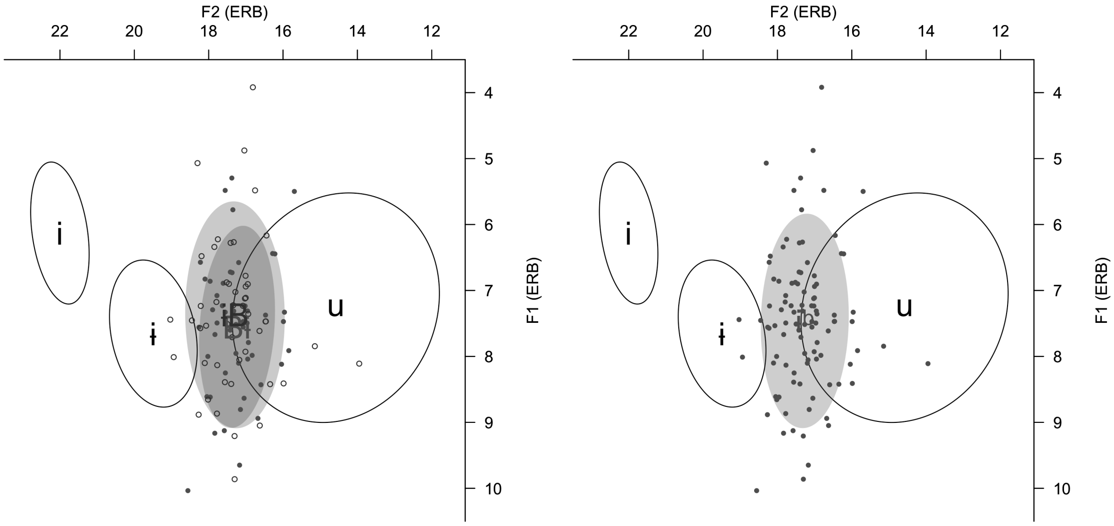
much closer to that of KD's [ɨ]/_B (17.80 ERB / 1378 Hz) than to that of non-labialized [ɨ] (19.22 ERB / 1635 Hz), and the mean F_2 difference between the [ɨ] in *lɨ̀gmà* and KD's non-labialized [ɨ] ($\Delta_{F_2} = 1.20$ ERB (227 Hz)) is very close to that between KD's [ɨ] and [ɨ]/_B ($\Delta_{F_2} = –1.42$ (–257 Hz)), as shown in Table 2.11. This suggests that the intervening non-labial consonant does not prevent labialization of the preceding [ɨ].



(a) Effect of /B_ and _B conditions

(b) Overall effect of B condition

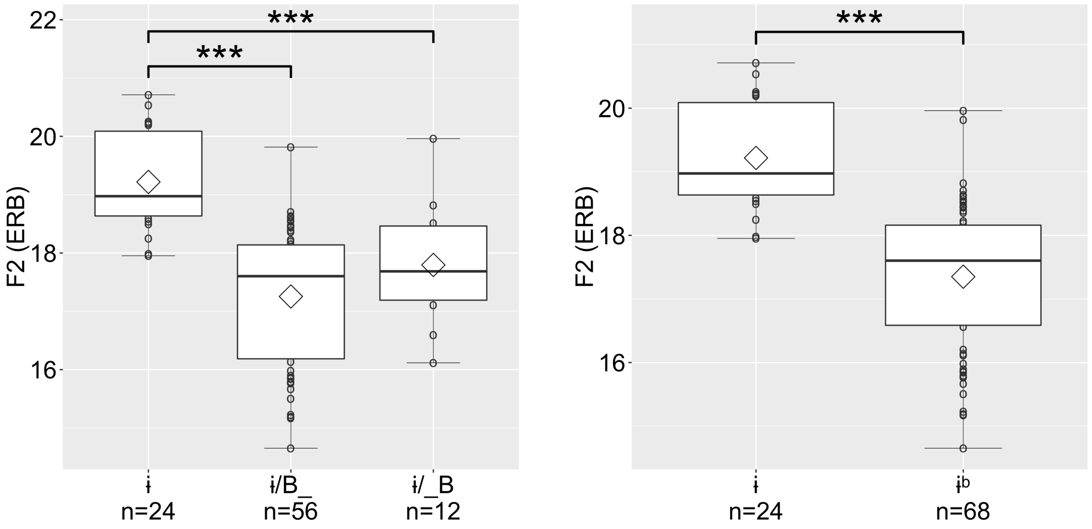
Figure 2.12: Effect of B conditions on [ɨ] (AK)



(a) [ɨ]/B_ and [ɨ]/_B

(b) [ɨ^b] = [ɨ]/B_ + [ɨ]/_B

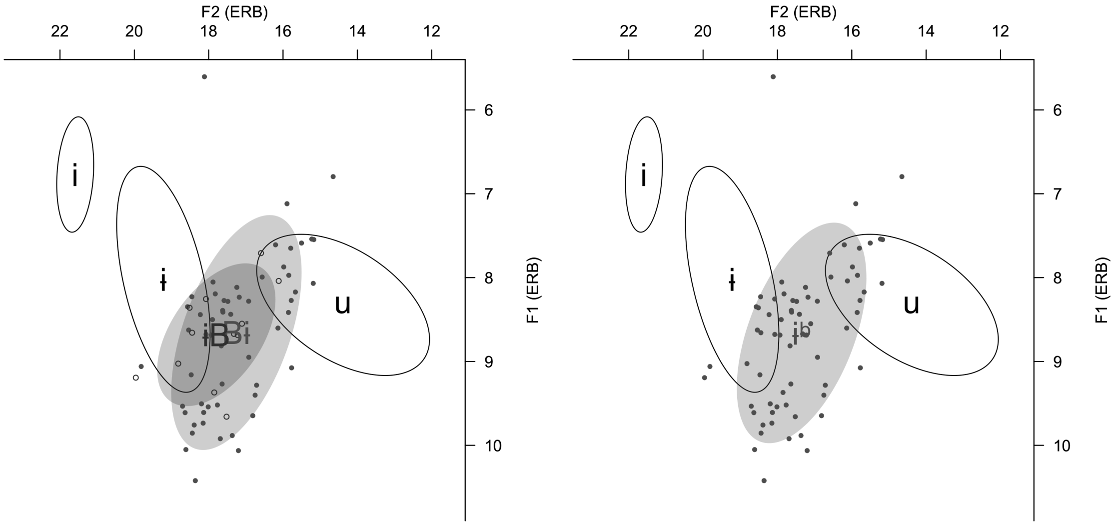
Figure 2.13: ɨ]/B_ [ɨ]/_B, and [ɨ^b] plotted against [i], [ɨ], and [u] (AK)



(a) Effect of /B_ and _B conditions

(b) Overall effect of B condition

Figure 2.14: Effect of B conditions on [ɨ] (KD)



(a) [ɨ]/B_ and [ɨ]/_B

(b) [ɨ^{b}] = [ɨ]/B_ + [ɨ]/_B

Figure 2.15: ɨ]/B_ [ɨ]/_B, and [ɨ^{b}] plotted against [i], [ɨ], and [u] (KD)

Speaker	Condition	F_2 (Hz)	$\Delta_{F_2\ (Hz)}$	F_2 (ERB)	$\Delta_{F_2\ (ERB)}$	t	df	p-value	
AK	ə	1583		18.96					
	∼ ə/_...U	1473	–110	18.38	–0.57	1.7	13.7	0.12	ns
KD	ə	1598		18.99					
	∼ ə/_...U	1426	–172	18.10	–0.89	2.0	18	0.059	ns

Table 2.12: Statistical significance of the effect of the U condition on the F_2 of [ə]

	F_2 (Hz)	$\Delta_{F_2\ (Hz)}$	F_2 (ERB)	$\Delta_{F_2\ (ERB)}$
[ɨ]	1688		19.49	
∼ g[ɨ́]nù	1696	+8	19.56	+0.07

Table 2.13: F_2 values of the [ɨ] in *gɨ́nù* (AK)

2.4.2 Effect of the U condition

2.4.2.1 Effect of the U condition on [ə]

As previously noted, the charts in Figure 2.2 and Figure 2.8 show a lowering of the mean F_2 [ə(ə)] in the presence of a following round vowel for both speakers, although this lowering effect is less strong than that caused by either of the two B environments. [ə]/_U is on average 0.57 ERB (110 Hz) lower than [ə] for AK, (Figure 2.16a), 0.89 ERB (172 Hz) lower for KD (Figure 2.16b). However, this difference is not statistically significant, as shown in Table 2.12 (t(13.7) = 1.7, p = 0.12 for AK; t(18) = 2.0, p = 0.059).

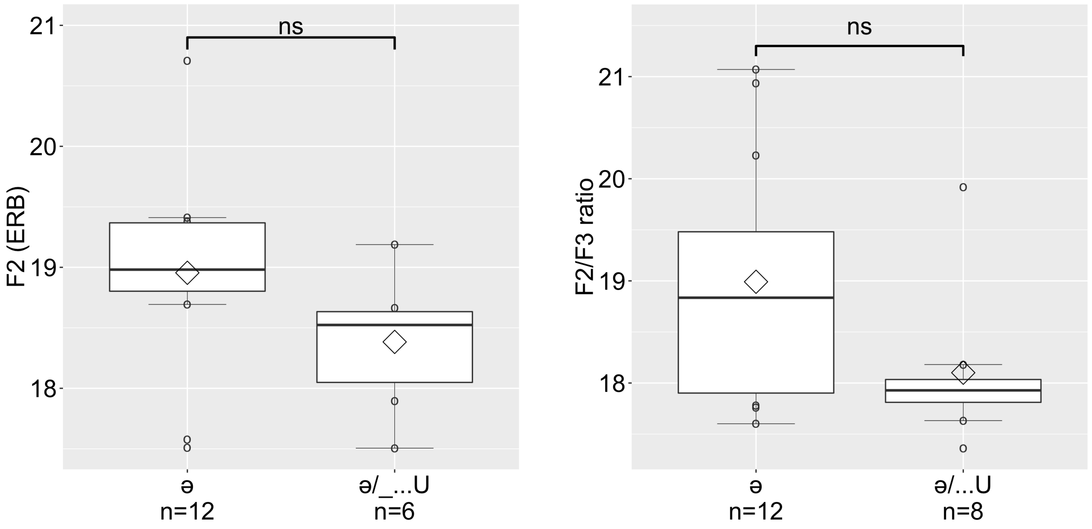
This can be seen on the vowel plot in Figure 2.17 (short vowels only), where the centre of the ə-U ellipse is noticeably further right than that of the E (= [ə]) cloud —indicating a substantial mean F_2 difference— but the F_2 range of ə-U is nearly entirely contained within that of the ə ellipse, contrary to that of $ə^b$ (= Bə + əB) ellipse, which is clearly occupies an intermediate range between [ə] and [o].

2.4.2.2 Effect of the U condition on [ɨ]

The effect of a following round vowel on [ɨ] cannot be tested convincingly, since only one word illustrating this condition is attested in the language: *gɨ́nù* 'nets', of which only one token, produced by AK, could be included in the sample. It is however interesting to note that the F_2 value of the [ɨ] in *gɨ́nù* (1696 Hz / 19.56 ERB) does not show any sign of lowering. As shown in Table 2.13, it is actually 0.07 ERB (8 Hz) higher than the mean F_2 of AK's non-labialized [ɨ] (19.49 ERB / 1688 Hz). This clearly contrasts with the extent of the effect of the B condition on [ɨ] (average F_2 lowering of 2.22 ERB / 402 Hz for AK, cf. Table 2.10), and suggests that a round V_2 has no more effect on a preceding [ɨ] than it does on a preceding [ə].

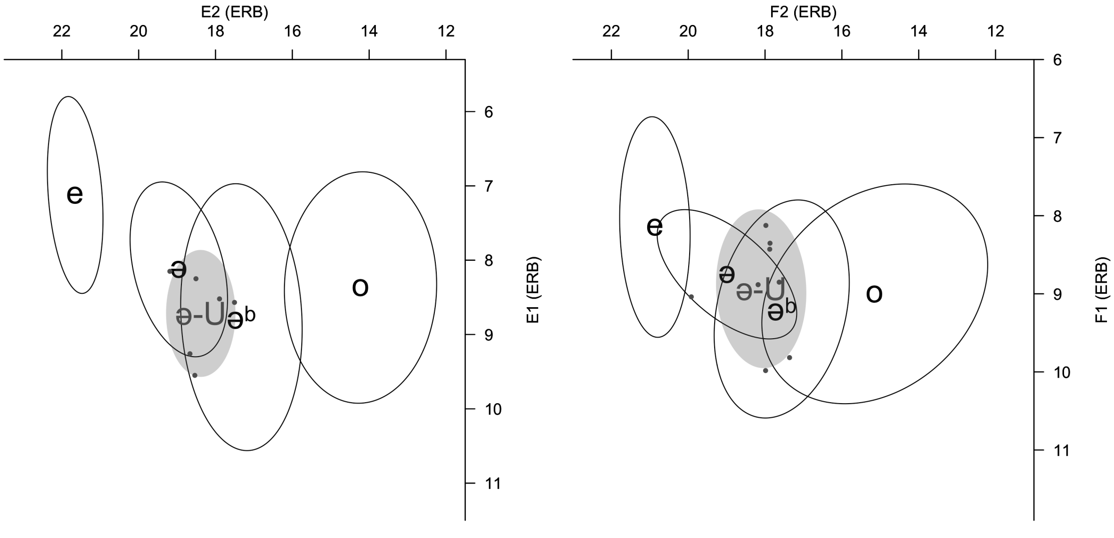
2.4.3 Effect of the W condition

One last condition needs to be addressed: the effect of /w/. It is particularly interesting given the blocking effect this consonant has when intervening between the round V_2 and the target of the rounding harmony (cf. ex. (10)). Since there is only one token of [wə] and none of [wəə] in the sample, I will focus exclusively on [əw] here.



(a) AK (b) KD

Figure 2.16: Effect of U condition on F_2 of [ə]



(a) AK (b) KD

Figure 2.17: [ə]/_...U plotted against [e], [ə], [$ə^b$], and [o]

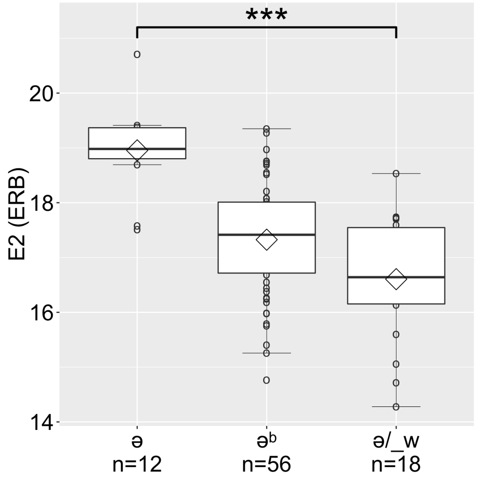


Figure 2.18: Effect of W condition on F_2 of [ə] (AK)

	F_2 (Hz)	$\Delta_{F_2\,(Hz)}$	F_2 (ERB)	$\Delta_{F_2\,(ERB)}$	t	df	p-value	
ə	1583		18.95					
∼ə/_w	1190	–393	16.60	–2.35	6.4	27.7	5.80e^{-7}	***
ə^b	1304		17.35					
∼ə/_w	1190	–114	16.60	–0.75	2.3	26.6	0.027	*

Table 2.14: Statistical significance of the effect of the W condition on the F_2 of [ə] (AK)

It is difficult to clearly discriminate between the vowel and glide portions in /Vw/ sequences. Consequently, the W-environment measurements are likely to be less accurate, and should be taken with caution. Despite this caveat, however, the results, shown in Figure 2.21, are congruent with the results obtained so far, and indicate that /w/ has a very significant F_2-lowering effect, like all other labial consonants, only a little stronger. As shown in Table 2.14, [ə]/_w is 2.35 ERB (393 Hz) lower in F_2 than [ə] (t(27.7) = 6.4, p = 5.80e-7), and 0.75 ERB (110 Hz) lower than [ə^b] (t(26.6) = 2.3, p = 0.027).

2.4.4 Cumulative effects

When more than one condition is met, the effect of each individual condition adds up, as I show in this section with AK's short [ə] only, for which the data is the most complete. This reveals an important property of the doubly triggered rounding harmony, which is sensitive to the coarticulatory effect of a labial consonant on non-low central vowels, but not to the amount of labial coarticulation exerted on these vowels.

Figure 2.19 presents a general summary of the effects of the three conditions B, U and W, and their various attested combinations on the second formant of AK's short [ə].

As can be seen in Figure 2.20a and Table 2.16, the cumulative F_2 lowering effect of two labial consonants (B_B) on [ə], such as in *màmlə̀l* 'my grand-child', is significantly greater than that of a single labial consonant. Indeed, [ə]/B_B is 2.51 ERB (425 Hz) lower in F_2 than [ə] (t(10) = 8.4, p = 7.72e-6), and 0.91 ERB (146 Hz) lower than that of short [ə^b] (t(.7) = –4.1, p = 0.011).

Conditions	#words	#tokens	Example	
BB	**2**	**5**		
BəB	1	3	mə̀mlə̀l	‘my grand-child’
BəəB	1	2	mə̀ə̀mə̀r	‘my grand-mother’
BU	**3**	**9**		
Bə-u	2	3	pə̄nùg	‘her nose’
Bəə-u	3	5	ɓə̀ə̀rú	‘orphans’
əBu	1	1	tə̀bú	‘fish sp. (pl)’
BW	**6**	**12**		
Bəəw	1	3	bə̀ə̀wə̀r	‘my grand-father’
Bəw	5	9	mə̀wrì	‘rams’
WU	**5**	**9**		
əwo	5	9	sə́wò	‘warthogs’
BWU	**2**	**3**		
Bəw-u	1	2	pə̂wrú	‘our friend’
Bəwo	1	1	mɛ́wó	‘scorpions’

Table 2.15: ə-words sample, multiple conditions (AK)

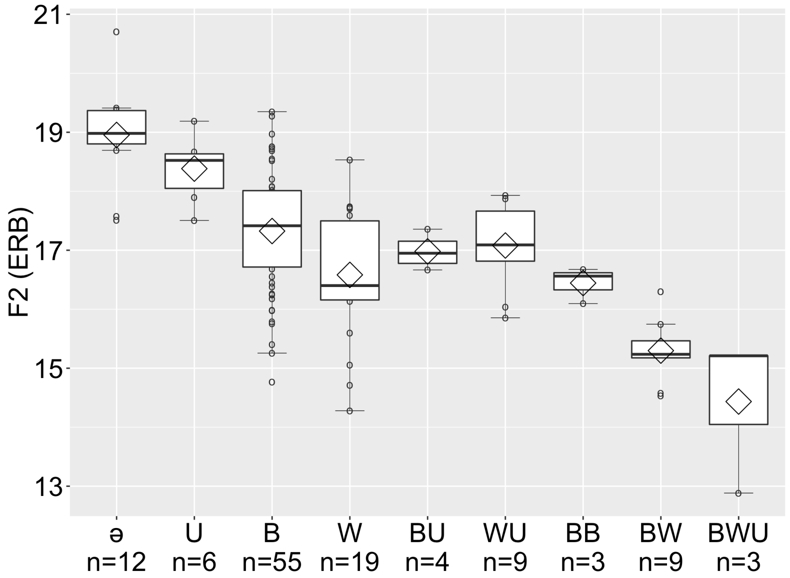


Figure 2.19: Effects of B, U and W conditions and their combinations on F_2 of [ə] (AK)

	F_2 (Hz)	$\Delta_{F_2\ (Hz)}$	F_2 (ERB)	$\Delta_{F_2\ (ERB)}$	t	df	p-value	
ə	1583		18.95					
∼ ə/B_B	1158	–425	16.44	–2.51	8.4	10	$7.72e^{-6}$	***
$ə^b$	1304		17.35					
∼ ə/B_B	1158	–146	16.44	–0.91	–4.1	4.7	0,011	*

Table 2.16: [ə]∼ [ə]/B_B and [$ə^b$]∼ [ə]/B_B, F_2 and F_2/F_3 variation (AK)

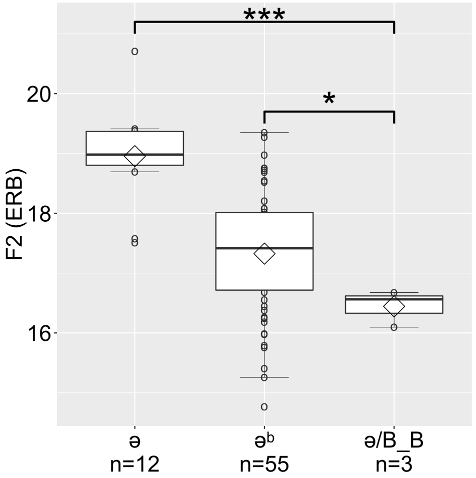


Figure 2.20: Effect of B_B condition on F_2 of [ə] (AK)

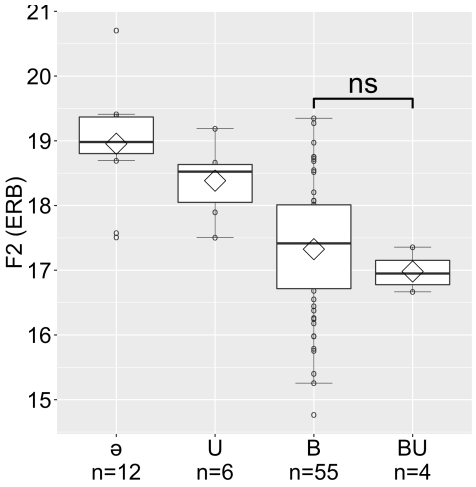


Figure 2.21: Cumulative effect of B and U conditions on F_2 of [ə] (AK)

	F_2 (Hz)	$\Delta_{F_2\ (Hz)}$	F_2 (ERB)	$\Delta_{F_2\ (ERB)}$	t	df	p-value	
$ə^b$	1304		17.35					
∼ ə/B_B...U	1238	–66	16.98	–0.37	1.7	9.9	0,13	ns

Table 2.17: Statistical significance of the effect of BU on [ə] (AK)

The F_2 lowering effects of a labial consonant (B) and a round V_2 (U) on [ə)] do appear to add up, as shown in Figure 2.21. As shown in Table 2.17, however, the mere ERB (66 Hz) difference between [$ə^b$] and [ə]/BU (t(9.9)=1,7, p=0.13) does not reach statistical significance. This is expected, given the lack of significance of the independent effect of the U condition shown in § 2.4.2 above.

As seen on Figure 2.19, the same can be said of cumulative effects involving W, W having, as noted earlier, a slightly greater F_2 lowering effect than B.

2.4.5 Summary and discussion

2.4.5.1 Coarticulatory effect from the labial consonant only

In summary, we have seen that a labial consonant has a very significant F_2-lowering effect on a neighboring non-low central vowel. The average F_2 difference between non-labialized [ɨ, ə] and labialized [$ɨ^{b}$, $ə^{b}$] (irrespective of vowel length) for both speakers is between 195 Hz and 407 Hz. The effect of a following labial consonant was not found to be significant on AK's long [əə], or on KD's short [ə]. However, the limited number of tokens involved as well as the fact the effect was in both cases close to significance suggests that it might prove statistically significant with more data.

We have also seen that the apparent (more limited) lowering effect of a following round vowel is not statistically significant. The number of tokens was also rather low in this case, which prompts the question whether the effect would prove significant with more data. Given that none of the U condition data show any significance, while most of the B conditions do show a (sometimes very highly) significant effect (and the non-significant cases are close to significant), the working hypothesis on which the theory of subfeatural representations and analysis presented in the next chapter are based is that only B has a significant F_2 lowering effect, not U.

The acoustic data presented here thus show that there is a phonetic distinction between non-labialized and labialized non-low central vowels. Although no perception experiment has been carried out yet to verify whether this strong acoustic difference is perceived as different by speakers, F_2 differences of that magnitude are so likely to be perceptible that I feel comfortable hypothesizing that they actually are.

2.4.5.2 The height similarity condition

The height similarity condition between the two vowels could be ascribed to the articulatory and perceptual enhancement relation that exists between rounding and height (cf. Terbeek 1977; Linker 1982; Stevens 1998; Kaun 1995, 2004): the higher a round vowel is, the more salient its rounding. Consequently, [ə] could be thought to be more similar to [o] when coarticulated with a following [o] than with a following [u], because the amount of lip rounding/protrusion/contact induced on [$ə^{u}$] by the high round vowel, although presumably greater than in [$ə^{o}$], is not that which is expected for [o]. In other words: [$ə^{o}$] is both articulatorily and perceptually more similar to [o] than [$ə^{u}$], which is why [$ə^{o}$] undergoes assimilation to [o] in /tə̀b-ó/ → [tòbó] (*[$tə̀^{o}$bó]), while [$ə^{u}$] resists the assimilation in /ɓə̀r-ú/ → [$ɓə̀^{u}$rú] (cf. (8b)). However, the fact that a round V_2 has no significant coarticulatory effect on a preceding [ɨ] or [ə] seems to indicate that the role of the [round] V_2 in the harmony is purely phonological, and the height requirement is likely due to a phonological similarity precondition on rounding harmony.

2.4.5.3 Intervening /w/

We saw that intervening /w/ causes at least as much labialization on a preceding vowel as a labial consonant, if not more. If what drives the doubly triggered rounding harmony is the partial assimilatory effect exerted by the consonantal co-trigger, as I argue here and in the next chapter, /w/ should qualify as a co-trigger. The blocking effect of intervening /w/ is thus not due to a lack of coarticulatory effect on neighboring vowels, but to an independent phonotactic condition banning round vowel + /w/ sequences. This is supported by the fact that such sequences are entirely absent from the language. This condition is likely to be the result of contrast preservation: a /w/ after a non-low round vowel is likely not to be easily perceptible.[13]

2.4.5.4 Cumulative coarticulation

Finally, we saw in Figure 2.20a that the coarticulatory effect of labial consonants is cumulative: the BB condition has a greater F2 lowering effect than the single B condition. Interestingly, there is no difference in the phonological status or behavior of singly coarticulated [ə^b, ^{b}ə] and doubly coarticulated [^{b}ə^b]. Cumulative coarticulation is irrelevant to the doubly triggered rounding harmony: whether the [ɨ^b, ə^b] are subphonemically rounded by one labial consonant, or more strongly so by two labial consonants does not change anything to their status as targets of the harmony: both are rounded in the presence of a following round vowel, and kept unchanged otherwise. In other words, the threshold of subphonemic rounding is such that the effect of one labial consonant is enough to reach it.

2.5 Conclusion

The data presented in this chapter show that the Laal doubly triggered rounding harmony is a categorical phonological process involving a partial coarticulatory effect: the harmony is triggered by a round V_2, and targets a preceding subphonemically rounded non-low central vowel [ɨ^b, ə^b]'. It is thus a phonetically grounded phonological process.

The instrumental measurements presented above also constitute evidence for the phonologization of the labial coarticulatory effect into quantal, discrete subphonemic categories. Non-labialized [ɨ, ə] and labialized [ɨ^b, ə^b] are subphonemic allophones, i.e. two separate categories distinct only by the presence vs. absence of partial, subphonemic labialization. This subphonemic distinction does not depend on the amount of labialization, as we saw, but simply on its presence, i.e. the presence of at least one labial consonant in the vowel's vicinity. In other words, what is at work here is not pure acoustic/perceptual information, but an abstract, stable, discrete version thereof.

Consequently, what we need is a model of phonology that accommodates non-contrastive subphonemic categories originating from phonetic effects. The theory of subfeatural representations that I propose in the next chapter is meant to be the basis of such a model.

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[13] The fluctuation in the realizations of the adverb [kə́w ∼ ków ∼ kó] 'also' and the verb [dɨ̀w ∼ dùù] 'surpass' seem to show that [ɨw ∼ u] and [əw ∼ o] are perceived as being the same sound in Laal.

Chapter 3

A theory of subfeatural representations in phonology

3.1 Introduction

In this chapter, I introduce SUBFEATURAL REPRESENTATIONS to capture the subphonemic distinctions involved in teamwork, such as the distinction between [ɨ, ə] and their labialized counterparts [ɨ^{b}, ə^{b}] in Laal. The basics of the theory of subfeatural representations are presented in § 3.2, and the theory is illustrated in § 3.3 with an analysis of Laal couched in Optimality Theory. Further elaboration of the theory and of the architecture of phonological grammar that it implies is then given in § 3.4.

3.2 Subfeatural representations: the basics

On the basis of the instrumental evidence and conclusions presented in chapter 2, I argue that the coarticulatory effect of labial consonants on neighboring non-low central vowels in Laal is such that [ɨ, ə] and their labialized counterparts [ɨ^{b}, ə^{b}] constitute two separate categories, perceptually distinct, but featurally identical. I also argue that this perceptual distinction allows [ɨ^{b}, ə^{b}] to form a natural class, targeted by the doubly triggered rounding harmony to the exclusion of non-labilalized [ɨ, ə].

Labialized [ɨ^{b}, ə^{b}] are not phonemically contrastive: the distinction between [ɨ, ə] and [ɨ^{b}, ə^{b}] is entirely predictable: [ɨ^{b}, ə^{b}] in the vicinity of a labial consonant, [ɨ, ə] elsewhere. The [ɨ^{b}, ə^{b}] ∼ [ɨ, ə] distinction is irrelevant to the simple rounding harmony, which targets all non-round vowels, whether or not they are labialized, e.g. both /pɨ́r/ [pɨ́^{b}r] 'catch' and /kɨ́r/ [kɨ́r] 'place (plural subject)' undergo rounding harmony when combined with a round suffix: *pú́r-ù* 'catch her' and *kúr-ù* 'place her' (cf. ex. (16) above).

What then is the phonological status of this distinction? At least two analyses are possible: a traditional binary-feature-based one, and a phonetically grounded one allowing some form of reference to phonetic detail. On the traditional featural account, labialized [ɨ^{b}, ə^{b}] could be analyzed as carrying a non-contrastive [+labial] or [+round] feature assigned to them through assimilation with the neighboring labial consonant, (V → [+labial] or [+round] / {B_, _B}). The doubly triggered harmony could then be described as a rounding harmony targeting [+labial] vowels, or as a [+ back] harmony targeting [+ round] central vowels. I will develop this conventional featural analysis in § 5.3, and show that it encounters problems that are either avoided or solved by the subfeatural approach.

I argue instead that [ɨ, ə] and [ɨ^{b}, ə^{b}] are identical in terms of standard binary or privative feature values, specifically they are both [–round], as clearly suggested by the fact that they are both targeted by the simple rounding harmony.[1] [ɨ^{b}, ə^{b}] are only distinct from [ɨ, ə] through the partial rounding caused by the neighboring labial consonant, a distinction that belongs to a separate level of analysis and representation, which encodes subphonemic categories, i.e. perceptually distinct categories that are not contrastive ("quasi-phonemes" in Kiparsky's (2013) definition). I propose an additional type of phonological representation to capture such distinct but non-contrastive categories: SUBFEATURES. This proposal is in keeping with the idea, supported by a growing body of evidence, that contrastiveness, i.e. unpredictable phonological distribution, and perceptual distinctiveness are independent criteria (Kiparsky 2013, Hall 2013 and references therein).

The featural system I propose is thus a two-tiered system: contrastive featural categories are subdivided into non-contrastive, perceptually distinct subfeatural categories. At the featural level, phonology establishes binary distinctions to define contrastive phonemes and group them into natural classes. For example, the Laal vowels are divided into a [+ round] /y, yo, ya, u, o, ua/ and a [–round] class /i, e, ia, ɨ, ə, a/, on the basis of both lexical contrast (e.g. *tɨ́m* 'hand' vs. *túm* 'poke' or *tɨ̄ɨ̄r* 'be unripe' vs. *tȳȳr* 'poles'), as well as their behavior in phonological alternations such as the simple rounding harmony.

The subfeatural level of representation, scalar in nature, captures differences in perceptual distinctiveness resulting from coarticulation. The [±round] contrast described above may thus coexist with a multi-level subfeatural rounding scale, both being separate (but substantively related) representations of the lip-rounding continuum. On that subfeatural scale, subphonemic perceptual distinctions may be encoded whenever relevant. For example in Laal, the perceptual rounding scale, corresponding at the contrastive level to the binary feature [+ round] vs. [–round], can be represented by a continuum between ⟦0 round⟧ and ⟦1 round⟧ (subfeatures are represented with double square brackets). [–round] vowels are expected to be ⟦0 round⟧, i.e. be perceptually devoid of any sign of rounding, while [+ round] vowels are ⟦1 round⟧, i.e. perceived as fully rounded. Labialized [ɨ^{b}] and [ə^{b}] may be encoded as a level of rounding intermediate between 0 and 1, say ⟦x round⟧ with $0<x<1$. The [–round] category is thus subdivided into two subfeatural categories: ⟦0 round⟧ [i, e, ia, ɨ, ə, a], which are not rounded at all and do not sound round, and ⟦x round⟧ [ɨ^{b}, ə^{b}], which sound somewhat rounded. The latter two vowels are featurally [–round], i.e. they form a natural class with other [–round] vowels, but subfeaturally ⟦x round⟧. This explains why they behave like their non-labialized counterparts with respect to the simple rounding harmony, which refers to binary features only, and how they can also be seen as a distinct category by the doubly triggered rounding harmony, which is sensitive to subfeatural distinctions, as illustrated in Figure 3.1.[2]

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[1] See § 5.3 for arguments supporting an analysis of both the doubly-triggered and the simple harmony as two cases of rounding harmony.

[2] The idea of a scalar representation of vowel rounding is already proposed by Pasquereau (2013), whose multi-valued [labial*p*] feature represents different degrees of rounding (form least round /o/ to most round /u/) corresponding to different degrees of phonological activity. However, [labial*p*], contrary to subfeatures, does not represent the subphonemic distinctions attested in the Laal harmony pattern. For more on scalar or multivalued features, see Ladefoged (1971: 43-44, 91-111), Johnson (1972), Lindau (1978), Clements (1991), Gnanadesikan (1997) and references therein.

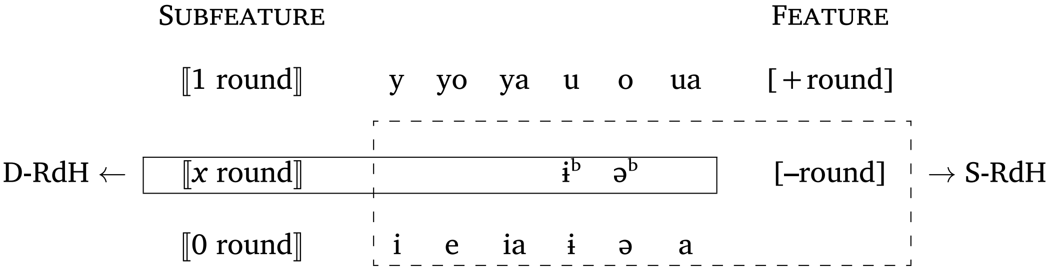


Figure 3.1: Targets of the doubly triggered (D-RdH) and simple (S-RdH) rounding harmonies

By convention, contrastive categories are represented by full subfeatural values, e.g. ⟦0 F⟧ vs. ⟦1 F⟧ for a binary or privative feature [±F], or ⟦0 F⟧ vs. ⟦1 F⟧ vs. ⟦2 F⟧ for a ternary feature, e.g. vowel height in a three-height system (cf. § 3.5). Intermediate subfeatural values x (e.g. $0<x<1$, or $1<x<2$ in a ⟦0...1...2 F⟧ system), on the other hand, correspond to perceptually distinct but non-contrastive "in-between" categories resulting from coarticulation. The subfeatural "distance" between two contrastive categories is set at 1.

3.2.1 Calculating subfeatural values: the Coarticulation function

Coarticulatory triggers have the property of assigning to their target a proportion of increase in the value of the affected subfeature ⟦F⟧ incurred by the coarticulatory effect of the trigger onto the target. I will call this proportion of increase a COARTICULATORY COEFFICIENT, and represent it as $p_{Trigger \rightarrow Target, [\![F]\!]}$, or simply p for short. The resulting intermediate subfeatural value x of the target segment is obtained through the application of the C(oarticulation) function defined in (20) and schematized in (21) below.

(20) $C_p(x_{init}) = x_{init} + p(x_{full} – x_{init})$

a. p is the coarticulatory coefficient, i.e. the proportion of increase in the value of ⟦F⟧ incurred by the trigger onto the target ($0<p<1$);

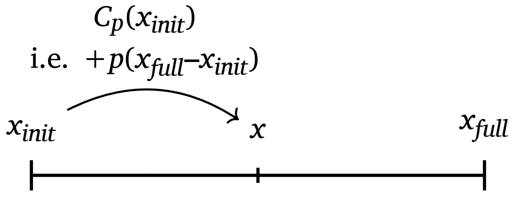
b. x_{init} is the (expected) initial ⟦F⟧ value of the target vowel before application of the coarticulatory function;

c. x_{full} is the full value of ⟦F⟧ (or the next full value up, cf. § 3.5);

d. $+ p(x_{full} – x_{init})$ is the amount of increase in the value of ⟦F⟧ incurred by the function.

e. Cases of multiple triggers targeting the same segment are accounted for by function composition, e.g. $C_{p_1}(C_{p_2}(x_{init}))$, where composition order is immaterial. When the C_p function is composed with itself, I will use the Picard notation $C_p^n(x_{init})$, e.g. $C_p^2(x_{init}) = C_p(C_p(x_{init}))$.

(21) Illustrative schema:



The coarticulatory coefficient p is the direct correlate of the coarticulatory effect of an specific trigger onto a specific target (e.g. labial consonant and non-low central vowel in Laal), and its value depends on the actual coarticulatory effect, i.e. on the articulatory and perceptual properties of each of the segments involved, but also on the distance between the two segments, the prosodic or morphological status of the two segments, etc.

We saw in chapter 2 that the rounding coarticulatory effect of a labial consonant on (near-) adjacent [ə] and [ɨ] is manifested through F_2 lowering. The coarticulatory coefficient $p_{B\rightarrow ə,\llbracket\text{rd}\rrbracket}$ involved in the coarticualtory labialization of non-low central vowels in Laal can thus be calculated on the basis of the F2 measurements provided in § 2.4. For example, assuming that the F_2 values of [ə] (18.95 ERB) and [o] (14.31 ERB) correspond to the subfeatural values ⟦0 round⟧ and ⟦1 round⟧ respectively, the proportion of increase from ⟦0 round⟧ [ə] to ⟦x round⟧ $[ə^b]$ $p_{B\rightarrow ə,\llbracket\text{rd}\rrbracket}$ can be calculated as the ratio between $\Delta_{F_2}[ə^b]$–[ə] and Δ_{F_2}[o]–[ə], as shown in (22).

$$(22)\quad p_{B\rightarrow ə,\llbracket\text{rd}\rrbracket} = \frac{F_2[ə^b]-F_2[ə]}{F_2[o]-F_2[ə]} = \frac{17.35-18.95}{14.31-18.95} = 0.34$$

Table 3.1 provides the value of p for all trigger-target pairs (i.e. B→ə and B→ɨ) and for both speakers.[3]

	$p_{B\rightarrow ə,\llbracket\text{rd}\rrbracket}$	$p_{B\rightarrow ɨ,\llbracket\text{rd}\rrbracket}$
AK	0.34	0.47
KD	0.39	0.40

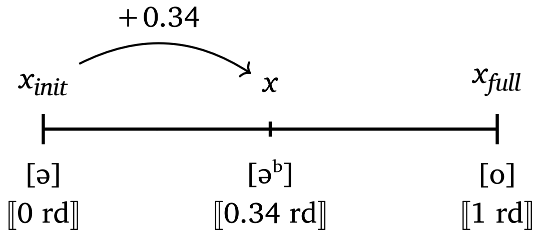
Table 3.1: $p_{B\rightarrow ə/ɨ,\llbracket\text{rd}\rrbracket}$ in Laal

The subfeatural value of x of an ⟦x round⟧ vowel can then be determined by applying the C_p function defined in (20) above, as illustrated in (23) with the labialized vowel $[ə^b]$ in a word like *pə̀d* ‘pass’ (AK).

(23) Application of the C_p function in Laal *pə̀d*:

a.
$$\begin{aligned} x &= C_p(x_{init}) \\ x &= x_{init} \quad + p(x_{full}-x_{init}) \\ &= 0 \quad\quad +0.34(1-0) \\ &= \boxed{0.34} \end{aligned}$$

b. Illustrative schema:



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[3] For the sake of simplicity, only short [ə] and [ɨ] are taken into account here.

In other words, in AK's speech, a labial consonant increases the subfeatural ⟦round⟧ value of a (near-)adjacent [ə] by 34%, making labialized [ə^{b}] subfeaturally ⟦0.34 rd⟧.

When there is only one coarticulatory trigger, the C_p function applies only once, and the resulting subfeatural value x is the same as the coarticulatory coefficient p ($x = C_p(0) = p$). When there is more than one coarticulatory trigger, however, the function applies as many times as there are triggers. For example, it applies twice in a form like *mə̀mlə̀l* 'my grand-son', where the first [ə] is surrounded by two labial consonants. The predicted value of x in this case is thus the result of the double application of the function, as illustrated in (24).

(24) Iterative application of the C function in Laal *mə̀mlə̀l*: $x = C_p^2(x_{init})$

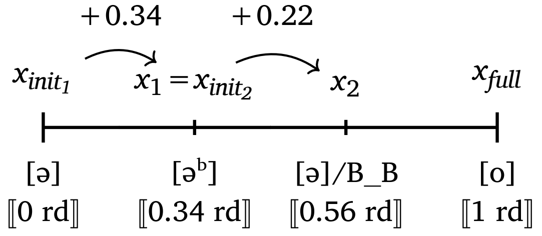
a. First application:

$$\begin{aligned} x_1 &= C_p(x_{init_1}) \\ &= x_{init_1} \quad + p(x_{full} – x_{init_1}) \\ &= 0 \quad +0.34(1–0) \\ &= \boxed{0.34} \end{aligned}$$

b. Second application:

$$\begin{aligned} x_2 &= C_p(x_{init_2}) \\ &= C_p(x_1) \qquad\qquad (x_{init_2} = x_1) \\ &= x_1 \quad + p(x_{full} – x_1) \\ &= 0.34 \quad + 0.34(1–0.34) \\ &= 0.34 \quad + 0.22 \\ &= \boxed{0.56} \end{aligned}$$

c. Illustrative schema:



This prediction matches the observed F$_2$ decrease incurred by two labial consonants on [ə] rather well. Indeed, If the F$_2$ values of [ə] (18.95 ERB) and [o] (14.31 ERB) correspond to ⟦0 round⟧ and ⟦1 round⟧ respectively, then the observed F$_2$ value of [ə]/B_B (16.44 ERB) corresponds to ⟦0.54 round⟧ (compare with the predicted ⟦0.56 round⟧ in (24b) above).

Subfeatures are thus not only the representation of a property of a single segment (e.g. [ɨ^{b}]), but also that of a relation between coarticulated segments. They represent knowledge about contextual realization, i.e. knowledge of segment interaction. The $C^{n}_{p_{B \rightarrow ə/ɨ, \llbracket \mathrm{rd} \rrbracket}}$ function —i.e. the ⟦$+p(x_{full} – x_{init})$ round⟧ increasing effect— is a representation of the coarticulatory interaction between labial consonants and (near-)adjacent [ɨ] and [ə]. The ⟦x round⟧ subfeature borne by the target vowel is a representation of the result of this interaction.

3.3 Illustrative analysis: the Laal doubly triggered rounding harmony

With the analysis sketched in § 3.2 and Figure 3.1 above, the doubly triggered rounding harmony can be reduced to a case of rounding harmony parasitic on height and backness, targeting only vowels that are at least ⟦x round⟧. Any theory of parasitic vowel harmony would presumably easily account for the Laal harmony on the condition that it be allowed to refer to subfeatural categories, whether it utilizes feature spreading (e.g. Padgett 1995; Jurgec 2011, 2013), feature alignment (Smolensky 1993; Kirchner 1993; Kaun 1995, 2004), feature agreement or no-disagreement constraints (Bakovic 2000; Pulleyblank 2002), Agreement by Correspondence (Walker 2000, 2000b, 2001; Hansson 2001, 2010; Rose and Walker 2004), or Wayment's (2009) Attraction Framework.[4]

The goal of this section is not to argue in favor of one specific theory of vowel harmony, but simply to illustrate how one such theory may easily account for the doubly triggered rounding harmony if it is allowed to refer to subfeatural representations. The illustrative analysis I propose here uses Hansson's (2014) Agreement by Projection (ABP) theory, a revision of Agreement by Correspondence (ABC), couched in Optimality Theory (Prince and Smolensky 1993/2004).[5]

First, independently of the harmony pattern, I propose to have subfeatural distinctions be enforced by the phonological grammar, through high-ranked markedness constraints penalizing both absence of expected coarticulation and presence of unjustified coarticulation, defined in (25) and (26) below (see § 3.4.3 below for a discussion of this choice). For the purpose of this analysis, the value of the coarticulatory coefficient involved in coarticulatory rounding of non-low central vowels is set at $p = .40$, which is the average value of $p_{B\rightarrow ə,⟦\mathrm{rd}⟧}$ and $p_{B\rightarrow ɨ,⟦\mathrm{rd}⟧}$ for both speakers. This is of course a simplification: a more thorough description would use one constraint per $p_{trigger\rightarrow target,⟦\mathrm{F}⟧}$ value.

(25) *⟦$<x_{init}+.40(1–x_{init})$ RD⟧/LAB:
Let X be a vowel; X may not be lower than ⟦x_{init} + .40($1–x_{init}$) RD⟧ (i.e. ⟦.40 round⟧ with one (near-)adjacent labial, ⟦.64 round⟧ with two, etc.) on the subfeatural scale if it is (near-)adjacent to a labial consonant.

(26) *⟦$>$0RD⟧/NO-LAB:
Let X be a vowel; X may not be higher than ⟦0 round⟧ on the subfeatural scale if it is not (near-)adjacent to a labial consonant.

As shown in the tableau in (27), these two constraints, if undominated, will always enforce labial coarticulation in labial contexts, and prevent it in non-labial contexts, whether or not the ⟦0.40 round⟧ subfeature is specified in the input: both /pɨ́r/ and /pɨ́ᵇr/ surface as [pɨ́ᵇr] in (27a-b), /tɨ̄n/ and /tɨ̄ᵇn/ as [tɨ̄n] in (27c-d).

---

[4] See Sasa (2009: 10-42) for an overview of Optimality-Theoretic treatments of vowel harmony.

[5] I use classical OT (with asterisks for penalties and strict constraint domination) rather than Harmonic Grammar (HG, Legendre et al. 1990) for convenience. The same analysis could be couched in HG. However, as I will show in § 5.2.2, the gang effects allowed by HG, which constitute one of the main advantages over classical OT, are not motivated in the data. Additionally, since the goal of this analysis is not to predict statistical distribution, using a stochastic version of HG such as Maximum Entropy (Hayes and Wilson 2008) is unnecessary.

(27)

		$*[\![<x_{init}+.40(1–x_{init})$ RD$]\!]$/LAB	$*[\![>0$RD$]\!]$/NO-LAB
a. /pɨ́r/	i. pɨ́r	*!	
	☞ii. pɨ́^{b}r		
b. /pɨ́^{b}r/	☞i. pɨ́^{b}r		
	ii. pɨ́r	*!	
c. /tɨ̄n/	☞i. tɨ̄n		
	ii. tɨ̄^{b}n		*!
d. /tɨ̄^{b}n/	i. tɨ̄^{b}n		*!
	☞ii. tɨ̄n		

To keep tableaux simple and legible, these two constraints will from now on be conflated into the general markedness constraint LABCOART.

I then analyze the harmony pattern using Hansson's (2014) revision of ABC. ABC is a theory of similarity-based segmental interaction that was initially developed for long-distance consonant agreement (Walker 2000, 2000b, 2001; Hansson 2001, 2010; Rose and Walker 2004). It was then extended to vowel harmony (Sasa 2009; Walker 2009; Rhodes 2012), long-distance consonant dissimilation (Bennett 2013, 2015), and local effects of assimilation and dissimilation (Inkelas and Shih 2014; Shih and Inkelas 2014; Shih 2013; Sylak-Glassman 2014).

The central insight of ABC is that (dis)harmony is driven by similarity threshold effects. Similarity is built into the system, rather than stipulated: harmony between segments is viewed, not as spreading, but as agreement between segments in a correspondence relationship based on phonological similarity. This surface correspondence is unstable (Inkelas and Shih 2014): two (or more) segments are sufficiently similar to interact (they are in correspondence), but are too uncomfortably similar to co-exist within a certain distance. Two repairs are possible: harmony (more similarity) and disharmony (less similarity). This theory seems particularly suited to parasitic vowel harmony, which involves specific similarity threshold effects between targets and triggers.

The basic mechanics of ABC theory involve two types of Output-Output correspondence constraints: CORR-XX establishes surface correspondence between segments X similar in a particular feature or set of features (e.g. obstruents, coronals, high vowels, etc.), while IDENT-XX[F] enforce agreement in the feature [F] between segments in the correspondence set defined by CORR-XX. Both types of constraints are ranked higher than the constraints enforcing faithfulness to the assimilating feature.

Based on a diagnosis of pathological properties of the division of labor between IDENT-XX[F] and CORR-XX, Hansson (2014) proposes to conflate the work of both constraints into a single "projection-based" Markedness constraint, defined as follows:

(28) $*[\alpha F][\beta rd]/[\gamma G, \delta H]$:

Let X and Y be segments; X and Y may not disagree in the feature [F] ($\approx$IDENT-XX[F]) if they are adjacent in the projection (i.e. the ordered set of output segments) specified as $[\gamma G, \delta H]$ ($\approx$ CORR-XX$[\gamma G, \delta H]$).

I adopt Hansson's (2014) projection-based constraints here.[6] If such a constraint is allowed to refer to subfeatural representations, it can easily account for the doubly triggered rounding harmony of Laal, as I show in the remainder of this section. The constraint that drives the doubly triggered rounding harmony is given in (29).

(29) *⟦≥ .40 RD⟧⟦1RD⟧/[+syll, αheight, βfront]:[7]
A segment whose subfeatural ⟦round⟧ value equals or exceeds .40 may not directly precede a ⟦1 round⟧ segment in the ordered set of output segments that are [+syllabic] (i.e. vowels) and share the same same [height] and [front] specifications. Assign one violation for each pair of neighboring segments that meet the criteria.

The constraint *⟦≥ .40 RD⟧⟦1RD⟧/[+syll, αheight, βfront] drives the harmony by establishing the threshold of subphonemic rounding beyond which a labialized [ə^{b}] or [ɨ^{b}] is targeted by the harmony at ⟦.40 RD⟧. This constraint stands in a markedness hierarchy that mirrors the featural similarity scale in table 3.2 below, where the similarity levels are ordered based on how much they restrict the number of potential targets: the highest level of similarity is the most restrictive. Note that while the ordering of the highest and lowest levels is self evident, there is no evidence in Laal for any ordering of the intermediate levels, and different orderings are likely to be possible, on a language by language basis.

Similarity between trigger and target	*Targeted by [u]*	*Targeted by [o]*
[+syll, αheight, βfront]	ɨ (incl. ɨ^{b})	ə (incl. ə^{b})
[+syll, αheight]	i, ɨ (incl. ɨ^{b})	e, ə (incl. ə^{b})
[+syll, βfront]	i, ɨ, e, ə (incl. ɨ^{b}, ə^{b})	
[+syll]	i, ɨ, e, ə, ia, a (incl. ɨ^{b}, ə^{b})	

Table 3.2: Similarity between round and non-round vowels in Laal: tentative scale

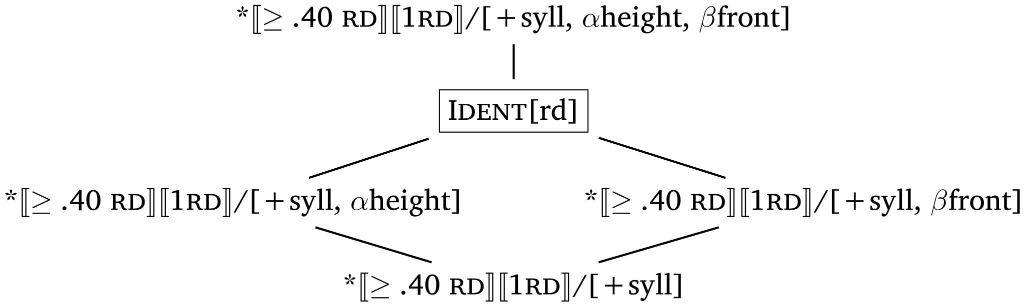
Each level of similarity in the scale could in theory be the threshold at work in a rounding harmony process. Consequently, the similarity scale translates into a Markedness constraint hierarchy, shown in (30), in which the constraint defined in (29) above is the highest. In the doubly-triggered rounding harmony, the similarity threshold at work is the highest level in the scale; IDENT[rd] must thus be ranked right below the highest Markedness constraint *⟦≥ .40 RD⟧⟦1RD⟧ /[+syll, αheight, βfront], but crucially higher than all the other constraints in the hierarchy. The effect of this ranking is illustrated in the tableaux in (31)-(34).

---

[6] Note that a regular ABC analysis of the Laal data using CORR-XX and IDENT-XX[F] constraints would work as well

[7] Only vowels are ever [+syllabic], i.e. can be syllable nuclei in Laal

(30) Subfeatural markedness constraint hierarchy:[8]



(31)

/ɓɨ̀r-ú/	LABCOART	*⟦≥ .40 RD⟧⟦1RD⟧ /[+syll, αht, βfr]	IDENT[rd]	*⟦≥ .40 RD⟧⟦1RD⟧ /[+syll, αheight]	*⟦≥ .40 RD⟧⟦1RD⟧ /[+syll, βfront]	*⟦≥ .40 RD⟧⟦1RD⟧ /[+syll]
a. ɓɨ̀r-ú	*!					
b. ɓɨ̀^{b}r-ú		*!		*	*	*
☞ c. ɓùr-ú			*			

(32)

/ɓə̀r-ú/	LABCOART	*⟦≥ .40 RD⟧⟦1RD⟧ /[+syll, αht, βfr]	IDENT[rd]	*⟦≥ .40 RD⟧⟦1RD⟧ /[+syll, αheight]	*⟦≥ .40 RD⟧⟦1RD⟧ /[+syll, βfront]	*⟦≥ .40 RD⟧⟦1RD⟧ /[+syll]
a. ɓə̀r-ú	*!					
☞ b. ɓə̀^{b}r-ú					*	*
c. ɓòr-ú			*!			

---

[8] The ranking of the lowest constraint *⟦≥ .40 RD⟧⟦1RD⟧ below all the other constraints in the hierarchy is motivated by the hypothesis that if such a hierarchy exists, less restrictive constraints are necessarily ranked lower than more restrictive ones. Since it cannot be motivated with Laal data, this ranking will not be reported in tableaux.

(33)

/ɓə̀r-ú/	LABCOART	$*[\![\geq .40\ \text{RD}]\!][\![1\text{RD}]\!]/[+\text{syll}, \alpha\text{ht}, \beta\text{fr}]$	IDENT[rd]	$*[\![\geq .40\ \text{RD}]\!][\![1\text{RD}]\!]/[+\text{syll}, \alpha\text{height}]$	$*[\![\geq .40\ \text{RD}]\!][\![1\text{RD}]\!]/[+\text{syll}, \beta\text{front}]$	$*[\![\geq .40\ \text{RD}]\!][\![1\text{RD}]\!]/[+\text{syll}]$
☞ a. mèn-ú						
b. mè^{b}n-ú	*!					*
c. myə̀n-ú			*!			

(34)

/gɨ́n-ù/	LABCOART	$*[\![\geq .40\ \text{RD}]\!][\![1\text{RD}]\!]/[+\text{syll}, \alpha\text{ht}, \beta\text{fr}]$	IDENT[rd]	$*[\![\geq .40\ \text{RD}]\!][\![1\text{RD}]\!]/[+\text{syll}, \alpha\text{height}]$	$*[\![\geq .40\ \text{RD}]\!][\![1\text{RD}]\!]/[+\text{syll}, \beta\text{front}]$	$*[\![\geq .40\ \text{RD}]\!][\![1\text{RD}]\!]/[+\text{syll}]$
☞ a. gɨ́n-ú						
b. gɨ́^{b}n-ù	*!	*				
c. gún-ù			*!			

Undominated LabCoart ensures that none of the first two inputs in (31) /ɓɨ̀r-ú/ and (32) /ɓə̀r-ú/ surfaces with a V_1 that is not at least $[\![.40$ round$]\!]$, since in all three forms, V_1 is adjacent to a labial consonant: candidates (31a)-(32a) are thus always suboptimal. Candidate (31a) *ɓɨ̀^{b}rú* violates $*[\![\geq .40\ \text{RD}]\!][\![1\text{RD}]\!]/[+\text{syll}, \alpha\text{height}, \beta\text{front}]$. The fact that this constraint is ranked higher than IDENT[rd] favors candidate (31c) ɓùrú, in which rounding harmony has applied, repairing the marked structure. On the other hand, candidate (32a) *ɓə̀^{b}rú* does not violate this constraint: it only violates constraints that are lower on the markedness hierarchy, and crucially ranked lower than IDENT[rd], which makes it the optimal output.

Finally, given the inputs /mèn-ú/ and gɨ́n-ù/ in (33) and (34), LABCOART strikes candidates (33b) *gɨ́^{b}nù* and (34b) *mè^{b}n-ú*, where labial coarticulation has over-applied (labial coarticulation targets only [ɨ] and [ə]), leaving only (33a) *mènú* and (34a) *gɨ́nù* as the optimal outputs, since the violation of IDENT[rd] incurred by rounding V_1 in candidate (33c) *myə̀nú* and (34c) *gúnù* is not compensated by the satisfaction of a higher constraint: rounding harmony is unnecessary in this case because there is no marked structure to repair.

To complete the analysis, two undominated constraints need to be added. The first one is a markedness constraint accounting for the opacity of intervening /w/, defined as follows:

(35) *[+syll](C)[–syll]/[–cons, +rd]

Let X be a syllabic vocoid and Y a non-syllabic one; X and Y may not co-occur in a sequence (optionally interrupted by a consonant) in this order if they agree in the features [consonantal] and [round] (i.e. if they are both round vocoids). Assign one violation per pair of (near-)adjacent segments meeting the criteria.

The second additional constraint that is needed is a positional faithfulness constraint (Beckman 1999) Ident$_{\sigma 2}$[rd], which accounts for the fact that unrounding of V$_2$ is not a possible repair (as shown by candidate (36d) below). The effect of these two constraints is illustrated in (36)-(37).[9]

(36)

/ɓɨ̀r-ú/	LabCoart	*[+syll](C)[–syll] /[–cons, +rd]	Ident$_{\sigma 2}$[rd]	*$\llbracket\geq$.40 rd$\rrbracket\llbracket$1rd$\rrbracket$ /[+syll, αht, βfr]	Ident[rd]	*$\llbracket\geq$.40 rd$\rrbracket\llbracket$1rd$\rrbracket$ /[+syll, αheight]	*$\llbracket\geq$.40 rd$\rrbracket\llbracket$1rd$\rrbracket$ /[+syll, βfront]	*$\llbracket\geq$.40 rd$\rrbracket\llbracket$1rd$\rrbracket$ /[+syll]
a. ɓɨ̀r-ú	*!							
b. ɓɨ̀^{b}r-ú				*!		*	*	*
☞ c. ɓùr-ú					*			
d. ɓɨ̀^{b}r-ɨ́			*!		*			

(37)

/mə́w-ó/	LabCoart	*[+syll](C)[–syll] /[–cons, +rd]	Ident$_{\sigma 2}$[rd]	*$\llbracket\geq$.40 rd$\rrbracket\llbracket$1rd$\rrbracket$ /[+syll, αht, βfr]	Ident[rd]	*$\llbracket\geq$.40 rd$\rrbracket\llbracket$1rd$\rrbracket$ /[+syll, αheight]	*$\llbracket\geq$.40 rd$\rrbracket\llbracket$1rd$\rrbracket$ /[+syll, βfront]	*$\llbracket\geq$.40 rd$\rrbracket\llbracket$1rd$\rrbracket$ /[+syll]
a. mə́w-ó	*!							
☞ b. mə́^{b}w-ó				*		*	*	*
c. mów-ó		*!			*			
d. mə́^{b}w-ə́			*!		*			

As seen, the effect of *[+syll](C)[–syll]/[–cons, +rd] is to favor candidate (37b) *mə́^{b}wó* despite the fact that it displays the marked vowel sequence that the phonology strives to eliminate

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[9] Directionality in this case is in fact accounted for by the combination of this positional faithfulness constraint and the directional markedness constraint penalizing $\llbracket\geq$.40rd$\rrbracket\llbracket$1rd$\rrbracket$ (which can only correspond to a [–rd][+rd] and not [+rd][–rd] sequence). If the [+rd] feature of V2 cannot be changed, then only anticipatory rounding will fix the marked $\llbracket\geq$.40rd$\rrbracket\llbracket$1rd$\rrbracket$ sequence. One could equally choose to work with non-directional markedness constraints (*$\llbracket\alpha$rd$\rrbracket\llbracket\beta$rd$\rrbracket$/...), and account for directionality using both the positional faithfulness constraint above and two separate Ident[+rd] and Ident[–rd] (or Ident-OI[rd] vs. Ident-IO[rd]) appropriately ranked (Ident-σ2[rd], Ident[+rd] $\gg$ *$\llbracket\alpha$rd$\rrbracket\llbracket\beta$rd$\rrbracket$/... $\gg$ Ident[–rd]), thus penalizing unrounding but not rounding.

elsewhere. Interestingly, while intervening /w/ blocks the harmony, it does not trigger dissimilation (e.g. to *méwò*), which would be another possible repair: this is thus a case where the system "chooses" to keep the "uncomfortable" level of similarity between [ə^b] and [o] unchanged.

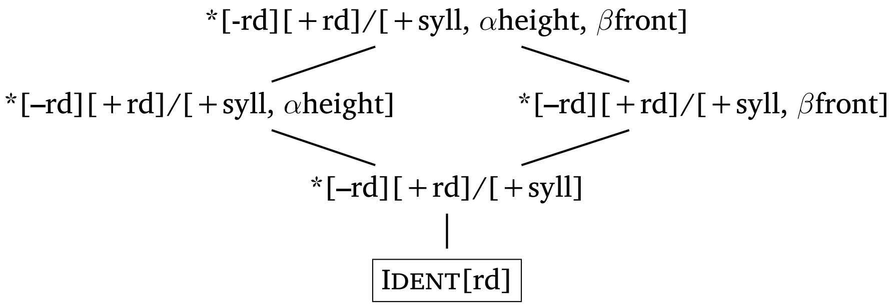
Finally, the simple rounding harmony, which belongs to a separate, morphologically specific sub-grammar,[10] is driven by a purely featural projection-based anti-disagreement constraint: *[–rd][+rd]/[+syll], defined in (38).

(38) *[–rd][+rd]/[+syll]

A [–round] segment may not directly precede a [+round] segment in the ordered set of output segments specified as [+syllabic] (i.e. a non-round vowel may not precede a round vowel). Assign one violation for each pair of neighboring segments that meet the criteria but fail to agree.

This constraint also stands in a markedness hierarchy, mirroring the similarity scale in table 3.2. In this case, however, IDENT-[rd] is ranked below the lowest constraint of the hierarchy, i.e. the threshold for rounding is at the lowest possible point, as shown in the Hasse diagram in (39), and illustrated in the tableaux in (40) and (41).

(39) Featural markedness constraint hierarchy:[11]



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[10] It is outside the scope of the present work to tackle the issue of the coexistence of these two sub-grammars within the same system. Cophonology theory (cf. Orgun 1996, Inkelas et al. 1997, Inkelas 1998, Anttila 2002, a.o.), or a stratal account, either in Lexical phonology or in stratal OT (cf. Kiparsky 1982, Booij 1996, 1997, Kiparsky 2000, 2003, Bermúdez-Otero 1999, Rubach 1997, 2000, a.o.) seem like promising paths to explore, given the association of each harmony with a different morphological stratum.

[11] Note that the rankings within the markedness constraint hierarchy are only motivated by the hypothesis that less restrictive constraints are ranked lower than more restrictive ones. Since they cannot be motivated with Laal data, these rankings will not be reported in tableaux.

(40)

/léér-nǔ/	LabCoart	*[+syll](C)[−syll] /[−cons, +rd]	Ident$_{\sigma2}$[RD]	*[−rd][+rd] /[+syll, αht, βfr]	*[−rd][+rd] /[+syll, αheight]	*[−rd][+rd] /[+syll, βfront]	*[−rd][+rd] /[+syll	Ident[rd]
a. léér-nǔ							*!	
☞ b. lyóór-nǔ								*
c. léér-nɨ̌			*!					*

(41)

/kə́w-ò/	LabCoart	*[+syll](C)[−syll] /[−cons, +rd]	Ident$_{\sigma2}$[RD]	*[−rd][+rd] /[+syll, αht, βfr]	*[−rd][+rd] /[+syll, αheight]	*[−rd][+rd] /[+syll, βfront]	*[−rd][+rd] /[+syll	Ident[rd]
a. kə́w-ó	*!							
☞ b. kə́^{b}w-ó							*	
c. ków-ó		*!						*
d. kə́^{b}w-ə́			*!					*

The analysis presented above is one of many possible analyses, and illustrates one of the advantages of the subfeatural representations proposed in this paper: extend the domain of application of existing theories of vowel harmony (and more generally assimilation) to complex multiple-trigger cases involving subphonemic teamwork.

3.4 The nature of subfeatures

3.4.1 A representation of phonetic knowledge

The theory proposed here crucially rests on the assumption that phonology has access to language-specific PHONETIC KNOWLEDGE (Kingston and Diehl 1994), i.e. "the speaker's partial understanding of the physical conditions under which speech is produced and perceived" (Hayes and Steriade 2004: 1). This is true of most phonetically grounded approaches to phonology, notably Steriade's (2009) P-map and similar licensing-by-cue approaches. Subfeatures are actually a reification of this knowledge: ⟦.40 round⟧ represents the knowledge that Laal speakers have of the labial coarticulation affecting [ɨ] and [ə] and its perceptual correlate.

Importantly, phonetic knowledge is abstract, and subfeatures accordingly represent abstract categories. They are discretized, scalar representations of phonologized coarticulation, not representations of actual, gradient acoustic/perceptual information. Like tone, subfeatural representations are quantal (not continuous, cf. Stevens 1989), contextually determined (not absolute values, see the discussion about vowel length in § 2.4.1.1.1, fig. 2.4), and stable. Consequently, the relationship between the real numbers posited in subfeatural representations and the observed phonetic distinctions are only approximate, and designed to capture relative levels rather than absolute values: ⟦.40 round⟧ is not an absolute F$_2$ value, but an indication that labialized [ə^{b}] and [ɨ^{b}] have 40% of the phonetic property or properties that distinguish [o] and [u] from [ə] and [ɨ] respectively.

Evidence of the abstract nature of subfeatures comes from the fact that a word like /ɓɨ̀r-ú/ 'fish hooks' is always realized [ɓùrú], never [ɓɨ̀^{b}rú], i.e. no Laal speaker/listener has ever uttered or heard a ⟦.40 round⟧ [ɨ^{b}] in this word. This is a problem if one is to derive the optimal output [ɓùrú] through phonotactic "reparation" of the marked structure [ɓɨ̀^{b}rú], which is what I propose to do. Indeed, where is the form [ɓɨ̀^{b}rú] to be found if it is neither in the underlying representation, nor in the uttered/perceived surface form? The answer is that the form [ɓɨ̀^{b}rú] is the predicted (but problematic) realization of /ɓɨ̀r-ú/, a prediction based on the speakers' knowledge of the coarticulatory effect of labial consonants on a neighboring [ɨ]. Indeed, ⟦.40 round⟧ [ɨ^{b}] does exist in articulation and perception, e.g. in words like /ɓɨ̀rà/ 'fish hook' or /pɨ́r/ 'catch', where the initial vowel is always realized and perceived as ⟦.40 round⟧ [ɨ^{b}], as we saw in § 2.4. Based on this phonetic experience, Laal speakers are able to determine that labial consonants contribute a 40% ⟦round⟧ increase to a neighboring non-low central vowel, and can therefore predict that, if it were not for vowel harmony, i.e. for the fact that the sequence [ɨ^{b}...u] is unlawful, /ɓɨ̀-rú/ would be realized with a ⟦.40 round⟧ [ɨ^{b}], like in [ɓɨ̀^{b}rà] and [pɨ́^{b}r]. It is this purely abstract, predicted phonetic realization [ɓɨ̀^{b}rú] that contains the marked structure ⟦.40 round⟧…⟦1 round⟧ that the language strives to avoid, and that it "repairs" by "rounding up" the initial vowel, as in the analysis proposed in § 3.3.

This concept of a predicted (but never realized) phonetic realization of the input, or "inferred input", was first proposed by Steriade (1997), and later developed by Jun (2002), as well as Gallagher (2007) and Flemming (2008) under the label "realized input." I will show the advantages of the subfeatural approach over the inferred/realized input approach in § 5.4.1.4. Hansson and Moore (2011: 16) sketch a very similar hypothesis regarding Kaska back harmony (cf. Figure 4.11 in § 4.4.2).

3.4.2 Subfeatures as emergent categories

Another assumption underlying the theory is that subfeatural representations are, like contrastive features, emergent (Boersma 1998, Mielke 2008 and references therein), i.e. they are generalizations that emerge from sound patterns. This assumption answers two major questions posed by subfeatural representations: the origin of subfeatures, and the limits on their values. If subfeatures are emergent, one expects to see them used only to distinguish categories that are perceptually distinct. In other words, the limits on human articulation and perception act as a stringent limiter on the possible types and number of subfeatures, as well as the number of values they may have: a subfeature may have only as many values as are necessary to account for the relevant phonological alternations, provided the categories they define are perceptually distinct. As a consequence, not only does the theory not allow infinite subfeatural scales (which would constitute a massive over-generation problem), it also predicts that the number of possible values will likely always be rather limited (e.g. how many perceptually distinct degrees of rounding can there be?). One could draw a parallel with tone, which constitutes a direct analogue: despite the possibility to make an infinite number of distinctions along the F0 continuum, one expects pitch differences to be phonologized only within the limits of human perception, i.e. only into a relatively limited number of tone levels, in accordance with typological observations.

3.4.3 Enforcing and manipulating subfeatures in a constraint-grammar

3.4.3.1 Enforcing subfeatural distinctions through high-ranked markedness constraints

In the analysis proposed in § 3.3 above, I have chosen to have the constraint grammar itself determine subfeatural distinctions, through undominated markedness constraints enforcing labial coarticulation (only) when necessary. (LabCoart = *⟦≤.40rd⟧/Lab + *⟦>0rd⟧/No-Lab). A crucial property of subfeatures illustrated by this analysis is that, in an OT grammar, they are not protected by faithfulness. Indeed, a faithfulness constraint referring to a subfeature, if ranked sufficiently high, would make this subfeature contrastive, contrary to the key intuition that subfeatures encode non-contrastive categories. This is shown in tableau (42) below, where both [pɨ́r] and [pɨ́^{b}r], [tɨ̄n] and [tɨ̄^{b}n] are predicted to be contrastive. The nature of subfeatures thus makes them invisible to faithfulness.[12]

(42)

		*Ident⟦*x* rd⟧/	LabCoart
a. /pɨ́r/	💣 i. pɨ́r		*
	☜ii. pɨ́^{b}r	*!	
b. /pɨ́^{b}r/	☞ i. pɨ́^{b}r		
	ii. pɨ́r	*!	*
c. /tɨ̄n/	☞ i. tɨ̄n		
	ii. tɨ̄^{b}n	*!	*
d. /tɨ̄^{b}n/	💣 i. tɨ̄^{b}n		*
	☜ii. tɨ̄n	*!	

Additionally, it is necessary to rank the markedness constraints responsible for assigning subfeatures very high, since distinctive coarticulatory effects such as labial coarticulation in Laal are systematic, i.e. never undone: markedness constraints responsible for enforcing subfeatural distinctions thus cannot be ranked below other constraints whose effects would undo coarticulation. In that sense, they are similar to other constraints that are necessarily ranked high, such as the constraint(s) ensuring that every language has a segment inventory. An interesting consequence of the high ranking of such constraints (e.g. LabCoart in Laal) is that they constitute the only part of the constraint grammar that can manipulate subfeatures, i.e. be satisfied by a subfeature

---

[12] This implies that subfeatures are not present in underlying representations. An alternative would be to say that faithfulness to subfeatures is always ranked very low, below the subfeature-enforcing markedness constraints, in which case subfeatures would be part of underlying representations, but never contrastively, being entirely predictable from context. The choice between these two positions ultimately depends on one's views on the Richness of the Base and Lexicon Optimization principles (Prince and Smolensky 2004: 205, 225–230). I tentatively choose to consider that subfeatures are defined as categories that faithfulness does not refer to, but the alternative is entirely viable as well.

being added to or removed from the input. All other constraints referring to subfeatures (e.g. *⟦≥ .40 RD⟧⟦1RD⟧/[αheight,βfront] in (29) above) can in theory be satisfied by manipulating either subfeatures or binary features, but only the latter will ever be optimal, since any subfeatural change will be filtered out by the high ranked constraints enforcing coarticulation. Subfeatural values can thus only be modified indirectly by changing the (substantively related) featural content of the input, e.g. changing [–round] into [+round] necessarily entails a change from ⟦0 round⟧ or ⟦.40 round⟧ to ⟦1 round⟧. In other words, the undesirable effects of coarticulation can only be undone by modifying the phonological environment responsible for it, not by simply modifying the subfeatural values that are a representation of those effects. In that sense, subfeatures are subordinate to classic binary features.

3.4.3.2 The architecture of the phonological grammar

Phonology is grounded in phonetics through language-specific abstract phonetic knowledge, derived through articulatory and perceptual experience. Abstract phonetic knowledge, which contains in particular knowledge of contextual realization, i.e. of the perceptual correlate of coarticulation, is what phonology uses to predict the realization of specific inputs. In cases where this predicted realization violates a phonotactic constraint, a phonological operation must apply to change the coarticulatory context in order to ensure that the realization of the output conforms to the phonotactics. The architecture of the phonological grammar that the theory developed here implies is schematized in fig. 3.2. Thick arrows indicate the directionality of communication between components.

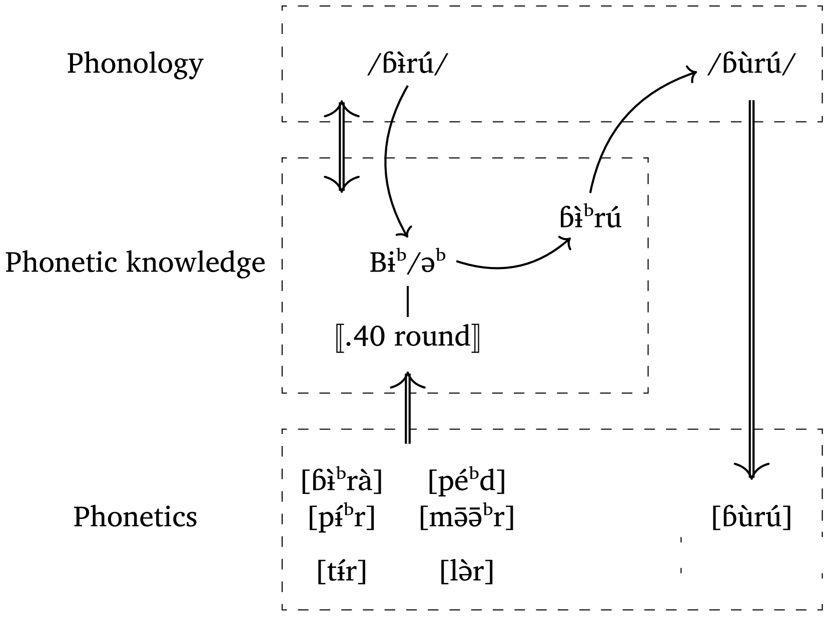

Figure 3.2: Phonology and phonetics mediated by phonetic knowledge

3.4.3.3 A weaker alternative: the Phonetic Filter

Alternatively, the role played by the high-ranked coarticulation-enforcing constraints —filter out candidates that do not conform to the coarticulatory grammar of the language— may be assigned instead to a "phonetic filter" built in GEN, as illustrated in fig. 3.3. Equipped with this filter, GEN may only generate output candidates that do not violate language-specific phonetic patterns, thus reducing the number of candidates submitted to constraint evaluation. This cannot consist in language-specific restrictions of course, since GEN, as part of the universal architecture of phonological grammar, cannot accommodate language-specific differences. GEN would only be able to refer to phonetic knowledge, conceived as a separate component of the grammar present in each language where language-specific phonetic patterns are to be found.

Given the Phonetic Filter, it is impossible for GEN to generate a candidate that lacks a subfeature if the language-specific coarticulatory conditions for that subfeature are met (underapplication of coarticulation), or one that carries a subfeature despite not meeting the coarticulatory conditions (overapplication). The only way to enforce or undo the coarticulatory effect responsible for the subfeatural specification in a candidate is to alter the environment that triggers it, e.g. from the input /ɓɨ̀rú/, GEN can produce the candidates [ɓɨ̀^{b}rú] and [ɗɨ̀rú], which both obey Laal-specific coarticulatory patterns, but not [ɓɨ̀rú] (expected subfeature missing) and [ɗɨ̀^{b}rú] (unjustified subfeature), which do not.

A corollary of this theory is that it is not only unnecessary, but impossible for a constraint in the phonological grammar to require a segment to carry a specific subfeature: subfeatures belong exclusively to phonetic knowledge, and are enforced by the Phonetic Filter. They cannot be manipulated by either GEN or EVAL. They can only be referred to in identifying contexts.

The Phonetic Filter approach appears to be an architectural variant of the high-ranked markedness constraints proposed in the illustrative analysis presented in § 3.3: both perform the same role, and make the same predictions. However, this equivalence is only observed in parallel models where constraints are all evaluated at once. Indeed, the Phonetic Filter requires every candidate to be a pronounceable word, which is incompatible with the postulation of abstract phonological representations, either in underlying representations or in pre-surface lexical strata, and as such is incompatible with derivational or multiple-step models like Stratal OT or Harmonic Serialism.

Enforcing subfeatural distinctions through high-ranked markedness constraints, as proposed in §§ 3.3 and 3.4.3.1 thus seems a more powerful option.[13]

3.5 Illustrative analysis 2: Woleaian *a*-raising

The iterativity of the Coarticulation function had no role to play in the Laal doubly triggered rounding harmony. The threshold of subphonemic rounding of ⟦0.40 round⟧ beyond which a labialized [ə^{b}] or [ɨ^{b}] becomes a target to the harmony is indeed reached after the first application of the function, i.e. the effect of one trigger is sufficient. Any further increase in the value of ⟦round⟧ incurred by an additional trigger (as in /pə́b-ó/ → [pób-ó] 'cobra-pl') is inconsequential.

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[13] Flemming's (2008) proposal also crucially rests on a similar phonetic filter mechanism. This filter is implemented as a separate, intermediate level of representation called "phonetic realization", with specific constraints applying prior to the phonotactic constraint grammar. See § 5.4.1.4 for a summary of this proposal, and a comparison with the subfeatural approach.

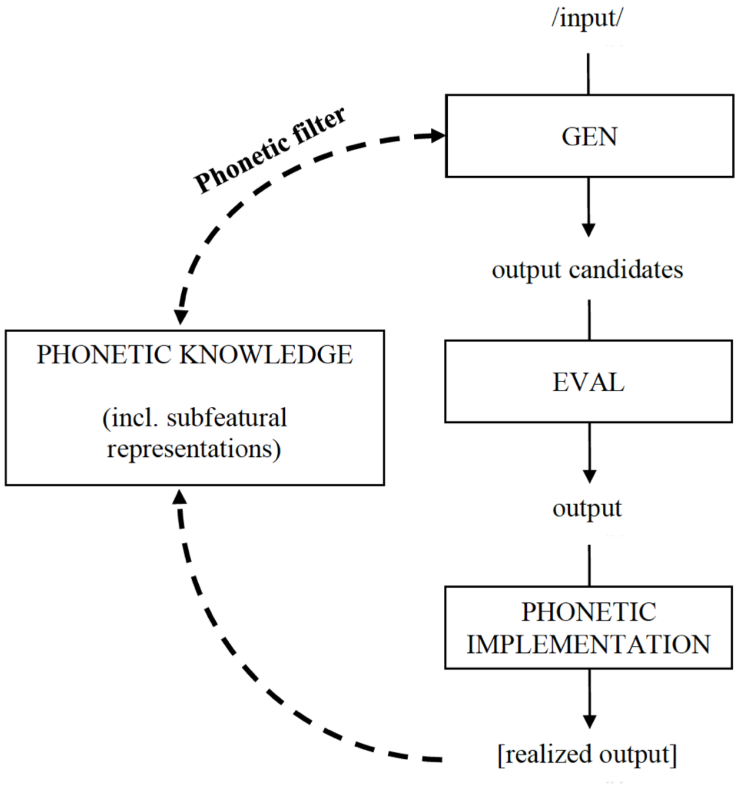

Figure 3.3: Implementation of phonetic knowledge through phonetic filter

In the case of Woleaian a-raising briefly presented in (1) and (2) (repeated in (43) and (44) below), which involves the cumulative effect of two triggers (at least in the hypothesis adopted here), the iterative nature of the function is crucial.[14]

(43) *a*-raising: $a \rightarrow e \;/\; V_{[+hi](C)\_}(C)V_{[+hi]}$
/ʉwal-i/ [ʉwe̲li̥] ‘neck of’
/ita-i/ [ite̲i] ‘my name’

(44) No a-raising if only one of the surrounding vowels is [+high]
a. /mafili/ [mafili̥] ‘to listen’
a. /nʉ-tage/ [nʉtage̥] ‘to sail with the sail narrowed’
b. /libbeja-i/ [libbejai] ‘my twins’

Before we can illustrate this, we first need to tackle the issue of the (sub)featural representation of vowel height. Since vowel height is a single articulatory and acoustic/perceptual dimension along which many languages contrast more than just two categories, its representation has always been somewhat problematic, in particular for models using only binary features (see Clements 2015 for an overview). The most commonly used representation, first proposed by Chomsky and Halle (1968), combines the two distinct binary features [±high] and [±low], with a ban

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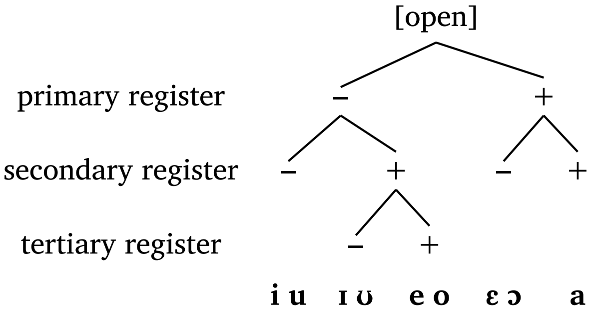
[14] See § 4.2.3 for more detail on subphonemic teamwork in Woleaian.

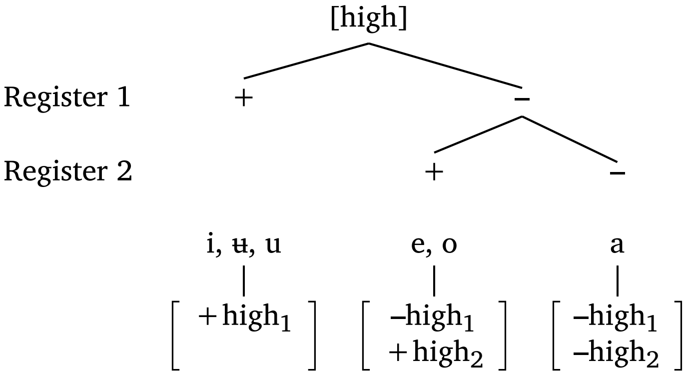
on contradictory [+high, +low]. It has also been proposed that vowel height might be better represented as a multi-valued feature (cf. Trubetzkoy 1939, Ladefoged 1971, Lindau 1978), e.g. [1 high] /a/ vs. [2 high] /e, o/ vs. [3 high] /i, ʉ, u/ in Woleaian. This is indeed more in keeping with the intuition that vowel height is only one property, and should therefore be represented with only one feature. Clements (1991, 2015) proposes a compromise solution integrating the advantages of both approaches, by representing vowel height "in terms of a single, hierarchically subdivided feature category" termed [open]. Vowel height, or aperture, is "divided into a number of hierarchically embedded registers," and each register and subregister is defined as an opposition between a [+open] and [–open] category. Vowel height is thus represented with "multiple occurrences of the single binary feature [open]," as illustrated in (45) below.

(45) Hierarchical representation of 5-height vowel system (Clements 2015: 44)



If we apply this analysis to Woleaian (using [high] instead of [open], to highlight the relation with the subfeature ⟦high⟧), the vowel system is first partitioned into two primary height registers: [+high$_1$] /i, ʉ, u/ vs. [–high$_1$] /e, o, a/. The latter register is further split into two secondary registers: [+high$_2$] /e, o/ vs. [–high$_2$] /a/, as shown in (46).[15]

(46) Hierarchical representation of Woleaian short vowels, after Clements (1991, 2015)



The subfeatural scale ⟦high⟧ exists alongside the classic featural representation of vowel height. The relations between the three-way featural contrast (in any of the three systems described above)

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[15] The reason why the primary division separates high vs. non-high vowels in Woleaian, as opposed to a primary split between low vs. non-low vowels, is that low and mid vowels seem to form a natural class, opposed to high vowels. This is suggested by the fact that 1) only high vowels trigger height assimilation (never mid vowels), and 2) low and mid vowels clearly pattern together, as can be seen from the a → e and a → o mergers operated by *a*-raising and *e*-backing/rounding. It could have been the reverse in another language. This is reminiscent of Dresher's (2009) approach to contrastiveness.

and the ⟦high⟧ subfeatural scale is shown in Table 3.3. Each contrastive height level is associated with an integer subfeatural value. Intermediate values are also represented, in this case a subdivision of [0 high] into three subfeatural values: non-raised ⟦0 high⟧, raised ⟦$C_p(x_{init})$ high⟧, resulting from one application of the coarticulatory function, and the projected doubly raised ⟦$C_p^2(x_{init})$ high⟧, resulting from two successive applications of the function (the parentheses indicate that this sound category is projected, hypothesized by the speaker, but never actually articulated or perceived).[16] The value of the coarticulatory coefficient *p* in each of these two intermediate values depends on the observed raising effect of high vowels onto neighboring low vowels, for which instrumental data have yet to be collected.[17]

SUBFEATURE				FEATURE(S)		
				Multi-valued	Binary/hierarchical	Binary
⟦2 high⟧	i	ʉ	u	[2 high]	[$+$high$_1$]	$\begin{bmatrix}+\text{high}\\ -\text{low}\end{bmatrix}$
⟦1 high⟧	e		o	[1 high]	$\begin{bmatrix}-\text{high}_1\\ +\text{high}_2\end{bmatrix}$	$\begin{bmatrix}-\text{high}\\ -\text{low}\end{bmatrix}$
(⟦$C_p^2(x_{init})$ high⟧)		(^{i}a^{i})		[0 high]	$\begin{bmatrix}-\text{high}_1\\ -\text{high}_2\end{bmatrix}$	$\begin{bmatrix}-\text{high}\\ +\text{low}\end{bmatrix}$
⟦$C_p(x_{init})$ high⟧		^{i}a, a^{i}				
⟦0 high⟧		a				

Table 3.3: Vowel height in Woleaian: subfeatural and featural representations

At first sight, the scalar subfeature ⟦high⟧ may seem to duplicate the multivalued feature [high]. This is not the case, however, as both representations play different roles. The multivalued feature [high] only represents the three-way height contrast. The subfeature ⟦high⟧ represents the (contextual) realization(s) of these three height levels relative to one another. In particular, [0 high] /a/ may be realized ⟦0 high⟧ (its lowest realization), or ⟦$C_p(x_{init})$ high⟧ when it is slightly raised by an adjacent [2 high] vowel. Crucially, both ⟦0 high⟧ [a] and ⟦$C_p(x_{init})$ high⟧ [^{i}a∼a^{i}] are phonologically [0 high]. The projected ⟦$C_p^2(x_{init})$ high⟧ [^{i}a^{i}] is also [0 high], which is why it is problematic: it is perceptually too close to ⟦1 high⟧ [e], and is accordingly changed to [1 high].

The cumulative effect at work in Woleaian *a*-raising is illustrated in (47) below, (the height contrast is represented with the multivalued feature [*n* high]).

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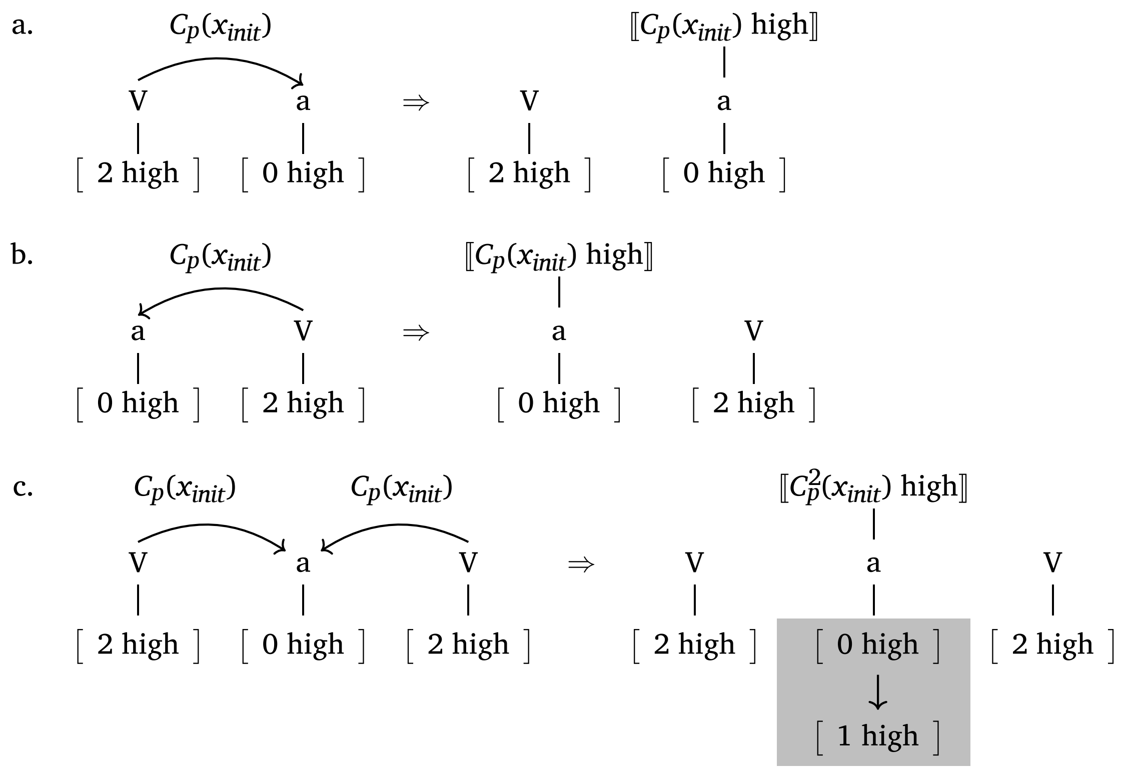
[16] With a subfeatural value of ⟦0 high⟧ prior to coarticualtion (i.e. $x_{init} = 0$), ⟦$C_p(0)$ high⟧ = ⟦p high⟧, and ⟦$C_p^2(0)$ high⟧ = ⟦$2p$–p^2 high⟧.

[17] The raised vowel ^{i} in [a^{i}] stands for the raising effect of the adjacent high vowel; in [^{i}a^{i}], the raising effect comes from both sides. This notation is borrowed from Flemming (2002). Note that a notation like [^{i}a^{i}] is very close to Q-theory (Shih and Inkelas 2014, Inkelas and Shih to appear), which subdivides every segment into three subsegments, which can be independently affected by assimilation processes.

(47)



⟦high⟧ subfeatural distinctions are enforced by COART, a high-ranked markedness constraint similar to LABCOART in Laal (cf. § 3.3), which is violated anytime height coarticulation over- or underapplies. In case of cumulative coarticulation, this constraint can only be fully satisfied by a candidate specified as $\llbracket C_p^2(x_{init})$ high$\rrbracket$, and not $\llbracket C_p(x_{init})$ high$\rrbracket$. Indeed, being $\llbracket C_p(x_{init})$ high$\rrbracket$, e.g. candidate b-ii in tableau (48), satisfies only one of the two coarticulatory requirements.

The a → e change can be analyzed as being driven by a high-ranked markedness constraint $*\llbracket C_p^2(x_{init})$ high$\rrbracket$/[0 high], penalizing [0 high] vowels whose subfeatural $\llbracket x$ high$\rrbracket$ value passes a threshold defined as $x = C_p^2(x_{init})$ high. This constraint would be motivated by the insufficient perceptual distance between this hypothesized realization of [^{i}a^{i}] and ⟦1 high⟧ [e] (cf. Flemming 1997, 2002 for a slightly different approach based on the same analysis). $*\llbracket C_p^2(x_{init})$ high$\rrbracket$/[0 high] must be ranked above IDENT[n high], which demands faithfulness to the value of the contrastive feature [high]. This ranking is illustrated in tableau (49).

Finally, to account for the fact that [^{i}a^{i}] is raised to [e] and not all the way to [i] (or to any other vowel), the faithfulness constraint IDENT[n high] must be defined as gradient, i.e. the number of violations it assigns depends on the extent to which the output candidate deviates from the input. This constraint is formally defined in (48) below. As seen in tableau (49), raising [^{i}a^{i}] all the way to [i] (candidate b-v) violates IDENT[n high] twice, while raising it to the closest vowel [e] (candidate b-iv) violates it only once, making this minimal raising the optimal repair.[18]

---

[18] Steriade (2009) highlights the importance of the degree of similarity between input and output as a selectional criterion in evaluating different phonotactically compliant outputs in her P-map model (cf. § 5.4.1).

(48) IDENT[*n* high]:[19]

For every [*n* high] feature in the input, a corresponding [*n* high] feature must exist in the output. Assign one violation per increment of change from *n* on the featural scale, e.g. a change to $n+1$ or n–1 incurs one violation; one to $n+2$ or n–2 incurs two violations.

(49)

		COART	*⟦$C_p^2(x_{init})$ high⟧	IDENT[*n* high]
a. /i...a/	i. i...a	*!		
	☞ii. i...^{i}a			
	iii. i...e			*!
b. /i...a...i/	i. i...a...i	*!*		
	ii. i...^{i}a...i	*!		
	iii. i...^{i}a^{i}...i		*!	
	☞iv. i...e...i			*
	v. i...i...i			**!

3.6 Conclusion

Subfeatures constitute a representation of segments in context, i.e. a representation of the phonetic knowledge of how segments interact when put together. This knowledge exists alongside phonology, and can be referred to by phonological processes, in a feedback/feed forward loop (cf. Boersma 1998) that constitutes a fluid and dynamic model of the phonetics/phonology interface. Phonology and phonetic knowledge are not ordered, but parallel and interactive, as illustrated in fig. 3.2 above.

The theory of subfeatural representations offers a straightforward account of cases of subphonemic teamwork such as the Laal doubly triggered rounding harmony or Woleaian *a*-raising, and is supported, in the case of Laal, by instrumental evidence. The ⟦.40 round⟧ subfeatural category corresponds to the labialized central vowels [ɨ^{b}, ə^{b}], which we saw in § 2.4 are clearly phonetically distinct from their non-labilalized counterparts [ɨ, ə].

The following chapter presents a preliminary typology of subphonemic teamwork on the basis of 50 cases identified so far, which shows that Laal and Woleaian are not isolated cases, and constitutes empirical support for the theory of subfeatural representations proposed here.

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[19] Note that this constraint could be rephrased to fit the binary [±high, ±low] feature model, or the hierarchical [±high$_1$, ±high$_2$] system *à la* Clements. Both systems represent height contrasts in such a way that changing [a] to [i] is more costly than changing it to [e]. Both [high] and [low] would need to be changed in the binary feature system ([–high, +low] → [+high, –low]). In the hierarchical system, [high] would need to be changed on both registers ([–high$_1$, –high$_2$] → [+high$_1$, $\emptyset$]

Chapter 4

A cross-linguistic typology of subphonemic teamwork

4.1 Introduction

In this chapter, I describe more cases of subphonemic teamwork similar to the Woleaian and Laal alternations presented in chapters 1 to 3, and establish a preliminary typology of subphonemic teamwork. I show how our understanding of the various cases of teamwork can benefit from the theory of subfeatural representations proposed in chapter 3. I finally show how the typology of subphonemic teamwork itself, in particular the discrepancy between the role played by vowels (overwhelmingly targets of teamwork) and consonants (overwhelmingly triggers), strongly suggests an approach that allows for a fine-grained, quantized representation of the contextual realization of segments, such as the theory of subfeatural representations proposed in chapter 3.

4.1.1 The database

The typological survey presented here is the first attempt to inventory the different types of subphonemic teamwork attested in the world's languages. It is based on a database of 52 cases that I was able to identify in 42 languages or language varieties, in descriptive and analytical sources consulted in the last three years. Many of these were first discovered in existing databases, notably Jeff Mielke's P-base (cf. Mielke 2008).[1] The data presented in this chapter are systematically taken from the original source (except for the Cantonese data in § 4.2.1.1, found in Flemming 2002). The depth of the description varies from source to source. I have tried to be as precise and thorough as possible, by consulting all available documents (articles, grammatical descriptions, dictionaries).

A brief list of the cases of subphonemic teamwork identified so far is presented in (50)-(55) below, organized by targeted phonological property (vowel backness, frontness, rounding, etc.) and teamwork-driven phonological process (vowel backing, fronting, rounding etc.). The source for each of these patterns can be found in appendix E.

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[1] `http://pbase.phon.chass.ncsu.edu/`

(50) Vowel frontness/backness (15 cases out of 52):

a. Backing:

Kɔnni (cf. § 4.2.1.3)	$/\mathrm{I}/ \rightarrow [\mathrm{U}] \ / \left\{\begin{array}{l} \mathrm{GU\_} \\ \mathrm{\_GU} \end{array}\right.$
Kaska (cf. § 4.4)	/ɛ/ → [ɐ] / _ɐ]$_{\sigma}$...ɐ
Louisiana Creole French	/a/ → [ɑ] / w_{l,r}]$_{\sigma}$
Anufo/Chakosi	/i/ → [ɨ] / G͡B_N
Thompson Salish	/e/ → [a] / {Gʷ,Qʷ}_{Gʷ,Qʷ}
	/e/ → [e] ~ [a] / B_Q

b. Fronting:

Cantonese (cf. § 4.2.1.1)	*DV$_{[+\text{front},+\text{rd}]}$D
Northern Gbaya (cf. § 4.2.1.2)	{u,o,ɔ} → [y,ø,œ / D_{i,e,ɛ}
Nyangumarta	/u,a/ → [y, æ] / J_J
Turkana	/o/ → [o] ~ [ʉ] / D_D (especially D_Di̥)
Wambaya	/a/ → [æ] / {ɳ,ɽ}_ɟ
Arabana, Wanggangurru	/a/ → [æ] / j_D (in σ́)
Wanggangurru (Eastern)	/a/ → [æ,e] / j_{C$_{\text{apical}}$, C$_{\text{laminal}}$} (in σ́)
Asmat	/u/ → [ʉ] / D_D

c. Fronting + raising:

Kɔnni (cf. § 4.2.1.4)	/a/ → [ɛ] / _Dɪ

(51) Vowel height (11 cases out of 52):

a. Raising:

Thompson Salish	/ə/ → [ᵻ] / J_J]$_{\sigma}$
Irish Gaelic	/e,o/ → [i,u] / Cʲ_{mʲ,nʲ,ṇʲ}
Khmuʔ	/ɛː/ → [eː] / {ɨ,u,c,ɲ}_j
Sonsorol (Pulo Anna)	/a/ → [ə] / {i,ɨ}_{i,ɨ}

b. Raising + fronting:

Woleaian (cf. § 4.2.3.1)	/a/ → [e] / V_high_V_high
Russian (cf. § 4.2.2.1)	/a/ → [i] / Cʲ_Cʲ (in immediately pretonic σ)
Taa (cf. § 4.2.2.2)	/a/ → [ɐ,ᵻ,e,i] / C_laminal(C)_(C){i,e}
Kalispel	/ə/ → [ɪ] / {tʃ,tʃ'}_{n,l,s}
Kumiái (Jamul Tiipay)	/a/ → [ɛ] / J_J$_{[-\text{nas}]}$ (in σ́)
Quichua (Ecuador)	/a/ → [e] / J_j]$_{\sigma}$
Irish	/a/ → [e] / Cʲ_Cʲ

(52) Vowel roundness (21 cases out of 52):

a. Rounding:

Laal (cf. chapter 2)	/ɨ,ə/ → [u,o] $/\left\{\begin{array}{l}\text{B\_C(C)u/o}\\ \text{\_Bu/o}\\ \text{\_(C)Bu/o}\end{array}\right.$
Iaai (cf. § 4.3.1.3)	*e > ø / B_G]$_{\sigma}$ (?)
Acehnese (cf. § 4.2.4.1)	/ɨ/ → [u] / B_B
Kazakh (cf. § 4.2.4.2)	/ɪ,ɯ/ → [ʏ,ʊ] / $X_{rd/lab}$_$X_{rd/lab}$
Wergaia (cf. § 4.3.1.1)	/e/ → [ø] / {B,G}_Ḍ

b. Rounding + backing:

Woleaian (cf. § 4.2.3.2)	/e/ → [o] / u_u
Tamil (cf. § 4.3.1.2)	/i,e/ → [u,o] / B_Ḍ
Wergaia	/a/ → [ɑ∼ɒ∼ɔ] / w_{Ḍ,ŋ}
Wemba Wemba	/a/ → [ɒ∼ɔ] / w_{Ḍ,r,ŋ,nV}
Madhi Madhi	/a/ → [ɒ∼ɔ] / w_{Ḍ,r}
Arabana & Wanggangurru	/a/ → [ɔ] / w_{B,G,Ḍ,r,j}
Wirangu	/a/ → [ɔ] / #w_{B,G}
Nyangumarta	/a/ → [ɒ] / w_G
Nisga’a	/a/ → [ɔ] $/\left\{\begin{array}{l}\text{B\_Q}\\ \text{Q\_B}\end{array}\right.$
Straits Salish (Samish)	/a/ → [a]∼[ɔ] / Q^{w}_{G,Q,G^{w},$B_{resonant}$}
Unami	/ə/ → [o] / Q^{w}_x
Tauya	/e/ → [o] / B_B
Kalispel	/ə/ → [u] / G^{w}_B,B^{w},j
Thompson Salish	/ə/ → [u] / G^{w},Q^{w}_G^{w},Q^{w} (in unstressed σ)

c. Unrounding (?)[2]:

Asmat	/o/ → [ɤ] $/\left\{\begin{array}{l}\text{\{t, s\}\_\{t, s\}}\\ \text{j\_\{t, \}}\end{array}\right.$

(53) Vowel acuteness/graveness (3 cases out of 52):

Fe’fe’ Bamileke, Igbo Akan (cf. § 4.3.2)	Epenthetic $V_{[+\text{hi}]}$ assimilates to cumulative [±grave] environment ($C_{[\text{grave}]}\_C_{[\text{grave}]}V_{[\text{grave}]}$)

(54) Vowel nasality (1 case out of 52):

Maléku Jaíka (cf. § 4.2.5)	V → Ṽ / N_N

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[2] It is unclear whether this is a genuine case of unrounding, however (cf. § 4.7.3.2).

(55) Consonant palatality (1 case out of 52):
Capanahua (cf. § 4.5.1) {s,ʂ} → ʃ / i_-iʃ

Only 16 cases —17 including the Laal doubly triggered rounding harmony seen in chapter 2— will be presented in detail in this chapter, among which each one of the listed phonological processes in (50)-(55) is illustrated at least once.

As can be seen from (50)-(55), all the cases of subphonemic teamwork I was able to identify target vowels, except one: the Capanahua double-sided palatalization in (55). I will come back to this striking discrepancy in § 4.5. Additionally, all involve assimilation. I will discuss in § 4.6 a potential case of subphonemic teamwork involving dissimilation attested in Finnish. The preponderance of assimilation results from one important flaw of the database in its present state, namely the fact that 34 of the 52 cases listed above were extracted from P-base using the search keywords "bidirectional assimilation" and "progressive & regressive assimilation". Double-sided assimilation patterns are thus very likely overrepresented. I did not go through all 7318 patterns listed in P-base to supplement this search. I simply added 15 cases I found in the many references I consulted. All are assimilatory patterns, and 12 of them also involve double-sided triggers (all but the Laal rounding harmony and the two Kɔnni alternations). I will come back to this potential issue in § 4.7.1.3.

The languages in the database are genetically and geographically diverse, as shown in Tables 4.1 and 4.2.

The sample is also diverse from a typological point of view. Different morphological types are represented, from agglutinating and polysyllabic (e.g., Kaska, Kazakh) to isolating and monosyllabic (e.g. Cantonese). Some languages have vowel harmony: Kazakh (backness, rounding), Laal (height, rounding), Kaska (backness), Igbo and Kɔnni (ATR). Both tonal (e.g. Cantonese, all African languages) and non-tonal languages are included, as well as languages with (e.g. Russian, Acehnese) or without (e.g. Laal, Taa) stress. Finally, the vowel systems are also extremely varied, as shown with the number of contrastive vowel per language in Table 4.3 (only the 17 languages described in the dissertation are included).

15 representative cases of subphonemic teamwork targeting a vowel are described in sections § 4.2 to § 4.4. Section § 4.5 describes the only attested case of consonant-targeting teamwork, as well as a few other potential cases. Finally section§ 4.7 summarizes the typological characteristics of subphonemic teamwork.

4.1.2 The typology

Two types of subphonemic teamwork can be identified, depending on the nature of the segments and featural interactions involved: Additive teamwork, where two (or more) triggers add up their subphonemic effects to trigger a categorical assimilation, and subphonemic enabling, where a subphonemic effect feeds a categorical assimilation process. Additive teamwork comes in three subtypes: self-additive, mutually enhancing, and coincidental, as summarized in (56).

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[3] For Australian language names, I follow the standard spelling used by the Australian Institute of Aboriginal and Torres Straight Islanders (AIATSIS).

[4] I adopt the inventory proposed by McCollum (2015). Other researchers have proposed different analyses of the Kazakh vowel system (see summary and references in McCollum 2015).

Phylum	Sub-classification	Language (dialect) [ISO code]
Algic	Eastern Algonquian	Delaware (Unami) [unm]
Athabaskan	Northern Athabaskan	Kaska [kkz]
Austroasiatic	Khmuic	Khmuʔ [kjg]
Austronesian	Malayo-Sumbawan	Acehnese [ace]
	Oceanic, Micronesian	Sonsorolese (Pulo-Annan) [sov], Woleaian [woe]
	Oceanic, Loyalty Islands	Iaai [iai]
Chibchan		Maléku Jaíka [gut]
Creole		Louisiana Creole French [lou]
Dravidian		Tamil [tam]
Indo-European	Celtic	Irish Gaelic [gle]
	Slavic	Russian (South-Central) [rus]
Isolate		Laal [gdm]
Mirndi		Wambaya [wmb]
Niger-Congo	Bantoid, Grassfields Bantu	Fe’fe’ Bamileke [fmp]
	Gbaya-Manza-Ngbaka	North-Gbaya [gya]
	Gur, Oti-Volta	Konni [lma]
	Jukunoid	Kpan (Kente) [kpk]
	Kwa, Potou-Tano	Anufo [cko]
Nilo-Saharan	Eastern Nilotic	Turkana [tuv]
Pama-Nyungan	Karnic	Arabana [ard], Wanggangurru [wgg]
	Kulin	Madhi Madhi [dmd], Wemba Wemba [xmw], Wergaia (Djadjala) [weg]
	Marrngu	Nyangumarta [nna]
	Thura-Yura	Wirangu [wgu]
Panoan		Capanahua [kaq]
Quechuan		Quichua (Ecuador, Puyo Pongo) [qxl?]
Salishan	Central Salish	Straits Salish (Samish) [str]
	Interior Salish	Kalispel [fla], Thompson [thp]
Sino-Tibetan	Sinitic, South Chinese	Cantonese [yue]
Trans New Guinea	Central-South New Guinea	Asmat (Flamingo Bay) [cns]
	Madang	Tauya [tya]
Tsimshian		Nisga’a [ncg]
Turkic		Kazakh [kaz]
Tuu		Taa (!Xóõ) [nmn]
Yuman		Kumiái (Jamul Tiipay) [dih]

Table 4.1: Languages by genetic affiliation

Macro-area	Area	Language
Africa	Central Africa	Fe’fe’ Bamileke, North Gbaya, Laal
	East Africa	Turkana
	Southern Africa	Taa (!Xóõ)
	West Africa	Konni, Anufo, Igbo, Kpan (Kente)
America (North)	California	Kumiái (Jamul Tipai)
	Louisiana	Louisiana Creole French
	Mid-Atlantic	Delaware (Unami)
	Pacific Northwest	Thompson, Kalispel, Straits Salish (Samish), Nisga’a, Kaska
America (Central)		Maléku Jaíka
America (South)	Northern Andes	Quichua (Ecuador, Puyo Pongo)
	Amazon	Capanahua
Asia	Central Asia	Kazakh
	East Asia	Cantonese
	South Asia	Tamil
	South-East Asia	Khmu?, Acehnese
Australia[3]		Nyangumarta, Wambaya, Arabana, Wanggangurru, Wirangu, Madhi Madhi, Wemba Wemba, Wergaia
Europe	Eastern Europe	Russian (South-Central)
	Western Europe	Irish Gaelic
New Guinea		Tauya, Asmat (Flamingo Bay)
Pacific islands	Micronesia	Woleaian, Sonsorolese (Pulu-Annan)
	New Caledonia	Iaai

Table 4.2: Languages by geographical location

(56) Four (sub-)types of subphonemic teamwork:
  a. Additive teamwork:
    i. Self-additive teamwork
    ii. Mutually enhancing teamwork
    iii. Coincidental teamwork
  b. Subphonemic enabling

All four (sub-)types are defined in §§ 4.1.2.1 and 4.1.2.2 below. Each type is illustrated with a schema using subfeatural representations. These abstract, general schemas only serve an illustrative purpose here, and are not intended to be accurate generalizations over each and every possible teamwork pattern. By convention, and to simplify the notation, they always illustrate cases with two double-sided triggers, and the phonological change triggered by the teamwork effect is always one from the negative to the positive value of the relevant binary feature(s).

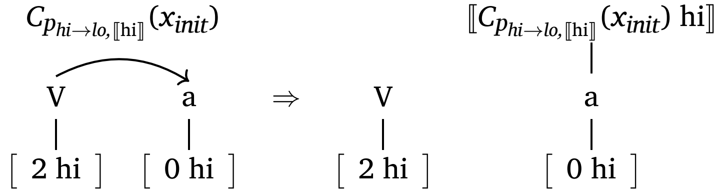
Language	Short modal/oral V	Long modal/oral V	Total contrastive V (incl. length, nasalization, phonation, etc.)
Kaska	3	5	8
Capanahua	4	–	4
Wergaia	4	–	4
Russian	5	–	5
Taa	5	–	20
Tamil	5	5	10
Woleaian	6	8	14
Northern Gbaya	7	–	12
Cantonese	7	–	7
Fe’fe’ Bamileke	8	8	16
Kɔnni	9	9	19
Iaai	10	10	20
Acehnese	10	–	27
Kazakh[4]	11	–	11
Laal	12	12	24

Table 4.3: Languages by vowel inventory size

4.1.2.1 Additive teamwork

4.1.2.1.1 Self-additive teamwork In self-additive teamwork, all the co-triggers contribute the same subphonemic effect to the target. 9 of the 17 cases of teamwork described in this dissertation are self-additive: Kɔnni, Cantonese, Northern Gbaya, Russian, Taa, Woleaian, Acehnese, Kazakh, Maléku Jaíka. The subfeatural analysis of Woleaian *a*-raising sketched in § 3.5 is repeated in (57) below. A high vowel contributes a proportion of increase $p_{hi\rightarrow lo,[\![\mathrm{hi}]\!]}$ in the value of the subfeature [\![high]\!] to an adjacent low vowel [a] through the application of the coarticulatory function $C_{p_{hi\rightarrow lo,[\![\mathrm{hi}]\!]}}(x_{init})$ defined in (20) in chapter 3. The resulting subfeatural value of the coarticulatorily raised $[{}^{i}a{\sim}a^{i}]$ is $[\![C_{p_{hi\rightarrow lo,[\![\mathrm{hi}]\!]}}(x_{init})$ high$]\!]$, as illustrated in (57a). With two adjacent high vowels, the function applies twice, making the target vowel $[{}^{i}a^{i}]$ subfeaturally $[\![C^2_{p_{hi\rightarrow lo,[\![\mathrm{hi}]\!]}}(x_{init})$ high$]\!]$. This subfeatural value passes the threshold (set at $[\![\geq C^2_{p_{hi\rightarrow lo,[\![\mathrm{hi}]\!]}}(x_{init})$ high$]\!]$) beyond which raised $[{}^{i}a^{i}]$ becomes too similar to the next contrastive vowel up the [\![high]\!] subfeatural scale [e] not to be reanalyzed as that vowel, i.e. become [1 high], as shown in (57b).[5]

(57) a.



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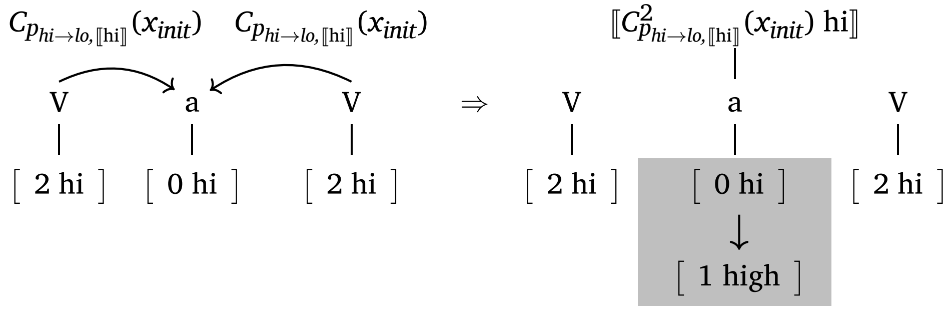
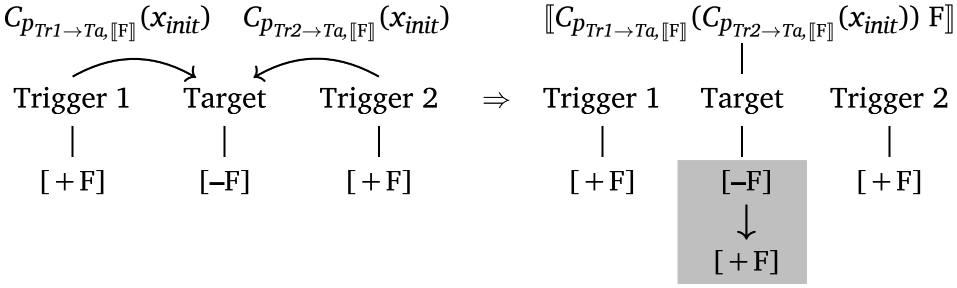
[5] With $x_{init} = 0$, $C_p(x_{init}) = C_p(0) = p$, and $C_p^2(x_{init}) = C_p^2(0) = 2p–p^2$.

b.



The following general schema can be proposed to represent self-additive teamwork within the theory of subfeatural representations:

(58) Self-additive teamwork



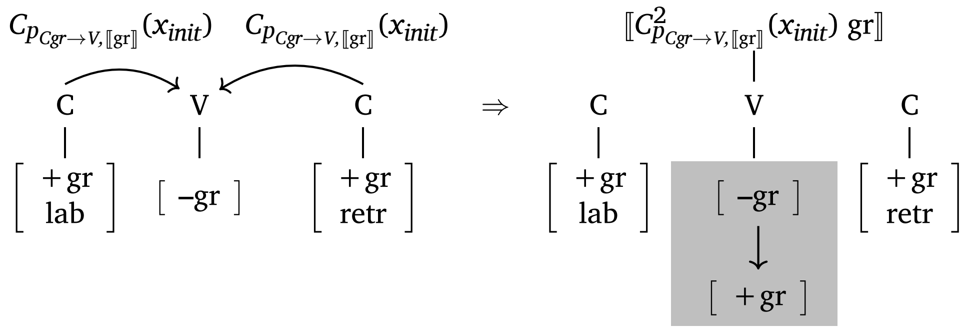
4.1.2.1.2 Mutually enhancing teamwork Mutually enhancing teamwork is a subtype of self-additive teamwork, where the two (or more) subphonemic effects at work are in an enhancement relation, i.e. they originate from two different articulations with the same acoustic/perceptual effect. The self-additive effect is thus only perceptual, not articulatory. Four cases are described in this chapter: Wergaia, Tamil, Iaai, and Fe'fe' Bamileke. The Tamil case is briefly illustrated below.

(59)	pi̱ɖi	[pu̱ɖi]	'like'
	ʋi̱ːɖu	[ʋu̱ːɖu]	'house'
	pe̱ʈʈi	[po̱ʈʈi]	'box'

Labial and retroflex consonants, as well as back rounded vowels, although different from an articulatory point of view, share acoustic/perceptual properties, specifically the downward drift of higher formants. In their acoustic feature system, Jakobson et al. (1952) propose to capture this property with the feature [+flat]. However, labials and retroflexes also qualify as [+grave], another acoustic feature defined in the same system by a low center of gravity of higher formants. Since in other languages (e.g. Wergaia, see § 4.3.1.1), the same phenomenon involves not only labial and retroflex, but velar consonants as well, which cannot be said to be [+flat], I choose to analyze this alternation as a case of gravity rather than flatness assimilation.

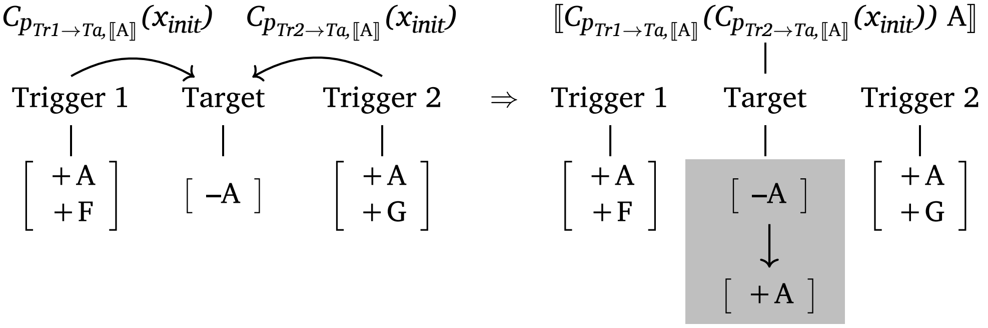
In the Tamil example above, the labial and retroflex consonants both have a formant lowering effect on the intervening vowel. The independent effect of each isolated trigger is however not sufficient to fully change the [–grave] target vowel to [+grave]. Only the cumulative effect of two triggers is (see § 4.3.1.2 for more detail). A representation of this cumulative subphonemic effect in subfeatural terms is presented in (60).

(60)



A general subfeatural schema for mutually-enhancing teamwork is proposed in (61) (where [A] is an acoustic feature, and [F] and [G] articulatory features).

(61) Mutually enhancing teamwork:

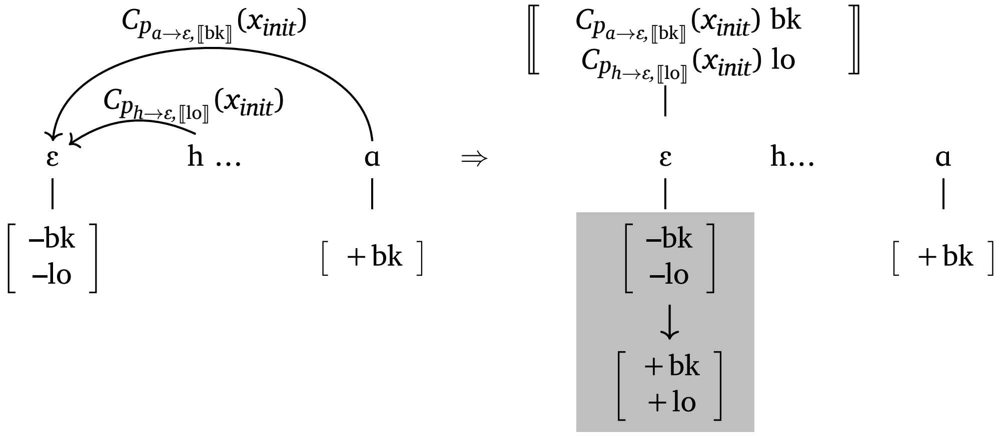


4.1.2.1.3 Coincidental teamwork Subphonemic teamwork may sometimes be coincidental, when the two subphonemic effects at work are different and not in an enhancement relation, but still lead to one categorical change. The only example of such an effect I have found so far is Kaska, where the front vowel /ɛ/ is lowered and backed to /ɑ/ when immediately followed by a tautosyllabic /h/ and followed by the vowel /ɑ/, as briefly illustrated in (62a) below.

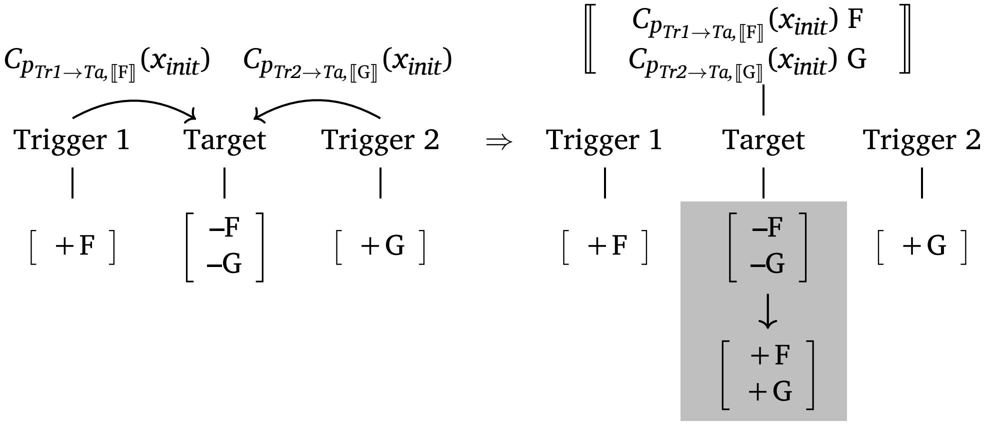
(62)	a.	/sɛ-h = tɑ:n/	*sa̲hta:n*		'(s)he put (long object) there'
	b.	/sɛ-Ø = tɑ:n/	*sɛta:n*	(**sata:n*)	'(long object) is there'
	c.	/sɛ-h = tsʉ́:ts/	*sɛhtsʉ́:ts*	(**sahtʉ́:ts*)	'(s)he put (fabric) there'

As shown by (62b-c), neither a following tautosyllabic /h/ nor a following /ɑ/ are sufficient to trigger the alternation. Both are necessary, as in (62a). The subphonemic lowering effect the tautosyllabic [h] (evidenced by instrumental measurements, see § 4.4.2) and the subphonemic backing effect of the following [ɑ] cumulatively lead to the full ɛ → ɑ change, as schematized in (63), with subfeatural representations. A general subfeatural schema is proposed in (64).

(63)



(64) Coincidental teamwork:



4.1.2.2 Subphonemic enabling

I found two cases of subphonemic enabling, i.e. partially subphonemic teamwork, as in the case of the Laal doubly triggered rounding harmony described and analyzed in detail in (chapters 2 and 3), and the Capanahua multiple trigger sibilant palatalization (cf. § 4.5.1). Teamwork in this case does not involve the addition of more than one subphonemic effects, but the interaction of one single subphonemic allophonic effect with a categorical assimilation triggered by a segment that has no noticeable coarticulatory effect on the target. This categorical assimilation is represented with a double arrow in the schema below (cf. chapters 2 and 3 for a detailed analysis of subphonemic enabling in Laal).[6]

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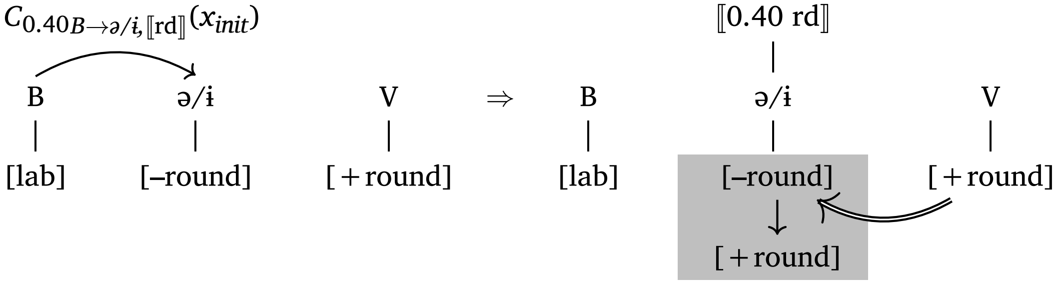
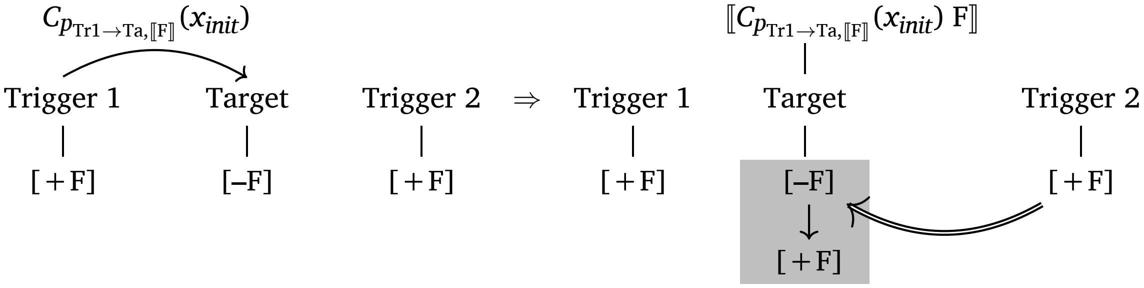
[6] Note that Capanahua teamwork-driven palatalization involves both self-additive teamwork ({s,ʂ} → [$^{\text{i}}$s$^{\text{i}}$, $^{\text{i}}$ʂ$^{\text{i}}$] / i_i) and subphonemic enabling ([$^{\text{i}}$s$^{\text{i}}$, $^{\text{i}}$ʂ$^{\text{i}}$] → [ʃ] / _-ʃ), as shown in § 4.5, ex. (205).

(65)



Subphonemic enabling can be schematized as follows.

(66) Subphonemic enabling:



4.1.3 Presentation of the case studies

In the remainder of this chapter, I first present the cases of teamwork that target vowels: self-additive (§ 4.2), mutually enhancing (§ 4.3), and coincidental (§ 4.3) (the only clear case of subphonemic enabling is the Laal doubly-triggered rounding harmony described in chapter 2). I then focus on teamwork targeting consonants (§ 4.5). I present the only real attested case (Capanahua, § 4.5.1, and discuss the case of Kpan, which looks like teamwork, but is not (§ 4.5.2). I then discuss a potential case of dissimilatory teamwork attested in Finnish (§ 4.6), concluding that it does not qualify as subphonemic teamwork, and that subphonemic teamwork is unlikely to give rise to dissimilation. Finally, the typological properties of subphonemic teamwork and their theoretical relevance are discussed in § 4.7.

The presentation of the data in each case follows the same steps: it starts with the description of the pattern, followed by a discussion of its phonetic underpinnings, and ends with a summary of the properties of the pattern, situating it in the general typology, which will be presented in § 4.7 at the end of this chapter. The summary is presented in the form of the following table.

4.2 Self-additive teamwork (vowel target)

4.2.1 Vowel fronting/backing

4.2.1.1 Cantonese inter-coronal fronting

Cantonese inter-coronal fronting is an example of self-additive teamwork made famous by Flemming (Flemming 1997, 2002). It consists in a morpheme structure constraint banning back rounded vowels between coronal consonants: $^*C_{cor}o/uC_{cor}$. This is illustrated in (68), after a

Teamwork	Type:	E.g. self-additive
	Phonological process:	E.g. assimilation
	Property(ies):	E.g. rounding
Target	Type:	V or C
	Weak/strong:	Weak or strong
Triggers	Number:	1, 2, 3
	Type:	C and/or V
	Hierarchy:	E.g. V trigger > C trigger
	Position w.r.t. target:	E.g. double-sided
	Locality w.r.t. target:	E.g. adjacent
Phonological status	Static pattern:	Yes/no
	Active alternation:	Yes/no
	Morphological conditioning:	Yes/no
	Post-lexical:	Yes/no
	Exceptions:	Yes/no/marginal

Table 4.4: Properties of subphonemic teamwork

presentation of the vowel inventory of Cantonese in (68), where the arrows indicate the vowel mergers that arise through trans-coronal fronting (Flemming 1997, Flemming 2002; data originally from Kao 1971, Cheng 1989, Cheng 1991.

(67) Cantonese vowel inventory
i y ⟵ u
e ø ⟵ o
a, a:

(68) Inter-coronal fronting (Cheng 1991: 110-111; Flemming 2002: 77)

tyt	‘to take off’	*tut, *tsut
tøn	‘a shield’	*ton, *tot, *tsot

However, if only one of the flanking consonants is coronal, back rounded vowels are allowed, as shown in (69).

(69)

tuk	‘bald head’
tok	‘to carry (on shoulders)’

If even one consonant is non-coronal, both back and front vowels are possible, as shown in 70.

(70)

kut	‘bracket’	vs.	kyt	‘to decide’
kot	‘to cut’			
kon	‘dry’			
ho	‘river’	vs.	hø	‘boots’

Flemming (2002: 77) analyzes this static pattern as a case of assimilation driven by the perceptual correlate of CV coarticulation: a coronal consonant tends to exert a light fronting coarticulatory effect on an adjacent vowel (by raising F2 during the transition between C and V). In

Front/back scale	a. /k^h u k/ [k^h u k]	b. /k^h u t/ [k^h u t]	c. /t^h u k/ [t^h u k]	d. /t^h u t/ [t^h u t]
[+ front]				y
↑				~~^{y}u^y~~
		u^y	^{y}u	
[-front]	u			

Table 4.5: Subphonemic threshold effect in Cantonese inter-coronal fronting

Cantonese, the fronting effect of one adjacent coronal consonant is insufficient for categorical phonological fronting ([-front] → [+ front]) to take place, but the cumulative and double-sided effect of two flanking coronals breaks the threshold and triggers the assimilation: [u^y] and [^{y}u] are not front enough to assimilate to [y], but [^{y}u^y] is (superscript ^{y} indicates the fronting effect of an adjacent coronal consonant on [u]):

> Two coronals have a cumulative effect on the distinctiveness of the contrast between front and back rounded vowels, resulting in a less distinct contrast in this environment. That is, in the contrast [k^{y}y^{y}t]-[k^{u}ʉ^{y}t], the distinction between /y/ and /u/ is realized during the release transitions and the vowel, whereas between coronals [t^{y}y^{y}t]-[t^{y}ʉ^{y}t], it would be realized in the vowel only. That is… the distinctiveness of a contrast spends on the duration of the differences as well as on the magnitude of the differences at a particular point in time.

This is illustrated in Table 4.5 below. Note that Flemming's analysis is mostly speculative, since he does not provide any instrumental evidence of the significance of the coarticulatory fronting effect of each co-trigger. I will however use it as a working hypothesis.

A subfeatural analysis along the lines proposed for Woleaian in § 3.2.1 is sketched in (71) below. Each co-trigger contributes the same amount of fronting. This fronting effect results from the application of the coarticualtory function $C_{p_{D\to U,[\![\mathrm{fr}]\!]}}(x_{init})$ (where "D" and "U" stand for "coronal consonant" and "back vowel" respectively).

(71)

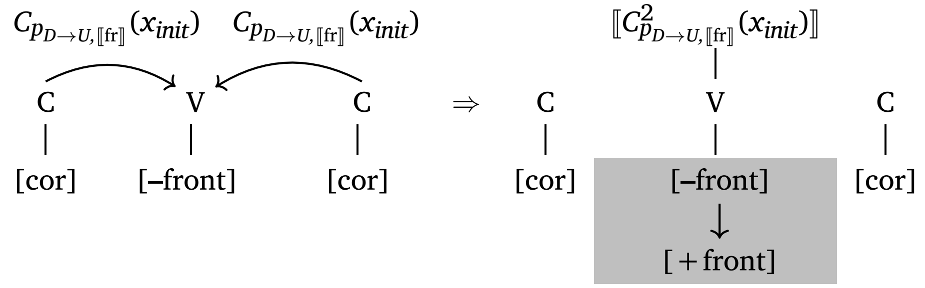


Table 4.6 summarizes the characteristics of Cantonese inter-coronal fronting.

4.2.1.2 Northern Gbaya doubly triggered fronting

A very similar double-sided vowel fronting process is attested in the northern dialects of Gbaya (Niger-Congo, Gbaya-Manza-Ngbaka), whose vowel and consonant inventories are presented in

Teamwork	Type:	Self-additive
	Phonological process:	Assimilation
	Property(ies):	Front/coronal
Target	Type:	V
	Weak/strong:	n/a
Triggers	Number:	2
	Type:	C
	Hierarchy:	equal co-triggers
	Position w.r.t. target:	double-sided
	Locality w.r.t. target:	strictly adjacent
Phonological status	Static pattern:	Yes
	Active alternation:	No
	Morphological conditioning:	No
	Post-lexical:	No
	Exceptions:	No

Table 4.6: Properties of Cantonese inter-coronal fronting

(72) and (73) below. The arrows in the vowel chart indicate the vowel changes incurred by the assimilatory process.

(72) Northern Gbaya vowel inventory (Moñino 1995: 58)

i	[y] ←——— u	ĩ		ũ
e	[ø] ←——— o			
ɛ	[œ] ←——— ɔ	ɛ̃		ɔ̃
	a		ã	

(73) Northern Gbaya consonant inventory (Moñino 1995: 58)

	Labial	Alveolar	Palatal	Velar	Labial-velar	Glottal
Stop	p, b	t, d		k, g	k͡p, g͡b	ʔ
Prenasalized	^{m}b	^{n}d		g	^{m}g͡b	
Implosive	ɓ	ɗ				
Nasal	m	n	ɲ	ŋ	ŋ͡m	
Fricative	f, v	s, z				h
Lateral		l				
Tap/flap	ⱱ	r				
Glide	w		j			

In all Northern Gbaya dialects, the oral back rounded vowels /u, o, ɔ/ are fronted to [y, ø, œ] when they are preceded by a coronal consonant (alveolar or palatal), and followed by a front vocoid /i, e, ɛ, j/. This is schematized in (74) below, and illustrated in (75)-(77) (unless noted otherwise, all examples are from the Kàrà ɓòdòè dialect, Moñino 1995: 61).[7]

---

[7] The dialects in questions are: Kàrá ɓòdòè, Kàrá ɓòkpàn, Kàrá ɓùgùì, Kàrá ɓòɲìnà, Yàáyùwèè ɓòyá, Yàáyùwèè of Bindinda.

(74) Double-sided back vowel fronting: $V_{back} \rightarrow V_{front}$ / V_{cor}__{V_{front}, j}

(75) u → y / C_{cor}__{i, e, j} (NB: /uɛ/ is unattested)

a. C_{cor}__

túí	[tyi]	‘bark cloth’
dúì	[dyi]	proper name
ndùì	[ndyi]	‘mouse’
súí	[syi]	‘swell’
sùé	[sye]	‘toad sp.’
tútùjè	[tytyje]	‘morning’

b. C_{noncor}__

kúì	[kui]	‘egg’[8]
búì	[bui]	‘White person’
kùè	[kue]	‘snail’

(76) o → ø / C_{cor}__{i, e, j} (NB: /oɛ/ is unattested)

a. C_{cor}__

tóí	[tøi]	‘carry’	
dóí	[døi]	‘forge’	
sóí	[sǿí]	‘squat’	
zóí	[zøi]	‘swim, bathe’	
tòè	[tøe]	‘baggage’	
dòè	[døe]	‘termite’	
ndóé	[ndøe]	‘termite sp.’	
sóé	[søe]	‘seat, insect sp.’	
jòjà	[jøja]	‘dance’	(Yàáyùwèè dialect, Noss 1981: 9)
tòjó	[tøjo]	‘dog’	(id.)
dójà	[døja]	‘grasshopper’	(id.)
sòjá	[søja]	‘vegetable’	(id.)
zòjà	[zøja]	‘mouse’	(id.)

b. $C_{non\text{–}cor}$__

kòè	[koe]	‘squirrel sp.’

(77) ɔ → œ / C_{cor}__{i, ɛ} (/ɔe/ is unattested, and I could not find any ɔjV example)

a. C_{cor}__

sɔ́í	[sœi]	‘be cloudy’
ndɔ̀ɛ́	[ndœɛ]	‘Albyzia zygia’
nɔ́ɛ́	[nœɛ]	‘bird’
sɔ̀ɛ́	[sœɛ]	‘Solanum sp.’
jɔ̀ɛ̀	[jœɛ]	‘dance’
ɲɔ̀ɛ́	[ɲœɛ]	‘bird sp.’

b. $C_{non\text{–}cor}$__

mbɔ̀ì	[mbɔi]	‘dowry, money’
ŋgɔ̀ɛ̀	[ŋgɔɛ]	‘throat abscess’

---

[8] Monino and Roulon’s (1972: 78) transcription [küi] is erroneous, as explicitly acknowledged in Moñino (1995: 61).

This double-sided fronting is very similar to Cantonese inter-coronal fronting, in that a morpheme structure constraint bans back rounded vowels from surfacing between two front segments. The teamwork effect is the same: the fronting effect of C_{cor} and V_{front} is not strong enough to fully front an adjacent back vowel, only the cumulative effect of both is.

Contrary to Cantonese, it is non-structure-preserving: front rounded vowels are not contrastive in Gbaya, they are in complementary distribution with their back allophones (cf. (72) above). One more important difference with Cantonese is that fronting applies only between a front consonant and a front vocoid, and never between two front consonants (with sonority lower than glide).[9] This is an indication that the consonantal co-trigger might have less strong of a fronting effect than the vocalic co-trigger. Note that both VVV and VVC sequences are unattested in Northern Gbaya, which makes C_{cor}__{V_{front}, j} the only context conducive to fronting.

Finally, although Moñino (1995) does not say it explicitly, his description of the pattern as well as the morphology of the language indicate that this alternation is very likely an active process in the language, e.g. a form like /ɗɔ́-í/ 'dig-ITERATIVE' is mostly likely realized [ɗœ́í].

An analysis of this cumulative effect in subfeatural terms would look exactly like the one sketched for Cantonese in (71), § 4.2.1.1.

The properties of this teamwork effect are summarized in Table 4.7.

Teamwork	Type:	Self-additive
	Phonological process:	Assimilation
	Property(ies):	Frontness
Target	Type:	V
	Weak/strong:	n/a
Triggers	Number:	2
	Type:	C and V
	Hierarchy:	V > C (?)
	Position w.r.t. target:	Double-sided
	Locality w.r.t. target:	Adjacent
Phonological status	Static pattern:	Yes, obligatory
	Active alternation:	Yes (?)
	Morphological conditioning:	?
	Post-lexical:	No (?)
	Exceptions:	?

Table 4.7: Properties of Northern Gbaya double sided vowel fronting

4.2.1.3 Kɔnni trans-dorsal backing

Two cases of self-additive teamwork involving vowel frontness vs. backness are attested in Kɔnni (Gur; Cahill 2000, Cahill 2007, Cahill 2009): trans-dorsal vowel backing, and trans-coronal vowel fronting, briefly illustrated in (78) and (79) below respectively.

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[9] The fronting of the first vowel in /tùtùjé/ → [tytyje] 'morning' in (75a) seems to contradict this statement. However, one could see this case as the result of reduplication with a strong base-reduplicant identity requirement, similar to the Dakota case documented by Shaw (1980: 344–355) and analyzed by Marantz (1982: 459).

(78) Trans-dorsal backing: $/\mathrm{I}/ \rightarrow [\mathrm{U}] \,/\! \left\{ \begin{array}{l} \mathrm{UG}\_ \\ \_\mathrm{GU} \end{array} \right.$

/kúgí-rí/	→	kúgú̱-rí	'cooking place-DEF.SG.1'
/ɲʊ̀ʊ̀gɪ̀-bʊ́/	→	ɲʊ̀ʊ̀gʊ̱̀-bʊ́	'smell-DEF.SG.4'
/yíbí-kʊ́/	→	yíbʊ̱́-kʊ́	'crocodile-DEF.SG.3'
/jɔ̀lí-kú/	→	jɔ̀lú̱-kú	'jackal-DEF.SG.3'

(79) Trans-coronal fronting: a → ɛ / _Dɪ

/bal-/	balɪ	~	bɛlɪ	'speak'
/tas-/	tasɪ	~	tɛsɪ	'kick'
/yal-/	yalɪ	~	yɛlɪ	'have'
/gbáríáŋ/	gbáríáŋ	~	gbɛ́ríáŋ	'earthworm'

A presentation of some aspects of the morpho-phonology is necessary before we delve into the details of these two cases.

4.2.1.3.1 Preliminary remarks on Kɔnni morpho-phonology The vowel and consonant inventories of Kɔnni are presented in (80) and (81) below. The arrows in (80) show which vowels merge with which other vowels in the two teamwork cases attested in the language: i → u and ɪ → ʊ through trans-dorsal backing (solid arrow), a → ɛ through trans-coronal fronting (dashed arrow).

(80) Kɔnni vowel inventory (Cahill 2007: 175)

	+ATR		-ATR		
Short:	i ⟶	u	ɪ ⟶		ʊ
	e	o	ɛ ⇠		ɔ
				a	
Long:	ii	uu	ɪɪ		ʊʊ
	ee~ie	oo~uo	ɛɛ~ɪa		ɔɔ~ʊa
				aa	

(81) Kɔnni consonant inventory (Cahill 2007: 97)

Labial	*Alveolar*	*Palatal*	*Velar*	*Labial-velar*	*Glottal*
p b	t d	tʃ j [dʒ]	k g	kp gb	
f v	s z				h
	l				
m	n	ɲ	ŋ	ŋm	
		y [j]	w		

In the remainder of this section, I will use the capital letters I and U to refer to the [+/-ATR] high vowel pairings [i, ɪ] and [u, ʊ] respectively, and D and G to refer to coronal and velar/dorsal consonants respectively.

A few words about vowel epenthesis and the morpho-phonology of verb stems are in order before the description of the Kɔnni facts. Monomorphemic verbs in citation form are maximally

C_1	V_1	C_2	V_2	C_3	V_3
All C	All V + length contrast	g (21) r (12) l (8) t (3) m (3) s (1) b (1)	I (epenthetic; I → U through trans-dorsal backing)	s (22) r (8) g (5) l (2)	I (epenthetic)

Table 4.8: Distribution of Cs and Vs in Kɔnni trisyllabic verb stems (Cahill 2007: 262-266)

trisyllabic, the vast majority being mono- or disyllabic (420 out of 461 in Cahill's (2007) database). Non-initial syllables in di- and trisyllabic verbs are subject to heavy phonotactic restrictions, summarized in Table 4.8.

The restrictions on vowel distribution are particularly drastic. Only V_1 is lexically specified, while $V_{2\ 3}$ are always high front /I/, the default epenthetic vowel in Kɔnni, whose [ATR] value is determined by V_1 Cahill 2000; Cahill 2007: 262-266). The final /I/ in di- and trisyllabic verbs is epenthesized to prevent illicit word-final consonants (only nasal consonants are allowed word-finally), and the second-syllable epenthetic /I/ in trisyllabic verbs prevents illicit consonant clusters (the only clusters attested in verbs are /ns, nt, ŋg/, found only in disyllabic verbs).[10]

Regarding consonants, C_3 may only be /s/, /r/, /l/ or /g/, which are also the most frequent consonants in C_2. As Cahill shows, these distributional restrictions on consonants, together with comparative data from other Gur languages, show that all trisyllabic verbs (and some of the disyllabic ones as well) used to be morphologically complex forms involving the four verbal extensions -s-, -r-, -l-, and -g-. Some are still attested in both their simple and derived forms, as shown by the forms in 82a and 82b respectively, although the two forms are synchronically unrelated, and both monomorphemic. For the sake of clarity, I have decided to isolate both the epenthetic /I/ and the fossilized extensions with dashes in the transcriptions (-I-, -C-), so as to clearly indicate the position of the epenthetic vowel both in the underlying forms (...C̱-C̱-) and in surface forms (...C-I̱-C̱-I̱).

(82) Vowel epenthesis in verbs:[11]

a.	Disyllabic	/hag-/	hag-ɪ̱	'get up'
		/gɪr-/	gɪr-ɪ̱	''surround, fence in'
b.	Trisyllabic	/hag-r-/	hag-ɪ̱-r-ɪ̱	'be strong'
		/gɪr-g-/	gɪr-ɪ̱-g-ɪ̱	'be crowded'

Vowel epenthesis also applies between noun roots and noun class suffixes, as illustrated with class 1 nouns in 83a. An /I/ is epenthesized between a consonant-final root and a consonant-initial suffix.

---

[10] Note that in Cahill (2007: 262-266), the only vowel in the verb that is explicitly analyzed as epenthetic is the final vowel. I have taken the liberty to extend this analysis to V2 in trisyllabic verbs, based on the full predictability of this vowel as well as the striking similarities with other cases of vowel epenthesis in the language.

[11] Tone is not distinctive on verbs, and will not be marked here. The default tone pattern of the citation form is LH, realized L.L.H on trisyllabic verbs Cahill, 2000).

(83) Vowel epenthesis in class 1 nouns:[12]

			Definite sg. *-rí*
a.	/tíg-/	‘house’	tíg-í̱-rí
	/chʊ́ʊ̀s-/	‘gecko’	chʊ́ʊ́s-í̱-ꜜrí
b.	/dàà-/	‘mouth’	dàà-rí
	/ɲʊ́ʊ́-/	‘chest’	ɲʊ́ʊ́-rí

4.2.1.3.2 trans-dorsal backing The short vowel /I/ may never precede or follow a high back vowel /U/ if the intervening consonant is velar (*IGU, *UGI), unless it is in the word-final syllable (I will come back to this condition in later, cf. (90)). This restriction holds both as a general static distributional constraint and as an active alternation: /I/ is changed to [U] in this context, illustrating both perseverative (UGI → UGU) and anticipatory (IGU → UGU) backing. The only vowel with which the alternation is visible is epenthetic /I/: derived UG-I- and -I-GU sequences are all realized [UGU], with a few partly predictable exceptions, as we will see (Cahill 2007: 244-250; Cahill 2009). Trans-dorsal backing is illustrated in (84)-(95).

The exhaustive list of verbs and nouns illustrating active perseverative trans-dorsal backing in Cahill (2007) is presented in (84) and (85) respectively. Remember from (82) that the vowel epenthesized into medial position (VC__CV) is normally /I/.

(84) Perseverative trans-dorsal backing (UG__) in verbs (exhaustive list):

/bʊg-r/	bʊg-ʊ̱-rɪ	‘learn’
/mʊg-s/	mʊg-ʊ̱-sɪ	‘suck’
/sug-s/	sug-u̱-si	‘wash’
/mʊg-r/	sʊg-ʊ̱-rɪ	‘wake’
/tug-r/	tug-u̱-ri	‘be bright’
/ɲʊg-s/	ɲʊg-ʊ̱-sɪ	‘sharpen’

In verbs, only epenthetic V_2 in trisyllabic stems is subject to trans-dorsal backing: it is indeed the only position where it is not in the word-final syllable, while still being preceded by a syllable containing /U/ Table 4.8 above). This vowel systematically surfaces as [U] whenever the requirements of trans-dorsal backing are met, as shown by the exhaustive list of trisyllabic verbs whose V_2 is [U] in 84, which is also the entire list of verbs where all the conditions for trans-dorsal backing are met: perseverative trans-dorsal backing is thus exceptionless in verbs.

I found 17 nouns in Cahill (2007) where the conditions for perseverative trans-dorsal backing are met. The assimilation takes place in only seven of them, all listed in 85. For the sake of clarity, I will keep these as well as other exceptions to the Konni pattern out of this section, and refer the reader to Appendix F (ex. 276 and 277) for more detail.

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[12] Noun classes will be indicated with numerals 1-5 in the glosses (e.g. DEF.SG.2 = ‘definite singular suffix of class 2’)

(85) Perseverative trans-dorsal backing (UG__) in nouns:

/kúg-rÍ/	kúg-ú̱-rí	‘cooking place-DEF.SG.1’
/bàɲʊ̀ʊ̀g-rÍ/	bàɲʊ̀ʊ̀g-ʊ̱̀-rí	‘soup leaf-DEF.SG.1’
/dààgbúg-rÍ/	dààgbúg-ú̱-rí	‘stump-DEF.SG.1’
/mʊ́g-rÍ/	mʊ́g-ʊ̱́-rí	‘river-DEF.SG.1’
/tʊ́g-rÍ/	tʊ́g-ʊ̱́-rí	‘termite hill-DEF.SG.1’
/kʊ̂g-tÍ/	kʊ́g-ʊ̱́-ꜜtí	‘ghost-PL’
/ɲʊ̀ʊ̀g-bÚ/	ɲʊ̀ʊ̀g-ʊ̱̀-bʊ́	‘smell-DEF.SG.4’

Anticipatory trans-dorsal backing is only attested in nouns, because the conditions for its application (__GU) cannot be met in verbs, where the vowels /u, ʊ/ are attested underlyingly only in the first syllable Table 4.8 above). The conditions for anticipatory trans-dorsal backing are actually only ever met in class 2 nouns, where the definite suffix -kʊ́ changes a preceding epenthetic /I/ to [U]. 33 of the 78 class 2 nouns listed in Cahill’s (2007: 439-456) Appendix B require vowel epenthesis between the root and the definite singular suffix *-kʊ́*. In 25 of them, all listed in 86 below, the vowel is [U]. An explanation regarding the eight nouns where anticipatory trans-dorsal backing fails to apply can be found in Appendix F (ex. 282).

(86) Anticipatory trans-dorsal backing (__GU): class 3 nouns with DEF.SG.3 *-kÚ*:

Stem	Stem + *-kÚ*	
/yíb-/	yíb-ʊ̱́-kʊ́	‘crocodile’
/jǐl-/	jìl-ʊ̱́-ꜜkʊ́	‘tongue’
/gìr-/	gìr-ʊ̱̀-kʊ́	‘fence’
/gàr-/	gàr-ʊ̱̀-kʊ́	‘clothes’
/lɔ̀l-/	lɔ̀l-ʊ̱̀-kʊ́	‘voice, throat’
/vɔ́r-/	vɔ́r-ʊ̱́-kʊ́	‘hole’
/jòl-/	jòl-ú̱-kú	‘jackal’
/kôr-/	kóꜜr-ʊ̱́-kʊ́	‘seat, inside’
/kʊ̂g-/	kʊ́g-ʊ̱́-ꜜkʊ́	‘ghost’
/chʊ̀b-/	chʊ̀b-ʊ̱̀-kʊ́	‘wing’
/kpííꜜl-/	kpííꜜl-ʊ̱́-kʊ́	‘hawk’
/dììs-/	dììs-ʊ̱̀-kʊ́	‘spoon’
/háàr-/	hááꜜr-ʊ̱́-kʊ́	‘boat’
/lààl-/	lààl-ʊ̱̀-kʊ́	‘cockroach’
/gbíàb-/	gbíáb-ʊ̱́-ꜜkʊ́	‘door’
/lèèl-/	lèèl-ṳ̀-kú	‘turtle’
/bʊ̀às-/	bʊ̀às-ʊ̱̀-kʊ́	‘viper’
/kùòl-/	kùòl-ṳ̀-kú	‘calabash’
/tùùr-/	tùùr-ṳ̀-kú	‘line, mark’
/gʊ́ʊ̀l-/	gʊ́ʊ́l-ʊ̱́-ꜜkʊ́	‘pit’
/gígàr-/	gígáꜜr-ʊ̱́-kʊ́	‘fish (sp.)’
/chìàkʊ̀r-/	chìàkʊ̀r-ʊ̱̀-kʊ́	‘scorpion’
/jíkꜜkɔ́r-/	jíkꜜkɔ́r-ʊ̱́-kʊ́	‘basket (sp.)’
/kpéꜜjús-/	kpéꜜjús-ú̱-kú	‘black kite’

/núꜜyíb-/	núꜜyíb-ʊ̱́-kʊ́	‘fingernail’[13]

Trans-dorsal backing is a clear case of phonological teamwork involving two co-triggers: /G/ and /U/. Both triggers are back but not enough to trigger categorical phonological backing of an adjacent /I/ on their own, as shown in the examples in (87) and (88) below, where absence of one of the two triggers is enough to prevent trans-dorsal backing.

(87) Missing trigger in perseverative trans-dorsal backing:

				Co-trigger U	Co-trigger G
a.	Vowel after /G/ is not /U/			*	✔
	/lag-s-/	lag-ɪ̱-sɪ	‘gather’		
	/pɔg-l-/	pɔg-ɪ̱-lɪ	‘hold’		
	/kpog-r-/	kpog-i̱-ri	‘break’		
	/hààg-rÍ	hààg-ì̱-rí	‘bush-DEF.SG.1’		
	/bɔ̀g-tÍ/	bɔ̀g-ì̱-tí	‘rope-PL’		
b.	Intervening C is not /G/			✔	*
	/sʊr-s-/	sʊr-ɪ̱-sɪ	‘rub’		
	/fur-s-/	fur-i̱-si	‘slurp’		
	/sul-s-/	sul-i̱-si	‘be full’		
	/chʊ́ʊ̀s-rÍ/	chʊ́ʊ́s-í̱-ꜜrí	‘gecko-DEF.SG.1’		
	/gʊ́ʊ́l-tÍ/	gʊ́ʊ́l-í̱-tí	‘pit-PL’		

(88) Missing trigger in anticipatory trans-dorsal backing:

				Co-trigger U	Co-trigger G
a.	Vowel after /G/ is not /U/			*	✔
	/jìb-kÁ/	jìb-ì̱-ká	‘knife-DEF.SG.3’		
	/pér-kÁ/	pér-í̱-ké	‘button-DEF.SG.3’		
	/wàl-kÁ/	wàl-ì̱-ká	‘antelope-DEF.SG.3’		
	/bɔ̂l-kÁ/	bɔ́ꜜl-í̱-ká	‘ball-DEF.SG.3’		
b.	Intervening C is not /G/			✔	*
	/wàg-bÚ/	wàg-ì̱-bʊ́	‘fight-DEF.SG.4’		
	/wàl-bÚ/	wàl-ì̱-bʊ́	‘sweat-DEF.SG.4’		
	/ɲìgìs-bÚ/	ɲìgìs-ì̱-bʊ́	‘lightning-DEF.SG.4’		
	/bòl-bÚ/	bòl-ì̱-bú	‘fire-DEF.SG.4’		

Words such as *bɔ̀gìtí* and *kpogiri* in (87a) as well as *bɔ́ꜜlíká* in (88a) show that the vocalic co-trigger must be not only back, but high as well. Cahill (2007) chooses to use the feature [dorsal] to capture this fact: velar consonants and the high back vowel U are both [dorsal], the latter by virtue of being not obly [+back] but also [+high], i.e. involving a velo-dorsal near-constriction (U is the vowel whose articulation is the closest to that of velar consonants).

Interestingly, only velar consonants may co-trigger trans-dorsal backing. Labials, which frequently trigger backing or rounding of neighboring vowels cross-linguistically, do not qualify as co-triggers, as shown by the words in (88b) above and (89) below.

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[13] < nú- ‘hand’ + yíb- ‘scratching’

(89) UB__: no agreement

/chʊ̀b-tÍ/	chʊ̀b-ì-tí	‘wing-PL’
/wùùb-rÍ/	wùùb-ì-rí	‘liver-DEF.SG.1’

I could not find any word in Cahill’s (2007) data where a labial-velar consonant would be in a position to potentially co-trigger trans-dorsal backing (no UG͡B__ or __G͡BU sequences). This is very likely to be an accidental gap, since labial-velar consonants are quite rare in non-word-initial position in Kɔnni: they are attested in only 61 out of the 1650 words in Cahill’s (2007: 79-84) data. /GBI/ is attested in only 11 of them, (but the preceding vowel is never the co-trigger /U/), and /GBU/ in only two words (but the preceding vowel is never /I/). Given that labial-velars are characterized by a velar closure and a labial release, and that labials do not participate in trans-dorsal backing, one could expect labial-velars to co-trigger agreement only when they follow the target, i.e. in the anticipatory case __G͡BU. Alternatively, the presence of the labial feature in the consonant could also be hypothesized to prevent labial-velars from participating in the alternation altogether. This question of the potential participation of labial-velars in trans-dorsal backing must however remain unanswered without more data.

Finally, trans-dorsal backing is subject to three additional conditions, which we have so far seen only in passing: adjacency, directionality, and position, defined in (90).

(90) Additional conditions on trans-dorsal backing:

a.	Adjacency:	The target needs to be adjacent to both co-triggers: directly string-adjacent to the consonant co-trigger, and tier-adjacent to the vowel co-trigger.
b.	Directionality:	Trans-dorsal backing is either perseverative or anticipatory, but never bidirectional, i.e. both triggers need to be on the same side of the target.
c.	Position:	The target of trans-dorsal backing cannot be in the word-final syllable.

The examples in (91) illustrate the necessity of the first two conditions: adjacency and directionality. Trans-dorsal backing does not take place if one (91a-b) or both (91c) triggers are non-adjacent to the target, even if they are both on the same side. It does occur either when the two triggers are on opposite sides of the target, as in (91d) and (91e), even if they are both adjacent to it.[14]

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[14] Because of the very restrictive phonotactic restrictions on verb stems, configurations violating adjacency and directionality can only be found in nouns.

(91) Violation of adjacency and directionality:

			Adjacency		Directionality
			U	G	
a.	U…G__		*	✔	✔
	bʊ́llɔ́g-í-rí	'bag-DEF.SG.1'			
	bʊ̀llɔ̀g-ì-tí	'armpit-PL.1'			
	kʊ̀jààg-ì-rí	'sore-DEF.SG.1'			
b.	GUC__		✔	*	✔
	bʊ̀gʊ̀r-ì-tǎŋ	'anklebone'[15]			
c.	GU…__		*	*	✔
	gʊ́ʊ́l-í-tí	'pit-PL.1'			
d.	UC__G		✔	✔	*
	mùl-ì-ké	'bird (sp.)-DEF.SG.3'			
	bàtúú↓l-í-ké	'English-DEF.SG.3'			
	wútúlí-ké	'intestine-DEF.SG.3'			
	chúnchúúr-í-ké	'puddle-DEF.SG.3'			
	chún↓chúl-í-ké	'tree (sp.)-DEF.SG.3'			
	fʊ́ʊ́r-í-ká	'food (sp.)-DEF.SG.3'			
e.	G__CU		✔	✔	*
	wàg-ì-bʊ́	'fight-DEF.SG.4'			
	dì-dìg-ì-rú	'cook (agentive noun)'			
	náág-í-↓bʊ́	'cow- DEF.SG.4'			

An interesting conclusion of these facts is that trans-dorsal backing not only requires two co-triggers, but also requires that these co-triggers be different, i.e. /U/ and /G/, never two /U/'s or two /G/'s. Of course, this might simply be due to the adjacency and directionality requirements: the only phonotactically licit configuration where two /G/'s or two /U/'s are adjacent to the target is flanking (G__G and UC__CU), which violates the directionality condition, while in words where the target is either preceded or followed by two identical triggers, one of the triggers necessarily violates the adjacency condition (G…G__, __G…G, U…UC__, and __CU…U).

The last condition listed in (90) above is that trans-dorsal backing may not target a vowel in the word-final syllable. This condition is systematic for verbs, a few examples of which are listed in (92), but suffers many exceptions in nouns. I found 10 nouns in Cahill's data where the the potential target of trans-dorsal backing is in the final syllable (root ending in /…ug-/ + epenthetic /I/ + indefinite suffix *-ŋ́*). In exactly half of these nouns, listed in (93) below, the positional condition is obeyed.

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[15] This noun is most probably a compound, although the meaning of the two parts it is made of is not clear: the first part is homophonous with the verb /bʊg-r-/ *bʊgʊrɪ* 'learn', and the second could be the noun *tǎŋ* 'stone' (see Cahill 2007: 57). Whatever the origin and meaning of the two parts, the third syllable's [ɪ] is most likely to be epenthetic.

(92) Target /I/ in verb final syllable

tʊg-ɪ	‘reach (a destination)’
sug-i	‘dip’
yʊg-ɪ	‘weave’
bʊg-ɪ	‘soothsay’
mʊg-ɪ	‘suck’
vug-i	‘swing’
ɲʊʊg-ɪ	‘smell something’
hʊʊg-ɪ	‘be rotten’

(93) Target /I/ protected from trans-dorsal backing in noun final syllable

		Indefinite sg *-ŋ́*
/kúg-/	‘cooking place’	kúg-ɪ̲́-ŋ
/bàɲʊ̀ʊ̀g-/	‘soup leaf’	bàɲʊ̀ʊ̀g-ɪ̲́-ŋ
/dààgbúg-/	‘stump’	dààgbúg-ɪ̲́-ŋ
/ɲʊ̀ʊ̀g-/	‘smell’	ɲʊ̀ʊ̀g-ɪ̲́-ŋ

In the other five nouns, trans-dorsal backing applies, thus violating the word-finality condition, as shown in (94). A detailed study of these exceptions is provided in Appendix F.

(94)

		Indefinite sg. *-ŋ́*
/mʊ́g-/	‘river’	mʊ́g-ʊ̲́-ŋ
/tʊ́g-/	‘termite hill’	tʊ́g-ʊ̲́-ŋ
/kʊ̂g-/	‘ghost’	kʊ́g-ʊ̲́-ꜜŋ́
/sʊ́g-/	‘fish trap’	sʊ́g-ʊ̲́-ŋ
/zùzùg-/	‘lung’	zùzùg-ú̲-ŋ

Another characteristic of trans-dorsal backing is that it does not target long /II/ (by definition non-epenthetic), as illustrated in (95) below. This cannot be shown for perseverative backing, since there is no noun (and of course no verb, cf. Table 4.8 above) in Cahill’s (2007) data containing the sequence UG directly followed by a long vowel.

(95) No trans-dorsal backing in /...II-kʊ́/:

mɪ̲̀ɪ̲̀-kʊ́	‘ant-DEF.SG.2’	
bɪ̲̀ɪ̲̀–kʊ́	‘goat-DEF.SG.2’	
chɪ̲́ɪ̲́-kʊ́	‘moon-DEF.SG.2’	
yɪ̲́ɪ̲́-kʊ́	‘blindness-DEF.SG.2’	
chɪ̀àfɪ̲́ɪ̲́-kʊ́	‘anus-DEF.SG.2’	(chɪ̀à- ‘waste’ + ?)
lɔ̀lɪ̀wɪ̲̀ɪ̲̀–kʊ́	‘larynx-DEF.SG.2’	(lɔ̀l- ‘flute’ + wɪ́ɪ́- ‘voice’)
wútúlínɪ̲́ɪ̲́-ꜜkú	‘colon-DEF.SG.2’	(wútúl- ‘intestine’ + nɪ́ɪ̂- ‘female’)

Finally, the nouns in (86) are the only five cases of static trans-dorsal back agreement I could find in Cahill’s (2007) description.

(96) Trans-dorsal back agreement as morpheme structure constraint (exhaustive list):

a.	bʊ̀gʊ̀rìtăŋ	‘anklebone’	< /bʊg-r + taN-/, with epenthetic u
b.	sùkùlí	‘heart’	< /suk + li/, with epenthetic u?
c.	púŋúꜜlúꜜŋ	‘fish (sp.)’	< /puŋ + luN-/, with epenthetic u?
d.	gʊ̀ŋgʊ̀m-í-ŋ	‘kapok fruit’	< reduplication /gʊm + gʊm-/?
e.	nʊ́nʊ́gʊ́ꜜŋ́	‘fish (sp.)’	< reduplication /nʊ + nʊgʊN-/?

The first noun (96a) is a fossilized compound Cahill (2007: 57). The second U in the underlined UGU sequence in this example is thus likely to have been epenthetic /I/, changed into [U] through perseverative trans-dorsal backing. The following two nouns (96b-c) might also be historical compounds, based on the fact they are trisyllabic, in which case the second vowel would also have been epenthetic /I/. The last two nouns (96d-e) are most probably reduplicative forms. Trans-dorsal backing in the first one (*gʊ̀ŋgʊ̀míŋ*) is thus accidental: the reduplicated base just happens to start with a GU sequence. This leaves the hypothetical unreduplicated root /nʊgʊN/ in (96e)as the only case that cannot be analyzed even historically as involving an epenthetic vowel.[16]

4.2.1.3.3 Phonetic motivations In the absence of precise data on vowel-to-vowel and consonant-vowel coarticulation in Kɔnni, the exact mechanisms at work in this case of teamwork must remain speculative. However, a few observations can be made that make some hypotheses more likely than others.

The fact that the target is always short /I/, and never any other vowel should not be too surprising, for at least two reasons: its phonetic weakness, and the fact that it is acoustically and articulatorily the most distant vowel from both co-triggers on the front/back continuum, hence the most prone to front/back related coarticulatory effects from the two triggers. We saw that only short /I/ is subject to trans-dorsal backing, and that most of the time this vowel is epenthetic, i.e. phonologically weak. This phonological weakness adds to the intrinsic phonetic weakness of high vowels, notably high front vowels, which tend to have shorter intrinsic duration cross-linguistically Maddieson 1997, and references therein). Cahill (2007: 179-80) provides average acoustic measurements that confirm that this universal tendency is observed in Kɔnni, as shown in Table 4.9: the two shortest vowels are [i] (65 ms) and [ɪ] (78 ms), closely followed by the two back vowels [u] (81 ms) and [ʊ] (80 ms), while the non-high vowels show clearly longer durations (between 94 ms and 114 ms). Note that long [ii] and [ɪɪ] are in average 144 ms and 141 ms long respectively for the same speaker, i.e. about twice as long as their short counterparts.

In addition to its phonetic and phonological weakness, [I] is also the most distant vowel from [U] and [G] articulatorily, since it involves a very high and fronted tongue position (coming close to a palatal constriction), while for [U] and [G] the tongue body must be as far back as possible (nearing or reaching velar constriction). This articulatory distance makes [I] naturally prone to local coarticulatory effects from [U] and [G], and also explains why [U] and [G] should trigger trans-dorsal backing, and no other vowel or consonant. Velar consonants are indeed the only dorsal consonants available (given the rarity of non word-initial labial-velars noted earlier), and [u] and [ʊ] are the most (the only?) dorsal vowels as we saw: [o] and [ɔ], being less high, involve a lesser degree of dorso-velar constriction.

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[16] As can be seen in Appendix F (ex. 276c-d), there are only two exceptions to the static pattern.

	Sample word	Average duration	Number of tokens	Standard deviation
i	sibi	65 ms	12	9
ɪ	dɪ̀dààrʊ̀	78 ms	22	10
u	kúgè	81 ms	12	13
ʊ	bʊ̀gʊ̀rʊ̀	80 ms	12	12
e	kpesi	94 ms	9	14
o	kosiŋ	99 ms	15	9
ɔ	bɔbɪŋ	114 ms	18	15
a	dɪ̀dàgɪ̀rʊ́	114 ms	15	11

Table 4.9: Short vowel duration in Kɔnni, one male speaker (Cahill 2007: 179)

Note that the coarticulatory effect of velar consonants on a neighboring high front vowel is not unlikely to be significant. Indeed, Cahill (2007: 176, 258-61) notes that the velar nasal coda /ŋ/ has a strong tendency to retract an immediately preceding front vowel /i, ɪ, e/ to [ɨ, ᵻ, ə], as illustrated in (97) below.[17] Cahill describes this as a gradient phonetic effect. The fact that Cahill does not say anything about other velar consonants clearly indicates that if they do have a similar effect, it is much less important. Once again, in the absence of acoustic measurements, it is impossible to be more precise.

(97)	/dèmb-ŋ́/	[dèmbɨ̱́ŋ]	'man'	cf.	[dèmbɪ̱̀ké]	'the man'
	/tìg-ŋ́/	[tɨ̱̌ŋ]	'village'	cf.	[tɪ̱̀kká]	'the village'
	/keŋ/	[kə̱ŋ]	'come'	cf.	[ke̱n-ne]	'is coming'

While the necessity for both triggers to be present is very likely due, as for all other kinds of teamwork, to a threshold effect, one needs to explain why the cumulative coarticulatory effects of adjacent /G/ and /U/ breaks the threshold only when both are on the same side of the target. In other words, if both /G/ and /U/ have a slight backing effect on an adjacent [I], why do we not get backing when the two triggers flank the target, i.e. UC__G and G__CU? One possible explanation is that in this context, the non-velar consonant that intervenes between /U/ and the target blocks the coarticulatory effect of the former onto the latter. This is likely to be the case when the intervening consonant is a coronal: a consonant involving a front constriction is likely to prevent or decrease any dorsal coarticulation between the trigger /U/ and target /I/ that it separates. This argument is less convincing, however, for cases where the intervening consonant is labial, since the articulation of a labial consonant does not involve the tongue, and the dorsal gesture of [U] could technically be maintained through the articulation of B in UB__, and anticipated through it in __BU.

It is conceivable, however, that the nature of the intervening non-dorsal consonant is irrelevant: its presence simply imposes a distance between /U/ and the target vowel that is sufficient to prevent (or limit) any articulatory overlap between them. The role of the intervening velar consonant could then be understood as an extension of the dorsal (high/back) articulation of /U/, a sort of articulatory proxy that extends the vowel co-trigger's dorsal articulation all the way to the

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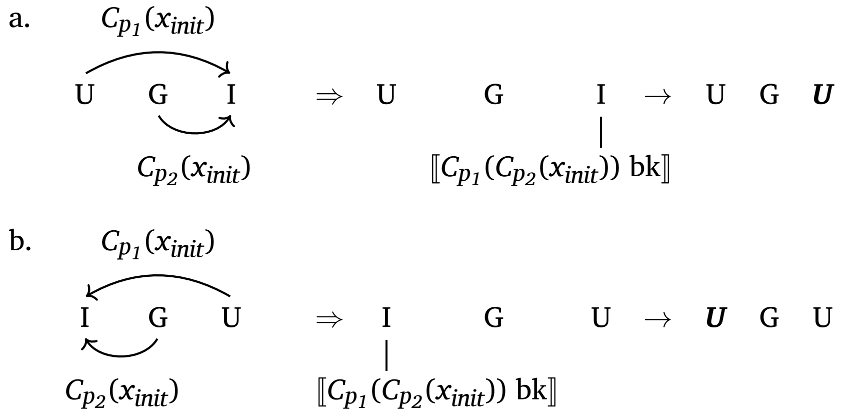
[17] For the vowels [ɨ, ᵻ], "preliminary measurements actually give F1 and F2-F1 values… almost exactly between [i, ɪ] and [u, ʊ]" (Cahill 2007: 259). Although Cahill does not provide F_3 measurements, anticipatory nasalization is likely to lower F_3 and thus contribute to the percept of rounding.

transition with the target front vowel, creating the conditions for (more) coarticulation. According to this hypothesis, the same-sidedness requirement is only emergent: it is the only configuration where the coarticulatory effect of U is not blocked by an intervening non-velar consonant.

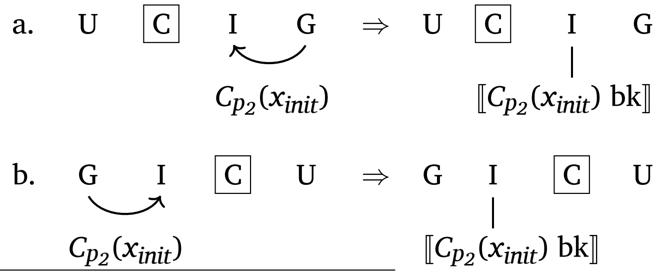
It is worth noting that /g/, virtually the only velar co-trigger attested in perseverative trans-dorsal backing, since non-stem-initial /k/ is extremely rare in nouns, and unattested in verbs (cf. Table 4.8), often weakens to [ɣ] intervocalically, or even deletes in fast speech (Cahill 2007: 117).[18] This weakening of intervocalic /g/ is of course very likely to bring the two vowels even closer together in the articulated output.[19] Note, however, that this is not a necessary condition for trans-dorsal backing, since the anticipatory version of this assimilation is only ever co-triggered by /k/ (86)). The lack of examples involving /g/ is probably due to an accidental gap.

On the condition that the phonetic hypotheses above are correct, Konni trans-dorsal backing can be given a similar analysis to that sketched for Woleaian in § 3.2.1, which holds for sef-additive teamwork in general. This analysis is sketched in (98) and (99) below, where the coarticulation-blocking effect of intervening non-dorsal consonants is represented with a boxed $\boxed{\text{C}}$, and p_1 and p_2 stand for $p_{U\rightarrow I,[\![\text{bk}]\!]}$ and $p_{G\rightarrow I,[\![\text{bk}]\!]}$ respectively, i.e. the proportion of increase in the subfeatural value of ⟦bk⟧ incurred by [G] or [U] on a neighboring [I]. Through the application of both Coarticulation functions, a doubly backed [I] gets a subfeatural value that passes the threshold beyond which the vowel is perceptually too close to ⟦1 back⟧ [U], and is therefore assimilated to it.

(98)



(99)



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[18] Cahill (1995; 2007: 138-9) shows that the extreme rarity of stem-internal /k/ in Kɔnni is due to a historical merger between /k/ and /g/ intervocalically (*k > g / V__V).

[19] The only two examples given by Cahill are *hɔ̀gú* ∼*hɔ̀ɣú* ‘woman’, and *tuguri* ∼*tuuri* ‘be bright’, which shows trans-dorsal backing across the weakened or deleted /g/. In both cases the weakened /g/ is surrounded by back vowels, and it is not clear whether this is a necessary condition for g → ɣ → Ø lenition to take place, or if the lenition applies irrespective of the quality of the neighboring vowels.

Teamwork	Type:	Self-additive
	Phonological process:	Assimilation
	Property(ies):	Dorsal (high and back)
Target	Type:	V
	Weak/strong:	weak (short and/or epenthetic)
Triggers	Number:	2
	Type:	C and V
	Hierarchy:	equal co-triggers (?)
	Position w.r.t. target:	same side, preceding or following
	Locality w.r.t. target:	adjacent
Phonological status	Static pattern:	Yes
	Active alternation:	Yes
	Morphological conditioning:	No
	Post-lexical:	No
	Exceptions:	Yes (mostly phonologically and phonetically explicable, cf. Appendix F)

Table 4.10: Properties of Kɔnni trans-dorsal backing

The properties of Kɔnni trans-dorsal backing are summarized in Table 4.10.

4.2.1.4 Kɔnni trans-coronal fronting

A front counterpart of trans-dorsal backing is also attested in Kɔnni: trans-coronal fronting. Specifically, the vowel /a/ is fronted to [ɛ] when followed by a front vowel, only if the intervening consonant is coronal (D for short). Trans-coronal fronting is thus a case of teamwork very similar to trans-dorsal backing: the front vowel and the coronal consonant both "want" to front the adjacent /a/, but are too weak to do it on their own, and can only succeed if they "team up". Contrary to trans-dorsal backing, however, this process is only optional, and happens more frequently in fast than in careful speech. (Cahill 2007: 250; 2009). It is illustrated in (100).

(100)	/bal-/	balɪ	∼	bɛlɪ	'speak'
	/dal-/	dalɪ	∼	dɛlɪ	'be much'
	/tas-/	tasɪ	∼	tɛsɪ	'kick'
	/yal-/	yalɪ	∼	yɛlɪ	'have'
	/gbalɪg-/	gbalɪgɪ	∼	gbɛlɪgɪ	'be tired'
	/gbáríáŋ/	gbáríáŋ	∼	gbɛ́ríáŋ	'earthworm'

Parallel to what we saw for trans-dorsal backing, long vowels resist trans-coronal fronting, as shown below.

(101)	/waal-/	waalı	‘broadcast (seed)’
	/taas-/	taasiı	‘join, assemble’
	/daar-/	daarı	‘wash dishes’
	/kpaal-/	kpaalı	‘fe fatty’
	/gbaas-/	gbaasiı	‘claim girl as wife’

Long [aa] is in average 229 ms long, i.e. nearly exactly twice the length of its short counterpart (114 ms, cf. Table 4.9). Notice that short [a] is thus much longer than short [i] (65 ms) and [ɪ] (78 ms), the two targets of trans-dorsal backing. However, it is still noticeably shorter than long [ii] (144 ms) and [ɪɪ] (141 ms), which resist trans-dorsal backing. Consequently, it cannot be determined at this stage whether relative duration is the sole predictor whether a vowel will undergo assimilation, or whether the resistance of long vowels to assimilation is due to some more abstract, phonological property.

The fact that the target /a/ is [-ATR] reduces the potential triggers to the only two [-ATR] front vowels /ɪ/ and /ɛ/. However, the latter, a rare vowel in Kɔnni, is never attested as a trigger of trans-coronal fronting (in fact the sequence aCɛ altogether is unattested).[20] Cahill surmises that if it were not for this accidental gap, /ɛ/ would probably qualify as a co-trigger. But it is also possible to hypothesize that, much like /U/ in trans-dorsal backing, /ɪ/ is a better trigger than /ɛ/, by virtue of being articulatorily more coronal: indeed the articulation of a high front vowel brings the front part of the tongue as close to the alveolar ridge as is possible for a vowel.

The examples in (102) show the necessity for the intervening consonant to be coronal: velars and labials never co-trigger trans-coronal fronting.

(102) Non-coronal intervening C

/chag-/	chagı	(*chɛgı)	‘be satisfied, sated’
/naŋ-/	naŋı	(*nɛŋı)	‘melt’
/nam-s-/	samısı	(*nɛmısı)	‘suffer’
/ŋmab-/	ŋmabı	(*ŋmɛbı)	‘shatter’

Trans-coronal fronting is subject to the same conditions of adjacency and directionality as trans-dorsal backing, except only anticipatory agreement is attested. It is the mirror image of trans-dorsal backing, and likely originates in a similar cumulative coarticulatory effect: the coronal consonant and the high front vowel both contribute some subphonemic fronting to the target vowel, and the addition of these two effects leads to categorical fronting of [a] to [ɛ]. The same-side requirement is, like in the case of trans-dorsal backing, likely to emerge from constraints on C-to-V and V-to-V coarticulation, in particular blocking by intervening non-coronal consonants. The same subfeatural analysis can thus be applied here as that proposed for trans-dorsal backing in (98).

There is also evidence that this alternation refers to a broader environment, and necessitates detailed knowledge about contextual realization. Indeed, whether it applies or not does not depend only on the two co-triggers and their position with respect to the target, but also on the segment that directly precedes the target vowel. For instance, a dorsal consonant immediately preceding the target vowel protects it from trans-coronal fronting, as shown in (103).

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[20] “I believe the same pattern would hold if the vowel following *a* were *ɛ*. However, *ɛ* is a relatively rare vowel... and I have no cases in my data of *aCɛ*... The result of all this is that *aCı* sequences are [accidentally, FL] the only ones that can be considered in this pattern” (Cahill 2007: 250, fn. 30).

(103)	/kal-/	kalı	(*kɛlı)	‘sit’
	/kàlìŋà/	kàlìŋà	(*kɛ̀lìŋà)	‘sleeping mat’
	/kag-l-/	kagılı	(*kɛ̀gìlì)	‘cross out’
	/gar-s-/	garısı	(*gɛrısı)	‘pass’
	/was-/	wası	(*wɛsı)	‘greet’

The subphonemic backing effect of the preceding dorsal thus seems to cancel out the fronting effect of the coronal co-trigger. Note that examples like *balı∼bɛlı* and *gbalıgı∼gbɛlıgı* in (100) above show that labials and labial-velars do not block trans-coronal fronting. This is particularly interesting regarding the earlier discussion about the potential role of labial-velars in trans-dorsal backing: labial-velars seem to pattern with labials rather than with velars, at least with regard to their effect on the immediate following vowel, which is unsurprising given that they are characterized by a labial release.

Another interesting case of blocking is attested with the diphthong [ʊa]. The long vowels /ee, oo/ and /ɛɛ, ɔɔ/ are most of the time realized as the diphthongs [ie, uo] and [ɪa, ʊa] respectively (Cahill 2007: 226-243). The [a] element in the [-ATR] diphthongs is subject to trans-coronal fronting, but only in the front diphthong [ɪa], as shown in (104).[21]

(104) Dipthongs [ɪa, ʊa] in trans-coronal fronting

a.	/pɛɛs-/	piasɪ	∼	pɪɛs-ɪ	‘ask’
	/chɛɛs-/	chɪasɪ	∼	chiɛs-ɪ	‘contribute’
	/tɛɛl-/	tɪalɪ	∼	tɪɛl-ɪ	‘remain (be left)’
	/fɛɛl-/	fɪalɪ	∼	fɪɛl-ɪ	‘be cool’
	/kpɛ́ɛ́-sÍ/	kpíá-sí	∼	kpíɛ́-sí	‘chicken-pl.3’
b.	/dɔɔr-/	dʊarɪ		(*dʊɛrɪ)	‘take top part off’
	/pɔɔs-/	pʊasɪ		(*pʊɛsɪ)	‘strip bark from tree’
	/yɔɔr-/	yʊarɪ		(*yʊɛrɪ)	‘fetch’

The fronting at work in (104a) might be a triple teamwork effect, the front onglide of the behaving as a third co-trigger by contributing some coarticulatory fronting. This could explain why fronting does not apply in (104b), where the onglide is [+back], and not only does not contribute any fronting, but is likely to counteract the cumulative fronting effect of the following [s] and [ɪ].

Remember that trans-coronal fronting does not apply to long /aa/. If the two V timing units in a long vowel are to be analyzed as essentially the same as the two V’s involved in diphthongs, then it is noteworthy that the second /a/ of long /aa/ never becomes [aɛ] under trans-coronal fronting. Trans-coronal fronting seems to be blocked by a preceding non-front vowel when applying to [V͡a] sequences. The fact that [a͡ɛ] is not an attested diphthong in the Kɔnni inventory might explain this blocking.

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[21] I have found no mention of the behavior of the [ie] and [ɪa] diphthongized realizations of /ee/ and /ɛɛ/ in the trans-dorsal harmony environment. In particular, I could not find any data that would show whether /uGie/ and /ʊGɪa/ are realized faithfully, or whether backing applies, yielding [ugue] and [ʊgʊa] respectively. It is more than probable that if it were the case, Cahill would have mentioned it. The fact that long vowels are mostly attested in the stem-initial syllable in Kɔnni, making the sequences /uGie/ and /ʊGɪa/ phonotactically impossible or unlikely, could explain the lack of relevant examples.

Teamwork	Type:	Self-additive
	Phonological process:	Assimilation
	Property(ies):	Frontness
Target	Type:	V
	Weak/strong:	weak (short)
Triggers	Number:	2
	Type:	C and V
	Hierarchy:	equal co-triggers (?)
	Position w.r.t. target:	same side, following
	Locality w.r.t. target:	adjacent
Phonological status	Static pattern:	Yes, optional
	Active alternation:	Yes, optional
	Morphological conditioning:	No
	Post-lexical:	No
	Exceptions:	Yes (phonetically explicable)

Table 4.11: Properties of Kɔnni trans-coronal fronting

Finally, Cahill notes that trans-coronal fronting is not systematic when the consonantal co-trigger is /t/, suggesting that /t/ is not as strong a trigger as the other coronal consonants involved, which are always either a sonorant /l, r/ or the fricative /s/. This is shown in (105).

(105) Ambiguity of co-trigger /t/

a.	/jat-/	jatɪ	~	jɛtɪ	‘unroll’
b.	/kpat-/	kpatɪ		(*kpɛtɪ)	‘finish’
	/nat-/	natɪ		(*nɛtɪ)	‘shout’

Note that if /t/ were subject to intervocalic lenition (e.g. to [ɾ]), its exceptionality would not be surprising, since it would involve quicker tongue movement and thus arguably shorter-duration coarticulatory effects. However, only voiced stops seem to undergo intervocalic lenition in Kɔnni (g → ɣ, b → β, d → ɾ, cf. Cahill 2007: 117-123). A more thorough articulatory and acoustic analysis of the realizations of intervocalic /t/ might shed more light on the underpinnings of its partial blocking effect in this pattern.

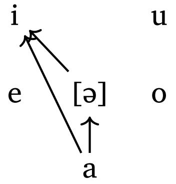
In conclusion, trans-coronal fronting is another illustration of the advantages of enriching phonology with fine-grained, scalar representations of the knowledge speakers have of segmental coarticulatory interactions and their perceptual correlates. The characteristics of trans-coronal fronting are summarized in Table 4.11.

4.2.2 Vowel raising and fronting

4.2.2.1 Russian (central and southern dialects)

A case of self-additive teamwork involving raising and fronting of a reduced vowel is attested in central and southern dialects of Russian, whose vowel system is presented in (106). The arrows indicate the vowel changes incurred by the teamwork process.

(106) Russian vowel system



Most of these dialects are characterized by pervasive unstressed vowel reduction (Crosswhite 2000). The quality of the reduced vowel depends both on its position with respect to the stressed syllable in the word and on its phonotactic environment. Most dialects have two patterns of vowel reduction: a moderate one in the immediately pretonic syllable, and an extreme pattern operating in all other unstressed syllables, as schematized in (107):

(107) Vowel reduction in central/southern Russian dialects

Other pretonic σ's	*Immediately pretonic σ*	*Stressed σ́*	*Post-tonic σ's*
extreme reduction	moderate reduction	(no reduction)	extreme reduction
i u	i u	i u	i u
ə		e o	ə
	a	a	

The reduction patterns are further subject to dialectal variation. Four patterns of atonic vowel reduction are attested in central and southern dialects spoken in the regions of Moscow, Kalinin, and Tula, defined by both position with respect to the stressed syllable and the palatalized (C^j) vs. non-palatalized (C) status of the adjacent consonant(s), as summarized in Table 4.12.

	Other pretonic (extreme reduction)			Immediately pretonic (moderate reduction)		
No adjacent C^j	{o, a}	→	[ə]	{o, (a)[22]}	→	[a]
C^j__	{e, o, a}	→	[i]	{e, o}	→	[a]
C^j__C^j	(id.)			{e, o, a}	→	[i]

Table 4.12: Pretonic vowel reduction is central/south Russian

As can be seen, the last reduction pattern in Table 4.12 (Crosswhite's "attenuated [a]-reduction") involves phonological teamwork: in the immediately pretonic syllable, the non-hi vowels {e, o, a} are reduced to [i] if flanked by two palatalized consonants, as schematized in (108) (Crosswhite 2000:115, 139-140).

(108) {e, o, a} → [i] / C^j_C^j in immediately pretonic σ

The moderate reduction patterns applying in the immediately pretonic σ in single- vs. double-sided palatal contexts are illustrated in (109) below.

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[22] /a/ can be considered to be trivially reduced to [a] in the immediately pretonic syllable.

(109)	a.	Cʲ__						
		e → a	/rʲeká/	[rʲaká]	‘river’	cf.	[rʲét͡ʃʲka]	‘little river’
		o → a	/tʲopló/	[tʲapló]	‘warmly’	cf.	[tʲóplij]	‘warm’
		a = a	/pʲatá/	[pʲatá]	‘heel’	cf.	[pjáti]	‘heels’
	b.	Cʲ__Cʲ (“attenuated [a]-reduction”)						
		e → i	/rʲet͡ʃʲnój/	[rʲit͡ʃʲnój]	‘river (adj.)	cf.	[rʲét͡ʃʲka]	‘little river’
		o → i	/tʲolét͡s/	[tʲilét͡s]	‘calf’	cf.	[tʲólkə]	‘heifer’
		a → i	/pʲatʲí/	[pʲití]	‘five (gen. sg.)’	cf.	[pʲátʲ]	‘five (nom. sg.)’

The three reduction patterns in Table 4.12 (reduction to [a], [ə], and [i]) can be analyzed as the result of two separate processes: 1) reduction of the non-hi non-fr vowels {o, a} to central [a] (moderate reduction) or [ə] (extreme reduction) (the only process at work in the absence of adjacent palatal consonants), and 2) assimilation of the reduced vowel to the neighboring palatalized consonant(s): [a, ə] → [i]. Only the palatal assimilation involves teamwork, as we will see (cf. (110)).

In the immediately pretonic syllable, vowel reduction is moderate in that it only changes the target vowel to the full vowel [a]. In all other pretonic syllables, the target vowel is reduced to the weaker vowel [ə], hence the term “extreme reduction.” This difference can be explained by reference to the relative weakness of these two syllable types: all unstressed syllables are weak, but some are weaker than others. Specifically, the syllable closest to the stressed syllable is less weak than all other pretonic syllables.[23] This three-way prosodic strength contrast has been analyzed in terms of foot structure (cf. Halle and Vergnaud 1987, Alderete 1995, cited in Crosswhite 2000): the stressed syllable is the head of an iamb (σ.σ́), which gives the immediately pretonic syllable an intermediate status: being unstressed, it is weak, and as such undergoes vowel reduction; however unlike all other unstressed syllables, it is footed, which makes it less weak than unfooted syllables, and explains why it is more resistant to vowel reduction (in the sense that the target vowel is not fully reduced to [ə]). I adopt this foot-based analysis here for convenience: it is not crucial to the description and understanding of the Russian data, but offers a very handy conceptualization and representation of the three-way strength contrast (strong vs. weak vs. super-weak) that plays a crucial role in the vowel reduction patterns, notably in explaining the teamwork effect involved in the “attenuated [a]-reduction” pattern, as we will see.

The presence of an immediately preceding palatalized consonant (Cʲ__) enlarges the set of targets (in all pretonic contexts) to all non-hi vowels by including front /e/. However, while this palatalized consonant is enough to assimilate reduced [ə] to [i] in unfooted pretonic (i.e. super-weak) syllables, it isn’t the case in the immediately pretonic syllable, where a second Cʲ following the reduced vowel is necessary for the palatal assimilation ([a] → [i]) to take place, as shown in (110).

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[23] I am only concerned with pretonic syllables here. Note that the immediately post-tonic syllable would in most dialects be as weak as the non-immediately pretonic syllables, which indicates that proximity to the stressed syllable is not a sufficient criterion to define relative prosodic weakness, giving weight to the metrical analysis proposed above.

(110)

		Vowel reduction				Palatal assimilation
a.	Other pretonic:					
	No adjacent C^j	o, a	→	[ə]		
	C^j__	e, o, a	→	[ə]	+	[ə] → [i]
b.	Immediately pretonic:					
	No adjacent C^j	o, (a)	→	[a]		
	C^j__	e, o, (a)	→	[a]		
	C^j__C^j	(id.)			+	[a] → [i]

The “attenuated [a]-reduction” pattern can thus be understood as consisting in two different processes: reduction of all non-hi vowels to [a], followed by palatal assimilation of the reduced [a] to the two adjacent palatalized consonants, as summarized in (111).

(111) “Attenuated [a]-reduction”: two ordered rules

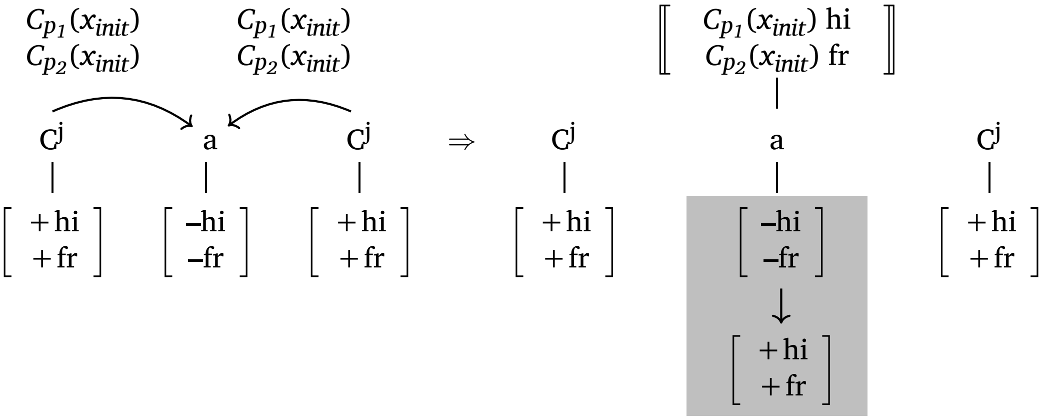
a.	Vowel reduction:	{e, o, (a)}	→	[a]	/ C^j__.σ́	(no teamwork)
b.	Palatal assimilation:	[a]	→	[i]	/ C^j__C^j (unstressed)	teamwork

The fact that teamwork is only necessary in the immediately pretonic syllable for palatal assimilation to occur can be analyzed as resulting from the relative phonetic weakness of the nuclei of the two types of pretonic syllables. In super-weak syllables, the reduced vowel [ə] is both very weak, which makes it particularly sensitive to coarticulation from adjacent consonants, and relatively close to every other vowel, given its central location in the vowel space, increasing the likelihood of perceptual confusability under coarticulation. When preceded by a palatalized consonant C^j, the formant transitions into the vowel from the palatal secondary articulation (lowest possible F1 and highest possible F2), which needs to be maintained and clearly articulated in a language where consonant palatalization is contrastive, is very likely to leave so little space for the realization of the cues to [ə] as to make it hardly distinguishable from [i].

In the immediately pretonic syllable, on the other hand, the moderately reduced vowel [a] is stronger (likely longer and more stable than [ə]), and also further away from [i] in the vowel space. The effect of a preceding palatalized consonant is likely to be less strong on [a], which is still perceptually distinct enough from [i] despite the [i]-like formant transitions. Adding a second adjacent palatalized consonant pushes the reduced vowel over the distinctiveness threshold, and assimilation to [i] takes place. In other words, [^{i}a] or [a^{i}] is enough of an [a] to resist coarticulation-driven assimilation, but [^{i}a^{i}] is not.

In subfeatural terms, a palatalized consonant contributes a double coarticulatory effect (raising + fronting) to an adjacent short, unstressed [a], involving two separate proportions of increase: $p_{C^{j}\rightarrow a,[\![\mathrm{hi}]\!]}$ and $p_{C^{j}\rightarrow a,[\![\mathrm{fr}]\!]}$. An [a] affected by two such triggers is thus subfeaturally both $[\![Cp_{C^{j}\rightarrow a,[\![\mathrm{hi}]\!]}(x_{init})\ \mathrm{hi}]\!]$ and $[\![Cp_{C^{j}\rightarrow a,[\![\mathrm{fr}]\!]}(x_{init})\ \mathrm{fr}]\!]$. Such a vowel is fully fronted and raised to [i] — the closest non-low front vowel in the reduced inventory /i, a, u/ characterizing the immediately pretonic position (cf. (107))— in accordance with the self-additive teamwork mechanism schematized in (58). This is illustrated in (112) below (with $p_1 = p_{C^{j}\rightarrow a,[\![\mathrm{hi}]\!]}$, and $p_2 = p_{C^{j}\rightarrow a,[\![\mathrm{fr}]\!]}$).

(112)



This example also clearly illustrates the role of relative weakness in teamwork, which I will come back to in § 4.7.4. The greater the strength difference between trigger and target, the less likely it is that teamwork will be necessary. Teamwork is typically observed when the strength difference is relatively small or null. In the central and southern Russian dialects described here, extremely reduced vowels are too weak to resist the assimilatory effect of a single trigger, whereas moderately reduced vowels are strong enough to resist one single trigger, which makes the combined effect of two triggers necessary for assimilation to occur. The properties of this teamwork effect are summarized in Table 4.13.

Teamwork	Type:	Self-additive
	Phonological process:	Assimilation
	Property(ies):	Palatal (high & front)
Target	Type:	V
	Weak/strong:	weak (moderately reduced)
Triggers	Number:	2
	Type:	C
	Hierarchy:	Equal co-triggers
	Position w.r.t. target:	Double-sided
	Locality w.r.t. target:	adjacent
Phonological status	Static pattern:	Yes
	Active alternation:	Yes
	Morphological conditioning:	No
	Post-lexical:	No (?)
	Exceptions:	No (?)

Table 4.13: Properties of Russian inter-palatal raising and fronting

4.2.2.2 South African Khoisan cumulative raising and fronting: the case of Taa

Most Southern African Khoisan languages[24] are characterized by a cumulative, double-sided assimilatory effect involving high and front segments targeting /a/ and raising it to [ɐ∼ə] and sometimes fronting it to [i,e]. I will describe this effect in the East !Xoon dialect of Taa (Tuu).

Taa is a dialect cluster spoken in southwestern Botswana and adjacent areas of eastern Namibia. Reliable phonological descriptions are available for two dialects: East !Xoon (or !Xóõ; Traill 1985; Traill 1994) and West !Xoon (Naumann forth.).[25] In this section, I use Traill's East !Xoon data, which are more abundant and precise than Naumann's published West !Xoon data (in particular Traill presents richer acoustic and articulatory data), but I adopt the phonological analysis developed by Naumann (forth.) for West !Xoon, in particular with regard to the consonant system. Naumann identifies more consonantal contrasts than Traill did, and, based on preliminary comparative data, says that most of these contrasts are probably also present in the eastern dialect.[26] The consonant inventory of Taa is presented in Table 4.14 below, where the shaded cells indicate the consonants that take part in the multiple-trigger raising and fronting assimilation described in this section.

Taa, like most other Southern African Khoisan languages, has a vowel system that makes use of the five vowel qualities /i, e, a, o, u/. Only the back vowels /a, o, u/ are attested phonologically as V_1, the two front vowels /i, e/ being attested underlyingly only in V_2. Additionally V_1 may be further specified for different phonation types (pharyngealization, glottalization, etc.), as illustrated in (113). Vowel nasalization is contrastive in all Southern African Khoisan languages, but only on V_2 (nasalization spreads to V_1 in phonetic realization). Transcriptions are all in IPA.

(113) East !Xoon vowel system, adapted from Naumann's (forth.) analysis of West !Xoon

	front	*back*				
V_1	–		u	+	*pharyngealized:*	Vˤ
	–		o		*glottalized:*	V’
		a			*breathy:*	V̤
					strident:	V
					breathy + glottalized:	V̤’
					phar. + glottalized:	V’
V_2	i		u	+	*nasalized:*	Ṽ
	e		o			
		a				

Southern African Khoisan languages are subject to very strict phonotactic restrictions, both on the shape of lexical stems and on phoneme distribution within stems (Beach 1938; Traill 1985;

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[24] The expression "Southern African Khoisan" subsumes all languages formerly classified as "Khoisan" except the two East African isolates Hadza and Sandawe, i.e. all the languages belonging to the Khoe-Kwadi (former Central Khoisan + Kwadi), Kx'a (former Northern Khoisan + ǂHoan), and Tuu (former Southern Khoisan) families spoken around the Kalahari basin in Southern Africa (Güldemann 2014).

[25] The language name is spelt !Xóõ in Traill's orthography. I adopt the most recent standardized (and diacritic-free) orthography proposed by Naumann (forth.), based on Güldemann's (1998) orthographic proposals for Southern African Khoisan, which is itself mostly based on Dickens's (1991) standard Ju|'hoan orthography.

[26] Bradfield (2014) similarly adopts Naumann's inventory while using Traill's East !Xoon data.

	Egressive			Ingressive					Egressive			
	labial	denti-alveolar	alv. affr./palatal	labial	dental	alveolar	palatal	lateral	velar	uvular	uvular-affricate	glottal
Oral stops												
Plain	p	t	t͡s	⊙	ǀ	!	ǂ	‖	k	q		(ʔ)
Voiced	b*	d	d͡z	⊙̬	ǀ̬	!̬	ǂ̬	‖̬	g	ɢ		
Vl. aspirated	pʰ	tʰ	t͡sʰ	⊙ʰ	ǀʰ	!ʰ	ǂʰ	‖ʰ	kʰ	qʰ		
Vd. aspirated	bʰ	dʰ	d͡zʰ	⊙̬ʰ	ǀ̬ʰ	!̬ʰ	ǂ̬ʰ	‖̬ʰ	gʰ	ɢʰ		
Vl. ejective	p’	t’	t͡s’	⊙’	ǀ’	!’	ǂ’	‖’	k’	q’	q͡χ’	
Vd. ejective			d͡z’		ǀ̬’	!̬’	ǂ̬’	‖̬’	g’	ɢ’	ɢ͡ʁ’	
Nasals												
Plain (vd.)	m*	n*	ɲ**	⊙̃	ǀ̃	!̃	ǂ̃	‖̃				
Voiceless					ǀ̥̃	!̥̃	ǂ̥̃	‖̥̃				
Glottalized	ˀm	ˀn			ˀǀ̃	ˀ!̃	ˀǂ̃	ˀ‖̃	ˀǀ̃			
Fricatives	f	s									χ	h
Sonorants		l**	ɟ∼j**									
Obstruent clusters												
Plain + q				⊙q	ǀq	!q	ǂq	‖q				
+ voice				⊙̬q	ǀ̬q	!̬q	ǂ̬q	‖̬q				
Plain + qʰ				⊙qʰ	ǀqʰ	!qʰ	ǂqʰ	‖qʰ				
+ voice					ǀ̬qʰ	!̬qʰ	ǂ̬qʰ	‖̬qʰ				
Plain + q’				⊙q’	ǀq’	!q’	ǂq’	‖q’				
+ voice					ǀ̬q’	!̬q’	ǂ̬q’	‖̬q’				
Plain + χ		t͡χ	ts͡χ	⊙χ	ǀχ	!χ	ǂχ	‖χ				
+ voice		d͡χ	dz͡χ	⊙̬x	ǀ̬x	!̬x	ǂ̬x	‖̬x				
Plain + q͡χ’	pq͡χ’	tq͡χ’	t͡sq͡χ’	⊙q͡χ’	ǀq͡χ’	!q͡χ’	ǂq͡χ’	‖q͡χ’				
+ voice		dzχ’	d͡zq͡χ’	⊙̬q͡χ’	ǀ̬q͡χ’	!̬q͡χ’	ǂ̬q͡χ’	‖̬q͡χ’				
Plain + ʔ				⊙ʔ	ǀʔ	!ʔ	ǂʔ	‖ʔ				
+ voice				⊙̬ʔ	ǀ̬ʔ	!̬ʔ	ǂ̬ʔ	‖̬ʔ				
Plain + h				⊙h	ǀh	!h	ǂh	‖h				
+ voice				⊙̬h	ǀ̬h	!̬h	ǂ̬h	‖̬h				

* *Attested in both C_1, intervocalic C_m, and coda*

** *Attested only in intervocalic C_m*

Table 4.14: The consonant system of West !Xoon (adapted from Naumann forth.)

Miller-Ockhuizen 2001; Miller 2010; Nakagawa 2006; Nakagawa 2010; Naumann forth.). As shown in (114), lexical stems are always bimoraic, and may be of three shapes only.[27]

(114) a. $C(C)_1V_\mu.C_mV_\mu$
b. $C(C)_1V_\mu N_\mu$ (likely from *C(C)V.NV)
c. $C(C)_1V_\mu V_\mu$ (likely from *C(C)V.CV)

The distribution of consonants within stems, summarized in (115), shows that the main locus of lexical contrast is on the stem-initial consonant(s). Virtually all the (numerous) consonants and consonant clusters are indeed attested in stem-initial position (which is also the only place where click consonants are attested), while only a handful of "weak", mostly sonorant consonants are attested stem-medially and finally.

(115) a. Onset (C_1 & C_1C_2): - All simplex consonants except a few sonorants (C_1)
(in East !Xoon: all but l, ɟ, ɲ, ŋ)
- All consonant clusters listed in Table 4.14 above (C_1C_2)
(seven in East !Xoon: CLICK + ʔ, h, q, q', q^h, χ, q͡x')
b. C_m / V_V: Only sonorants and /b/ (C_m = medial consonant)
(six in East !Xoon: b [b∼β], ɟ m, n, ɲ, l)
c. C_m#: Only nasals (cf. (124)b) (in East !Xoon: m, n)

4.2.2.2.1 Taa cumulative raising and fronting Traill (1985: 69-70) notes that /a/ is subject to coarticulatory and assimilatory raising and fronting effects from neighboring segments:

> The vowel *a* has the greatest number of contextual variants and is subject to assimilatory pressure from both a preceding consonant and succeeding consonant or vowel. It is raised and fronted when followed by *i, e* either contiguously, or after an intervening consonant. The greatest assimilatory effect on a is exerted by the combined effects of a preceding dental consonant such as *t, l, ǂ* and a following *i, n.* In this environment, *a* is pronounced either as a lowered-high and slightly centralized vowel [ɪ], or as a raised-mid central [ɜ]. In certain cases, it may assimilate fully to the high tongue position of the surrounding consonants and [i] yielding a long [iː].

The assimilation patterns described by Traill involve several potential triggers, sometimes operating together: the back vowel /a/ partially or fully assimilates to a following front vowel /i, e/ if it is preceded by a subset of coronal consonants, which includes all coronal egressive consonants, and all the dental /|, |̃, $|^h$, …/ and palatal /ǂ, ǂ̃, $ǂ^h$, …/ clicks. This set of coronal consonants is shaded in Table 4.14, and detailed in (116) below. I will henceforth represent it as $C_{[+]}$ (vs. $C_{[-]}$ for the consonants that do not participate in the assimilatory patterns described here).[28]

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[27] The phonological generalizations presented here are drawn primarily from Nakagawa's (2010) analysis of G|ui (Khoe-Kwadi) and Naumann's (forth.) analysis of the West !Xoon dialect of Taa (Tuu), but can be considered to hold, with only minor changes, for all South African Khoisan languages, except perhaps for Kalahari Khoe East and Kwadi (Tom Güldemann, p.c.).

[28] The only two coronal egressive consonants that are not in this list are /n/ and /^{ʔ}n/. There are very few lexical stems in the dictionary that start with either of these consonants (n = 25, ^{ʔ}n = 4), and none of them presents the phonotactic characteristics conducive to the raising and fronting assimilation. This is very likely to be an accidental gap.

(116) Coronal C_1:

a.	Included coronals (= $C_{[+]}$)	- egressive:	t, d, tʰ, dʰ, t’, s, ts, d͡z, t͡sʰ, d͡zʰ, t͡s’, d͡z’
		- clicks	ǀ, ǂ (+ accompaniments)
b.	Excluded coronals ($\subset C_{[-]}$)	clicks:	! (+accompaniments)

The target vowel may be modal /a/, glottalized /a’/, or breathy /a̤/, but not pharyngealized /aˤ, aˤ’/ or strident /aʢ/, which are not affected. This is expected, as pharyngealization is antagonistic to raising.

The effects mentioned by Traill are illustrated in (117)-(119) below with words taken from his dictionary (Traill 1994; see also Traill 1985: 91).[29]

(117) a → ɜ∼ɨ / $C_{[+]}_C_{m}$i[30]

a. C_m = non-coronal b, m

/ʔái dʰábí/	[ʔíi dʰɜ̱́bí]	male name
/sàmi/	[sɜ̱̀mi]	‘spin’
/ǂábi/	[ǂɜ̱́bí]	‘young steenbok’

b. C_m = coronal n, l

/tali/	[tɜ̱li]	?
/tʰāli/	[tʰɜ̱̄li]	‘skin for carrying a child’
/sáni/	[sɜ̱́ní]∼[sí̱ni]	‘pre-orbital gland, scent mark’
/ǂál-i/	[ǂɨ̱́l-i]	‘fold-CLASS.1’ (concord suffix on verb)

(118) a → i / $C_{[+]}_$i

/tà̤i/	[ti̤̱i]	‘pad (of paw)’	cf. pl. tà̤ba-tê
/sâ-i/	[sî̱i]	‘come to-CLASS.1’	cf. sá-ã ‘come to-CLASS.2’
/ǀā̤i/	[ǀi̤̱i]	‘aardwolf’	cf. pl. ǀà̤ba-tê
/ǀá-i/	[ǀí̱i]	‘see-CLASS.1’	cf. deverbal form ǀâã
/ǂài/	[ǂì̱i]	‘steenbok’	cf. pl. ǂàba-tê
/ǂ̬ái/	/ǂ̬í̱i/	‘thick skin on neck of certain animals’	cf. pl. ǂ̬ába-tê

(119) a → e / $C_{[+]}_$e

/tà̤’-e/	[tè̤̱’e]	‘welcome- class.3’	cf. deverbal form tà̤’a
/ǀ̃ā-e/	[ǀ̃ē̱e]	‘see-CLASS.3’	cf. deverbal form ǀâã
/ǂâẽ/	[ǂê̱ẽ]	‘jaw’	cf. pl. ǂâm(a)-tê

The examples (117)-(119) above illustrate two types of changes: partial assimilation (/a/ → [ɜ] raising) and total assimilation (/a/ → [i, e] raising and fronting). Both are allophonic. Indeed, [ɜ] is not a contrastive phoneme in any known Taa variety: it is a non-structure preserving allophone of /a/. As for the two front vowels /i, e/, they are not attested in V_1 underlyingly (at least in the analysis chosen here), so a front V_1 can only be interpreted as an allophone of /a/.

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[29] Traill does not provide a phonetic transcription for each entry in the dictionary, but only for a few (most of the time to indicate raising and fronting). Many entries where the conditions for raising and fronting are met do not include such a transcription. It is unclear whether these are exceptions or if this is just due to inconsistency on the part of the author. I tentatively assume the latter.

[30] (117a) /tali/, given without translation by Traill (1994: 40), is most probably one of the following two words (or both?), for which no phonetic transcription is provided in the dictionary: tāli ‘lightning’, and tàli ‘clotted blood’. (117b) /sáni/ is given two phonetic transcriptions in the dictionary: [sɜ́ni] (p.162) and [síni] (p.185).

The raising effect of a front V_2 on an immediately preceding /a/ is observed even when the initial consonant does not belong to the $C_{[+]}$ set. If the initial consonant is a glottal stop /ʔ/, total assimilation applies, and /a/ is changed to [i, e]:

(120) a → {i, e} / ʔ_{i,e}

/ʔái dʰábí/	[ʔíi dʰɜ́bí]	male name	
/ʔá-i/	[ʔíi]	‘eat-CLASS.1’	cf. deverbal form ʔâã
/ʔá-e/	[ʔée]	‘eat-CLASS.3’	cf. deverbal form ʔâã

With any other initial consonant (C[–] = all but $C_{[+]}$ and /ʔ/), only partial assimilation is attested: /a/ is raised to [ɜ], and sometimes fronted to [æ∼ɛ∼e], as shown in (121) and (122) below, with the few examples I could find in Traill’s (1994) dictionary, where indication of this partial assimilation is unfortunately only rarely provided.[31]

(121) a → ɜ∼æ∼i / $C_{[-]}$(C)_i

/!âĩ/	[!êĩ]	‘non-burning end of a stick’
/‖ai/	[‖æi]	?[32]

(122) a → ɜ∼æ∼ɛ / $C_{[-]}$(C)_e

/n!áe/	[n!ǽe]	‘die down (of the wind)’
/‖âe/	[‖ɛ̂ɛ]	‘three’
/ǀ̃áɲa ‖ʔáe/	[ǀ̃ɜ́ɲa ‖ʔǽe]	name

Since [ʔ] is a place-less segment, it can be thought to be neutral with respect to height/front coarticulation and assimilation. If that is indeed the case, the examples in (120) constitute evidence for the intrinsic assimilatory effect of a front V_2 on an immediately preceding /a/. The $C_{[-]}$ consonants in (121) and (122) are thus not neutral, but seem to counteract the effect of the following front vowel, by preventing it from affecting the target vowel to the full extent of its power.

The nature of the intervening C_m in the $C_{[+]}$__C_mi context also seems to be relevant to the assimilation pattern (remember that the only six C_m attested in Taa are b∼β, ɟ∼j, m, n, ɲ, l). As can be seen in (117a) above, when C_m is non-coronal [b, m], the cumulative effect of $C_{[+]}$ and /i/ raises /a/ to [ɜ]. When C_m is a coronal [l, n], as in (117b), raising to [ɪ] (/ǂál-i/ → [ǂíli]) and even full assimilation to [i] (/sáni/ → [sɜ́ní]∼[síni]) are attested, which indicates that the intervening coronal helps the high/front assimilation by adding some of its assimilatory power. Finally, a palatal C_m (mostly /ɲ/, /ɟ/ is extremely rare in C_m position) seems to qualify as a co-trigger of the assimilation even when the following vowel is /a/, as shown in (133).

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[31] Bradfield (2014: 36) notes that in Traill’s !Xóõ recordings on the UCLA phonetics lab archive “all <-ai> words with back clicks appear to show the same degree of raising as other cases of moderate raising. There is not enough data to make any statistically meaningful claim, but both auditory impression and acoustic measurements suggest this. For example, in one recording <!hai> appears to show considerable assimilation, varying from [əi] to [ɛi] in the same speaker.”

(123) a → ɜ∼e∼i / $C_{[+]}$__ɲa[33]

/ˀǀ̃àɲa/	[ˀǀ̃ɜ̀ɲa]	‘marriage’
/ǀ̃áɲa ǁʔáe/	[ǀ̃ɜ́ɲa ǁʔǽe]	name
/ǂ̬à̤ɲ̤a/	[ǂ̰é̤ɲ̤a]	‘dew claw of a lion’
/ǂ̬áɲa/	[ǂ̰éɲa]	‘pout’[34]
/qâi tʰàɟa/	[tʰàɟa]∼[tʰìɟa]	‘work metal, hammer flat’

Finally, the consonants belonging to the $C_{[+]}$ set do not trigger any phonological effect on their own, that is, in the absence of any other segment with high/front assimilatory power.

The properties of the assimilation pattern described so far are summarized in Table 4.15, where the degree of assimilation is represented through different shades of gray (the non-low back vowels /o, u/ are omitted). Note that it is not clear what effect the combination of $C_{[+]}$__ and __Ce (i.e. $C_{[+]}$__Je, $C_{[+]}$__Le, and $C_{[+]}$__Be) has on V_1 /a/: based on Traill’s description quoted above, one would expect a → ɜ raising. One would also expect the raising and fronting effect of __Ce to be less important than that caused by __Ci (e.g. [ɜ∼ɛ∼e] rather than [ɜ∼ɨ∼i]). However, I could not find any illustration of this in Traill’s (1985) description of East !Xoon, nor in his dictionary, which could be an indication either that there is no effect, or that the effect is less salient. I will thus ignore the $C_{[+]}$__Ce contexts in the remainder of the discussion.

	CVV			$C(C)_1VC_mV$								
	__i	__e	__a	__Ji	__Je	__Ja	__Li	__Le	__La	__Bi	__Be	__Ba
ʔ__	i	e	a	–	–	–	–	–	–	–	–	a
$C_{[+]}$__	i	e	a	–	–	ɜ∼i	ɜ∼i	ɜ?	a	ɜ	ɜ?	a
$C_{[-]}$__	ɜ∼e	ɜ∼ɛ	a	–	a	a	a	a	a	a	a	a

Table 4.15: Realization of V_1 = /a/ in all possible C(C)__(C)V contexts

Table 4.15 clearly illustrates the cumulative effect at work in this pattern, and the different levels of assimilatory strength of the co-triggers involved. The post-target front vowels __i,e are strong enough to fully assimilate an immediately preceding /a/, as revealed by their effect in isolation, that is, with neutral /ʔ/ in C_1 (cf. (120) above). This makes them the strongest triggers. All the other co-triggers are weak: they do not have any effect on their own. However, they can team up with other weak co-triggers to either raise /a/ to a non-low central vowel [ɜ∼ɨ] or raise and front it to [i, e], depending on their relative strengths, as illustrated in the trigger strength hierarchy in Figure 4.1 and fig. 4.2.

The strength of the effect of /i, e/ on a preceding /a/ also depends on distance: it disappears when both vowels are separated by an intervening consonant, unless the consonant immediately preceding the target is of the $C_{[+]}$ type, in which case the conjoined effort of these two co-triggers still depends on the nature of the intervening consonant. Intervening palatals ($\subset C_{[+]}$) are strong enough to qualify as one of the two co-triggers needed for raising to [ɜ] and sometimes even full

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[33] There are three more $C_{[+]}$__ɲa words in the dictionary for which no phonetic transcription is given: *tàʼɲa* ‘thank’, *ǀāhɲa* ‘red’, and *ǂáʼɲa* ‘black’. Whether these are exceptions or simply omissions is unclear. Note also the a → i full assimilation in /máɲa/ → [mı̃́ːa] (from [míɲa]) ‘kin’, despite the initial $C_{[-]}$.

[34] These two words are listed in the dictionary as ǂgèhɲa and ǂgéɲa respectively. I have taken the liberty to interpret V_1 as being underlyingly /a/, in accordance with the analysis adopted here (cf. (113))

High/front assimilatory strength						*Counteracting effect*		
super-strong		*strong*		*weak*		*weak*		*strong*
__i	>	__e	>	$C_{[+]}$__, __J	>	__L	>	$C_{[-]}$__, __B

Figure 4.1: Trigger strength hierarchy in Taa raising/fronting

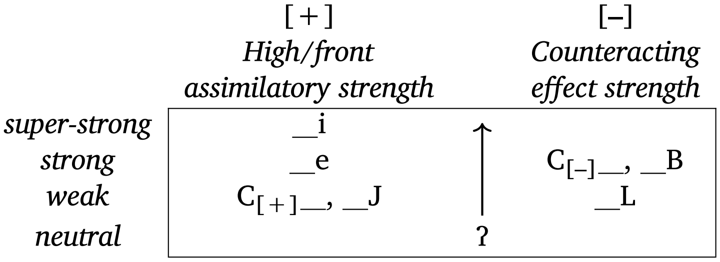

Figure 4.2: High/front assimilatory strength scale

assimilation to [i] (if the following vowel is not a back rounded vowel). Dentals ($\subset C_{[+]}$) are only strong enough to help two existing co-triggers to push the assimilation a little further than [ɜ]. Finally, labials ($\subset C_{[-]}$) seem to have a similar counteracting effect to that of initial $C_{[-]}$.

The effects of all the possible trigger combinations are summarized in Table 4.16, where the notation [a∼b] stands for a continuum of attested phonetic realizations from [a] to [b], e.g. [ɜ∼i] refers to any realization between [ɜ] and [i] on the low/back to high/front diagonal, including [ɪ], [ɛ], [e] (cf. Figure 4.3 in § 4.2.2.2.2 below).

Trigger strength					*Triggers*			*Effect*	
ss[+]	s[+]	w[+]	w[–]	s[–]					
✔		(✔)			($C_{[+]}$)	__	i	/a/ → [i]	strongest effect
	✔	(✔)			($C_{[+]}$)	__	e	/a/ → [e]	
✔		✔	✔		$C_{[+]}$	__	Li	/a/ → [ɜ∼i]	
		✔✔			$C_{[+]}$	__	J	/a/ → [ɜ∼i]	
✔				✔	$C_{[-]}$	__	i	/a/ → [ɜ∼e]	
	✔			✔	$C_{[-]}$	__	e	/a/ → [ɜ∼ɛ]	
✔		✔		✔	$C_{[+]}$	__	Bi	/a/ → [ɜ]	weakest effect
		✔			$C_{[+]}$	__		/a/ = [a]	no effect
		✔				__	J		
✔			✔			__	Li		
✔			✔	✔	$C_{[-]}$	__	Li		
✔				✔		__	Bi		
✔				✔✔	$C_{[-]}$	__	Bi		
		✔		✔	$C_{[-]}$	__	J		
				✔	$C_{[-]}$	__			

Table 4.16: Trigger combinations and their effects

I have until now ignored one of the triggering contexts mentioned by Traill (1985: 70, 1994: 40):

$C_{[+]}$__N, where N represents a coda nasal (i.e. m, n, cf. (115)). We saw earlier what effect the three nasals /m, n ɲ /have when they occupy the C_m slot in a $C_{[+]}$__C_mV word (cf. (123) and preceding prose). Traill (1994: 40) does not establish any difference between coda nasals and C_m nasals with respect to their role in high/front assimilation, and simply lists $C_{[+]}$__m, $C_{[+]}$__n, and $C_{[+]}$__ɲ as co-triggering contexts. However, coda nasals do not behave like C_m nasals. Coda /n/ systematically causes /a/ to raise to [ɜ], whatever the nature of the preceding consonant(s), as illustrated in (124). Note that coda /m/ does not seem to have any effect on a preceding /a/ (or at least, no C(C)am entry in the dictionary includes a phonetic transcription that would show a raising effect).

(124)	a → ɜ / _n		
	a.		$C_{[+]}$(C≠χ,q͡χ’)__n
	/tá-n/	[tɜ́n]	‘to-CLASS.5’
	/sá-n/	[sɜ́n]	‘come to-CLASS.5’
	/t͡s’án/	[t͡s’ɜ́n]	‘taste’
	/t͡s’àn/	[t͡s’ɜ̀n]	‘return, turn’
	/ǀ̃àn/	[ǀ̃ɜ̀n]	‘head’
	/’ǂ̃ā̤n-tê/	[’ǂ̃ɜ̤̄n-tê]	‘sack (pl.)’
	/ǂʔán/	[ǂʔɜ́n]	‘think’
	/ǂài ǂqʰàn/	[ǂìi ǂqʰɜ̀n]	‘plant sp.’
	b.		$C_{[-]}$__n
	/k-án/	[kɜ́n]	‘copula-CLASS.5’
	/b-ān/	[mɜ̄n]	‘because-1sg’ (NB: nasal harmony)
	/ǁqʰà-n/	[ǁqʰɜ̀n]	‘different-CLASS.5

The examples in (125) show that /n/ has this raising effect only when in coda position.[35]

(125)	/ǂʔàn/	[ǂʔɜ̀n]	‘penis (sg.)’
	/ǂʔàna/	[ǂʔàna]	‘penis (pl.)’

Given the lack of difference between $C_{[+]}$__n and $C_{[-]}$__n, I have decided to exclude coda /n/ from the set of triggers, tentatively choosing to see the systematic raising effect it causes as an independent phenomenon. It would not be difficult to include it among the triggers, but would complicate the already complex description.

4.2.2.2.2 Phonetic underpinnings As noted by Traill (1985: 114), the basis of these assimilation patterns is raising and fronting, mainly caused by the non-low front vowels [i,e]. This is clearly shown in the vowel plot in Figure 4.3, where the various realizations of /a/ form a diagonal from low/back [a] to high/front [i].

The role of the $C_{[+]}$ consonants “seems to be that they facilitate the raising process” (Traill 1985: 114). $C_{[+]}$ consonants are laminal, i.e. they involve substantial contact between the front part of the tongue and the region of the palate comprised between the upper teeth and the alveopalatal region. This can be seen for the dental [ǀ] and palatal [ǂ] click types on the the top two

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[35] Alternatively, one could see the difference between [ǁʔɜ̀n] and [ǁʔàna] as resulting from the counteracting effect of the following low/back vowel.

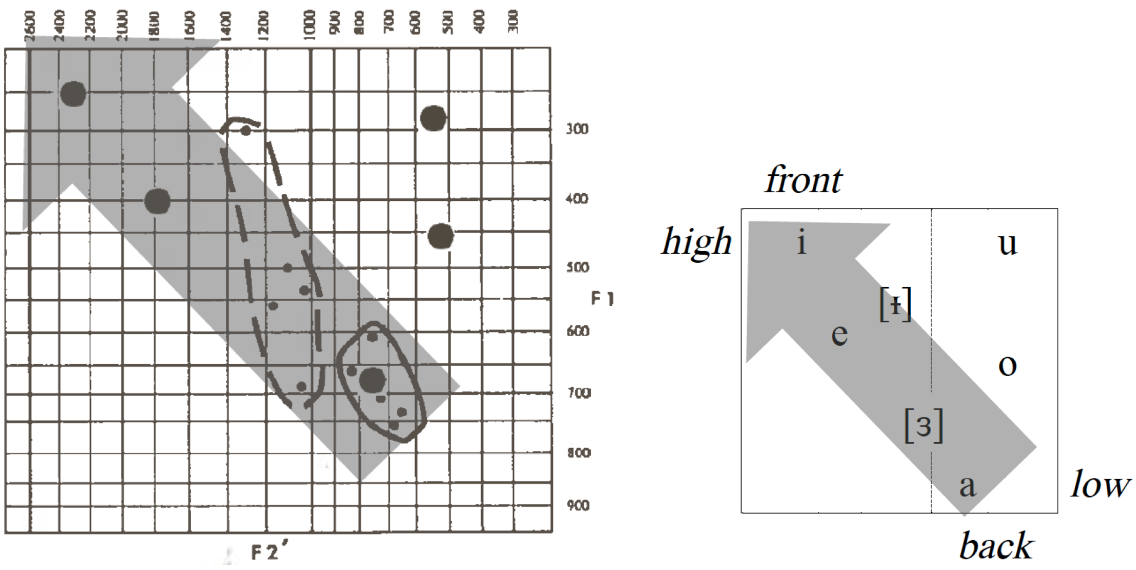

Figure 4.3: Fronting and raising in East !Xoon

On the left: F1 by F2' (i.e. F2 - F1) plot of the five 'basic' East !Xoon vowels. The large dots represent average values are from vowels in V'V and some VV sequences with both vowels identical in quality. The scatter for non-coarticulated [a] (enclosed with a solid line) and raised [a] (enclosed with a broken line) is plotted with small dots. (adapted from Traill's (1985: 71-72) Figures 5 and 6). —On the right: a schematized version

tracings in Figure 5. It is also the case for [s], [t] and [ts'] (and presumably all the denti-alveolar stops and affricates) (Traill 1985: 114-123). This is what explains the split between the two sets of coronal consonants noted in (116) above: the alveolar click series [!] ($\subset C_{[-]}$) is not laminal, but apical. In order to maintain the apico-alveolar closure during the production of the click (in particular during the rarefaction phase), the pre-apical part of the lamina is lowered and kept away from the palate. The same can be said about the articulation of lateral [ǁ] ($\subset C_{[-]}$), which also involves an apico-alveolar constriction. Traill (1985: 109) notes that "The two laminal clicks | and ǂ have generally a greater amount of tongue contact with the palate than the apical clicks ! and ǁ." as can be seen on the tracings in Figure 4.4.

The high and front position of the tongue involved in the articulation of laminal segments is what is important here, in particular after the anterior release. As shown on Figure 4.5 with the superimposed tongue outline for the hold positions of the five clicks and the vowels [i, e, a], the articulation of the laminal clicks [|, ǂ] brings the middle and front parts of the tongue to a position that is very close to that required for the production of [i] and [e]. "Conversely, the apicality of *!* and *ǁ* and its magnification during suction introduces an articulatory distance from *i* and *e*."

Finally, the tracings on Figure 4.7 clearly show the intermediate articulatory position of [ɜ] between [a] and [i]: the tongue in [ɜ] is raised away from [a] and towards [i], without reaching the height of [e], as seen on Figure 4.6. Interestingly, "if one examines the position of the root of the tongue for [ɜ], one sees that there is a wider pharynx for [ɜ] than for *e*. The largest assimilatory change from the tongue position of *a* thus lies in advancing the tongue root toward the tongue root

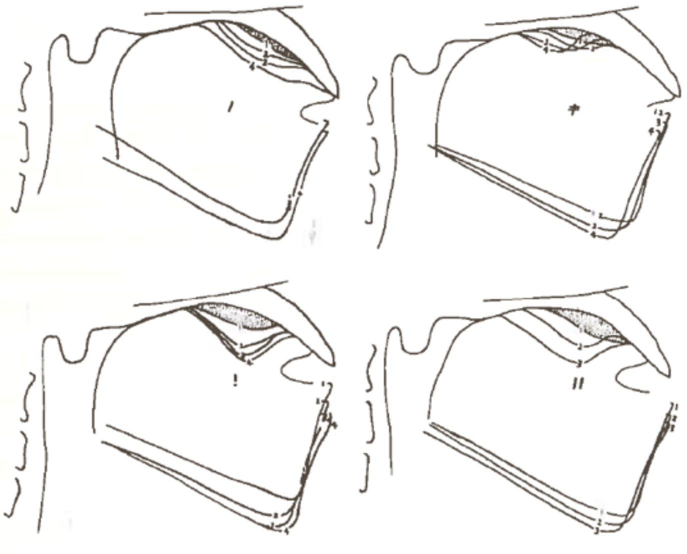

Figure 4.4: Differences in tongue movements in production of |, ǂ, !, ‖

For one speaker, traced from selected frames during the rarefaction phase. Tongue position 1 encloses the air chamber prior to the commencement of suction (shaded area). The lowest tongue position is traced from the frame preceding release of the anterior closure. The observable differences in pharyngeal width are due to independent co-articulatory effects, and do not correlate with the shape of the suction chamber. (Traill 1985: 110, Fig.25)

position of *i*” (Traill 1985: 73-74). In other words, this assimilation clearly involves both raising and fronting: the acoustic diagonal identified in Figure 4.3 above is mirrored in articulation by a diagonal that takes the tongue from a low and retracted position for [a], through an intermediate position for [ɜ] and [e], to a high and advanced position for [i].[36]

The fact that pharyngealized [aˤ] and strident [a^{ʢ}] are not affected by the high/front assimilation also has an articulatory basis: as shown in Figures 4.8 and 4.9, their articulation involves a significant retraction and lowering of the tongue root (in particular for the strident vowels, which involve aryepiglottal trilling). Given this articulatory property, it is unsurprising that there are no front pharyngealized or strident vowels in Taa.

Finally, its must be noted that C$_{[+]}$ clicks co-trigger the assimilation even when separated from the target vowel by a consonant, in the case of C$_{\text{click}}$C initial clusters, as shown in (126)-(128) below.

(126) a → ɜ / C$_{[+]}$_Ci
CLICK + ʔ /ǂʔáli/ [ǂʔɜ́li] ‘flick off from’

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[36] Bradfield’s (2014: 34-35) analysis of of this assimilation as involving only raising, inspired by Traill’s proposition that the feature [+high] be employed to account for it, seems to be missing an important point. An analysis of this assimilatory pattern must account for both raising and fronting, preferably with something else than “a late rule “filling in [-back]”, which would not account for the gradient differences noted earlier between the potential co-triggers.

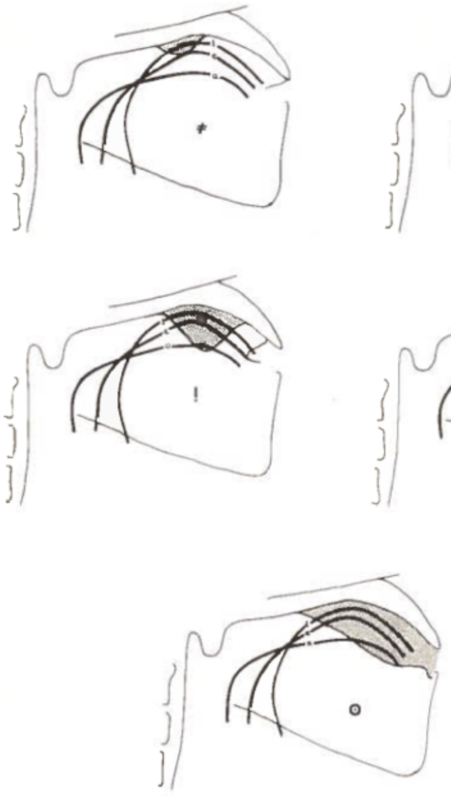

Figure 4.5: Tongue positions for the suction cavities of the five clicks prior to release (shaded areas) with the tongue positions of the vowels i, e, a superimposed (Traill 1985: 110, Fig. 27)

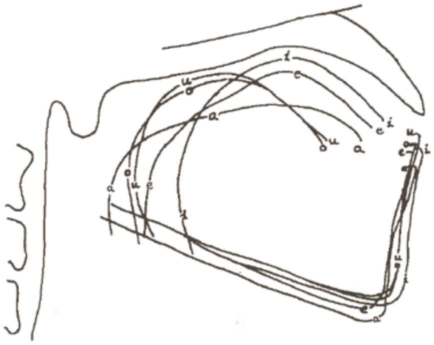

Figure 4.6: Tongue and jaw positions for the vowels [i e a o u]

For one subject, traced from a single frame during the steady state production of the first vowel in the demonstrative ti’i, ta’a, te’e, tu’u, and the nonsense form to’o. (Traill 1985: 73, Fig. 7)

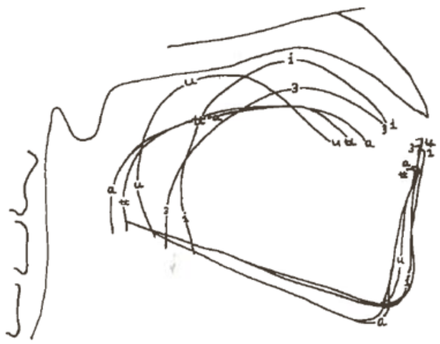

Figure 4.7: Tongue and jaw positions for the vowels transcribed [ɜ ʉ]

For one subject, traced from a single frame during the steady state production of the vowel in the utterances tán [tɜ́n] ‘to it’ and tùm [tʉ̀m] ‘swallow’, together with the positions for [i a u]. (Traill 1985: 74, Fig. 8)

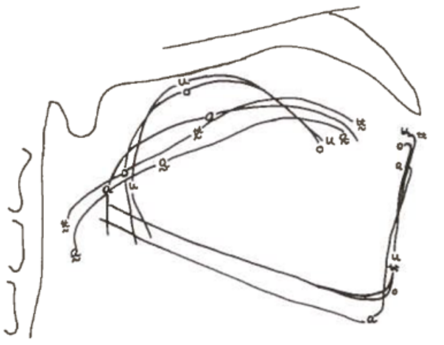

Figure 4.8: Tongue and jaw positions [a^ʕ ʉ^ʕ]

For one subject, traced from a single frame during the steady state production of the first vowel in the utterances qà^{ʕ}a [qà^{ʕ}a] ’long ago’ and tù^{ʕ}m [tʉ̀^{ʕ}ʉm] ‘skin’, together with the positions for the non-pharyngealized vowels a, o, u. (Traill 1985: 75, Fig. 9)

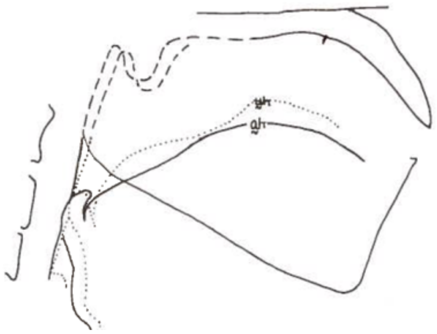

Figure 4.9: Tongue positions and pharyngeal constriction for [aʕ] (solid line) and [ʉʕ] (dotted line)

For one speaker, traced from single frame during the steady state production of the vowel in the utterances ʔāʕna ‘type of toy’ and dūʕba ‘buttocks.’ (Traill 1985: 77, Fig. 11a)

(127) a → i / $C_{[+]}$_i

CLICK + ʔ	/|ʔài/	[|ʔìi]	‘lover’	cf. pl. |ʔàba-tê
CLICK + h	/ǂhái/	[ǂhíi]	‘posterior aspect of a body part’	cf. pl. ǂhába-tê
CLICK + q’	/|q’ài sà/	[|q’ìi sà]	‘backwards, behind, rear’ [37]	
CLICK + q^h	/|q^hái/	[|q^híi]	‘buffalo’	cf. pl. |q^hába-tê
	/ǂq^hài/	[ǂq^hìi]	‘domestic dog’	cf. pl. ǂq^hàba-tê

(128) a → e / $C_{[+]}$_e

CLICK + ʔ	/|ʔá-e/	[|ʔée]	‘chase-CLASS.3’	cf. deverbal form |ʔáã
CLICK + q	/|qáe/	[|qée]	‘Nama’	cf. pl. |qám
CLICK + q^h	/ǂq^háe/	[ǂq^hée]	‘bush sp.’	cf. pl. ǂq^hám

However, the seven consonants that can occur as the second element in a stem initial cluster (q, q^h, q’, χ, q͡χ’, ʔ, h, cf. (115) and Table 4.14 above) do not all behave alike. While /ʔ, h, q, q’, q^h/ are transparent to the assimilatory effect exerted by the initial consonant, as we saw in (126)-(128) above, the uvular fricative /χ/ and ejective affricate /qχ’/, on the other hand, block the effect of the preceding $C_{[+]}$: /$C_{[+]}$χ/ and /$C_{[+]}$q͡χ’/ clusters behave like $C_{[-]}$ consonants.[38] The reason for this is likely due to the length of these two consonants: “the duration of this [intervening consonant] varies but may be considerable, from a mean 28ms for the uvular accompaniment [q], to a mean 88ms for the glottal stop accompaniment [ʔ], to a mean of 130ms for the velar fricative accompaniment [χ]” (Traill 1997: 108; cf. also Traill 1993). That fricatives and affricates should be longer than stops is in no way surprising, and the longer the second consonant in a $C_{click}C$

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[37] This word is spelt |qhìi in the dictionary. I have taken the liberty to interpret V_1 as being underlyingly /a/, in accordance with the analysis adopted here (cf. (113)).

[38] Note in passing that Bradfield’s (2014: 34) generalization that all the uvular second consonants block the effect of the preceding $C_{[+]}$ consonant does not concord with Traill’s (1985, 1994) original data, where it is clear that only the uvular fricative and ejective affricate have this blocking effect, while the non-fricated uvulars are transparent.

cluster, the more time the front part of the tongue has to move towards the low target position necessary for the articulation of the following [a]. There seems to be a length threshold beyond which the C_m blocks the effect of C_1 on the target vowel: [ʔ, q, q’, q^h, h] are below the threshold, [q͡χ’, χ] above.

In conclusion, This acute assimilation is a clear example of self-additive teamwork involving cumulative subphonemic coarticulatory effects. A scalar ⟦acute⟧ subfeature would be an adequate representation of such effects. The exact quantification of these effects is however still poorly known. The scales presented in the preceding paragraph (cf. Figures 4.1 and 4.2, and Table 4.16) are only based on Traill’s transcriptions, and not on thorough acoustic/perceptual grounds. More precise phonetic measurements need to be made before we can define with certainty the number of steps on the subphonemic scale.

Teamwork	Type:	Self-additive
	Phonological process:	Assimilation
	Property(ies):	Front and high vs. non-front/non-high)
Target	Type:	V
	Weak/strong:	n/a
Triggers	Number:	Up to 3
	Type:	C, V
	Hierarchy:	Yes
	Position w.r.t. target:	Double-sided
	Locality w.r.t. target:	(Near-)Adjacent
Phonological status	Static pattern:	Yes
	Active alternation:	Yes
	Morphological conditioning:	No
	Post-lexical:	No
	Exceptions:	?

Table 4.17: Properties of East !Xoon doubly triggered fronting and raising

4.2.3 Vowel raising and rounding/backing: Woleaian

Two teamwork effects are attested in Woleaian (Oceanic, Sohn 1975): a → e raising, briefly described in § 1.3 and analyzed in § 3.5, whereby the low vowel /a/ is raised to [e] when wedged between two high vowels (129), and e → u rounding/backing, where /e/ is similarly changed to [o] when both the preceding and the following vowel is high and back/rounded (130).[39]

(129) a → e / $V_{[+hi]}$—$V_{[+hi]}$
a. /ʉwa-li/ [ʉwe̲li̥] ‘neck of’
b. /ʉwa-la/ [uwale̥] ‘his neck’

---

[39] Word-final short vowels are devoiced. Word-final /a/ is realized [o̥] when following a back rounded vowel, [ə̥] otherwise.

(130) e → o / u_u

a.	/ule-ule/	[ulo̱ulo̥]	‘slice, cut’
b.	/sauwefaŋi/	[sauwefaŋi̥]	‘small eel’

As can be seen, the presence of only one trigger in (129b) and (130b) is not sufficient for the assimilation to take place: the target vowel needs to be wedged between two triggers as in (129a) and (130a).

The vowel system of Woleaian is presented in (131). The arrow indicates the a → e and a/e → u mergers that arise through teamwork.[40]

(131)

4.2.3.1 Vowel raising

The double-sided *a*-raising of Woleaian, first described by Sohn (Sohn 1971; 1975: 29-31)), is further illustrated in (132) below.

(132)

a.	/ʉwa-li/	[ʉwe̱li̥]	‘neck of’
b.	/ita-i/	[ite̱i̥]	‘my name’
c.	/jali-jali/	[jalije̱li̥]	‘fast flier’
d.	/ragi-ragi/	[ragire̱gi̥]	‘to line up’

If only one of the flanking syllables has a high vowel as in (133a-d), or if the target vowel is long as in (133e), *a*-raising does not occur.

(133)

a.	/ʉwa-la/	[ʉwale̥]	‘his neck’
b.	/ita-ʃa/	[itaʃe̥]	‘our name’
c.	/le-lamwo/	[le-namwo̥]	“inside of the lagoon’
d.	/libbeja-i/	[libbejai]	‘my twins’
e.	/ni-gaau-sapa/	[nigaausape̥]	‘area below eye’

Example (133d) further illustrates two properties of *a*-raising. First, the flanking high vowels must be in syllables adjacent to the syllable of the target vowel. The assimilation is thus strictly local. Secondly, the palatal glide /j/ does not qualify as a co-trigger, i.e. in the sequence /jai/, only the vowel /i/ qualifies as a potential trigger. This is further illustrated in (134) with both /j/ and /w/, neither of which ever co-triggers *a*-raising. Note that they do not block raising when intervening between the target and one of the triggers, as shown in (132c) /ʉwali/ [ʉwe̱li̥] and (133d) /libbeja-i/ [libbejai].

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[40] /ee/ and /ɵɵ/ are closer to open [ɛː] and [œː]. Short [ɵ] and [ɔ] are allophonic realizations of /e/ and /a/ respectively, when followed by a round vowel: /e/ → [ɵ] / _(C)y/u/o/ɵɵ and /a/ → [ɔ] / _(C)o (Sohn 1975:) /y, u, o/, as we will see in § 4.2.3.2. Similarly, short [ɔ] is an allophone of /a/ in certain backing contexts. Word-finally, long vowels are shortened and post-consonantal short vowels are devoiced: VV → V / _#, V → V̥ / C_#. Finally, word-final *a* is systematically raised to *e*.

(134)			
	/jalʉta/	[jalʉte̥]	‘small uninhabited island’
	/walʉ/	[walʉ̥]	‘forest, bus, woods’
	/jawa/	[jawe̥]	‘mouth’

The phonetic basis of this case of teamwork is straightforward: high vowels are expected to exert some level of coarticulatory raising on the vowel of an adjacent syllable. The coarticulatory effect of a maximally high vowel / i, y, u/ onto a maximally low vowel /a/ can be expected to be greater than between two vowels of contiguous height, given the distance to be covered by the articulators (tongue and jaw) to move from one target to the next. However, in Woleaian, the effect of one high vowel is not sufficient to cause /a/ to raise to /e/: [^{i}a] or [a^{i}] are not close enough to [e] to be assimilated, only [^{i}a^{i}] is, i.e. only the cumulative, double-sided effect of two flanking high vowels breaks the threshold of height coarticulation and triggers *a*-raising.

The strength relation between triggers and target is summarized in (223) below. Short [a] is strong enough to resist raising from one high vowel, but not the effect of two high vowels. Long [aa], on the other hand, is stronger than even two teamed up triggers.

(135) Relative strength of triggers and target in Woleaian *a*-raising

Target		*Trigger*	
aa	↑		
		$V_{hi}\_\_V_{hi}$	(a → e)
a			
		$\_\_V_{hi}$, $V_{hi}\_\_$	

Table 4.18 below illustrates the subphonemic threshold effect at work in Woleaian *a*-raising. Contrastive height levels (low /a/ and mid /e/) are shaded, I and E stand for high and non-high vowels respectively, and the threshold beyond which the subphonemically raised [a] is attracted to the next phonemic level /e/ is represented with a dashed line. As can be seen, [^{i}a] and [a^{i}] (ex. b and c) remain below threshold necessary for the phonological raising to occur, only [^{i}a^{i}] (ex. d) passes it, and is changed to [e].

Height scale	a. /E a E/ [E a E]	b. /I a E/ [I a E]	c. /E a I/ [E a I]	d. /I a I/ [I a I]
e				e
↑				$/{}^{i}\cancel{a}^{i}/$
		^{i}a	a^{i}	
a	a			

Table 4.18: Subphonemic threshold effect in Woleaian a → e raising

4.2.3.2 Vowel rounding/backing

Similarly to what happens to [a] between two high vowels, the vowel [e] is changed to [o] when surrounded by two high back rounded vowels: e → o / u_u, as illustrated in (136). Contrary to *a*-raising, the double-sided e → o assimilation is not described or analyzed in the literature. The data presented below is taken directly from Sohn and Tawerilmang’s (1976) dictionary.

(136)	a.	/uleule/	[ulo̲ulo̥]	toponym
		/ule-ule/	[ulo̲ulo̥]	‘slice, cut’
		/ule-uleti/	[ulo̲uleti̥]	‘cooked shredded coconut meat’
		/gouse-use/	[gouso̲uso̥]	‘to cover up one’s body (with sheets)’
	b.	/sauwefaŋi/	[sauwefaŋi̥]	‘small eel’
		/tugu-teŋarigi/	[tuguteŋarigi̥]	‘kind of basket’

As seen by comparing (136a) and (136b), the two triggers are necessary for the assimilation to take place.

Since /u/ is is a trigger of both teamwork effects, /a/ is also systematically changed to [o] between two *u*’s, as shown in (137).

(137)	a.	/usa-usa/	[uso̲uso̥]	‘slice, cut’
	b.	/ura-uraagi/	[uro̲uraagi̥]	‘wade:PROG’
	c.	/ruwa-uwa/	[ruwo̲uwo̥]	‘boundary, partition’

In a rule-based account, this could be analyzed as the successive application of both assimilations: a → e / $V_{hi}\_V_{hi}$ feeding e → o / u_u: *usausa* → *useusa* → *usousa* (then [usouso̥] after application of final-vowel assimilation and devoicing).

Interestingly backing of [e] to [o] is only teamwork-driven word-internally. When [e] is final (including when it originates from underlying /a/, systematically raised to [e] word-finally), it is changed to [o] when the preceding vowel is a back rounded vowel [u(u), o(o), ɔɔ] (Sohn 1975: 26), as shown in 138).

(138)	/buna/	[buno̥̲]	‘heart’	cf.	/buna-le/	[buna̲le̥]	‘his heart’
	/ssonga/	[ssongo̥̲]	‘anger’				
	/gotɔɔta/	[gotɔɔto̥̲]	‘crack’				

Only one trigger is necessary in this case, and that trigger need not even be [u], but may be any back rounded vowel, including low [ɔɔ]. Independent evidence shows that word-final vowels are clearly weaker than word-internal vowels in Woleaian. In particular, they undergo weakening processes (short vowel devoicing, long vowel shortening) that do not target other vowels. Vowels are thus organized along a three-step strength scale: long vowels are the strongest (evidenced by their resistance to *a*-raising and word-final devoicing), followed by short word-internal vowels, and finally word-final short vowels: VV > V > V#.[41] To change [e] to [o], self-additive teamwork is unnecessary word-finally, where the target vowel is too weak to resist the effect of even one back/rounded trigger. On the other end of the scale, long vowels are strong enough to resist even the cumulative effect of two triggers. This leaves the intermediate level of strength, word-internal short [e], strong enough to resist one trigger, but too weak to resist the effect of two triggers teaming up.

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[41] This scale is actually defined by two orthogonal criteria: vowel length (VV > V), and position in the word (V(V)... > V(V)#). For ease of presentation, I collapse these two scales into one (VV > V > V#), and omit word-final long vowels, which we do not need to discuss here.

Finally, Sohn (1975: 17) mentions that “*e* is pronounced with slight lip rounding when it occurs before a round vowel”, as illustrated in (139) below.[42]

(139)	a.	Before [ʉ] (very frequent)		
		/ssegʉ/	[sse̹gʉ̥]	‘full’
		/bbelʉ/	[bbe̹lʉ̥]	dirty’
		/jarengʉ/	[jare̹ngʉ̥]	‘coconut cream’
		/gerʉgerʉ/	[ge̹rʉge̹rʉ̥]	‘to scratch’
	b.	Before [u] (only four cases found, but the last two show productivity)		
		/ssebu/	[se̹bu̥]	‘to trickle’
		/malemwu/	[male̹mwu̥]	‘to drown’
		/lewe-mwu/	[lewe̹mwu̥]	‘your tongue’
		/rebe-mwu/	[rebe̹mwu̥]	‘your moustache’
	c.	Before [ɵɵ] (only five cases found)		
		/faailemɵɵ/	[faaile̹mɵ]	‘kind of string’
		/kerɵɵ/	[ke̹rɵɵ]	‘be scraped’
		/laaligerɵɵ/	[laalige̹rɵ]	‘fish sp.’
		/mwerɵɵ/	[mwe̹rɵ]	‘back-side (calf) of upper leg’
		/jerɵɵrʉ/	[je̹rɵɵrʉ̥]	‘back-side (calf) of upper leg’
	d.	Before [o] (only one case found)		
		/sessoro/	[se̹ssoro̥]	‘back-side (calf) of upper leg’

This is evidence that rounded vowels, have a slight rounding effect on a preceding [e]. There is thus evidence that each one of the two triggers involved in the e → o / u_u teamwork-driven alternation has a partial phonetic (or at least allophonic) effect. The examples in (139) illustrate the partial effect exerted by the post-target trigger, while the effect of the pre-target trigger is evidenced by the rounding of final [e] to [o] independently exerted by a preceding round vowel, illustrated in (138) above.

Note that in order to round a word-internal [e] to [o], not only are two triggers necessary, but only [u] —the vowel presumably exerting the strongest backing/rounding effect, by virtue of being the most round and the most back— qualifies as co-trigger. The relative strength relations between targets and triggers is represented in (140) below, while Table 4.19 summarizes the cumulative effect at work in double-sided e → o / u_u.

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[42] This rounding is not reflected in the orthography used in Sohn’s (1975) grammar. Sohn and Tawerilmang (1976) transcribe it as [ə] in the phonetic transcriptions proposed in the introduction (e.g. p. xvi), and spell it <eo> (i.e. [ɵ]) in the dictionary entries. In the absence of phonetic measurements, I have decided to remain agnostic as to the exact phonetic effect of the following round vowel, and to indicate the slight rounding of the vowel by the IPA symbol [e̹].

(140) Relative strength of triggers and target in Woleaian *e*-rounding/backing

Target		*Trigger*	
ee	↑		
		u__u	(e → o)
		$\_\_V_{[+rd]}$	(e → ȩ)
e			
		$V_{[+rd]}\_\_$	(e# → o#)
e#			

back/round	a. /E e E/ [E e E]	b. /U e E/ [U e E]	c. /E e U/ [E e U]	d. /U e U/ [U e U]
o				o
↑				~~${}^{u}e^{u}$~~
			e^{u}	
		${}^{u}e$		
e	e			

Table 4.19: Subphonemic threshold effect in Woleaian e → o rounding/backing

Short [a] may be subject to both cumulative raising and cumulative backing/rounding, if both triggers are both high and back/round, i.e. /u/. Table 4.20 below summarizes the two self-additive teamwork effects targeting word-internal short [a] in Woleaian.

		[+hi]			[–hi]	
		…i	…ʉ	…u	…e	…o
[+hi]	i…	e	ȩ	ȩ	a	a
	ʉ…	e	ȩ	ȩ	a	a
	u…	e	ȩ	o	a	a
[–hi]	e…	a	a	a	a	a
	o…	a	a	(a)	a	a

Table 4.20: double-sided assimilation of /a/ in Woleaian

A subfeatural analysis of Woleaian *a*-raising was provided in § 3.5. The same analysis can be applied to *e*-backing/rounding, simply replacing the ⟦high⟧ subfeature by ⟦back⟧ or ⟦round⟧, depending on the chosen representation for back rounded vowels.

4.2.3.3 Domain

Sohn (1975: 30) notes that *a*-raising applies across word boundaries, as shown in the examples below.

(141) a. between subject marker and verb:
/i maŋi-maŋi/ [i me̠ŋimeŋi] ‘I think’
I think

b. between subject marker and Aspect/Negation:
/i tai…/ [i te̱i…] 'I do not…'
I NEG

c. between noun and modifying intransitive verb:
/malʉ kaila/ [malʉ ke̱ile̥] 'strong man'
man be.strong

d. between verb and following PP:
/gaaʉ ŋalii/ [gaaʉ ŋe̱li] 'to say to him'
say to.him

The first two examples show application of *a*-raising between what could be a pronominal clitic and the following element within the verbal complex. If the clitic analysis of subject pronouns (Sohn's "subjective") is correct, then these two examples do not illustrate assimilation across a word boundary. Example (141a) also shows that reduplication does not block nor complicate a-raising.

More convincing are the examples in (141c-d), where *a*-raising occurs across the boundary between a noun and a modifying intransitive verb, or between a verb and a preposition + pronominal suffix complex (*ŋalii-∅* 'to-it/him/her')indirect object pronoun.[43]

Finally, Sohn (1975: 30–31) remarks that *a*-raising only applies across a word boundary if the two words are not separated by a pause, as shown in (142) below.

(142) a. /se-maly maly/ [semalʉ̥ // ma̱lʉ̥] 'one bird'
one-ANIMATE bird

b. /werii sari laala/ [weri // sa̱ri̥ laale̥] 'see that child'
see child that

c. /seli-maly tau-jafa/ [selimelʉ̥ ta̱ujafe̥] 'three swimmers'
three-ANIMATE EXPERT-swim

Woleaian *a*-raising is the only case of subphonemic teamwork I have found so far that applies across word boundaries. I will come back to the significance of this fact in § 4.7.5.

The characteristics of Woleaian *a*-raising and *e*-backing/rounding are summarized in table 4.21.

4.2.4 Vowel rounding

4.2.4.1 Acehnese

A case of subphonemic teamwork is attested in Acehnese (Austronesian, Malayo-Sumbawan; Durie 1985) involving vowel rounding by neighboring labial consonants, which is reminiscent of, but different from the Laal doubly triggered rounding harmony, as we will see. Acehnese has the vowel- and consonant systems illustrated in (143) and (144).[44]

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[43] Note that 'modifiers' (Sohn 1975: 54sq.) have phonological effects on the head noun or verb they modify. In particular, as illustrated in (141c), the final short vowel of the head noun is not devoiced (cf. Sohn 1975: 21). This is however different from compounding in Sohn's (1975: 102sq.) analysis, and looks more like morphosyntax-sensitive phonology —a sort of *liaison* effect.

[44] I follow Flemming (2002) in changing Durie's non-low back unrounded ɯ, ɤ, ʌ to central ɨ, ə, ɐ respectively, on the basis of Durie's own description of these vowels as "somewhat central auditorily", confirmed by his acoustic measurements (Durie 1985:16, 18).

Teamwork	Type:	Self-additive
	Phonological process:	Assimilation
	Property(ies):	Height, and back/round
Target	Type:	V
	Weak/strong:	weak (short)
Triggers	Number:	2
	Type:	V
	Hierarchy:	equal co-triggers
	Position w.r.t. target:	double-sided
	Locality w.r.t. target:	(syllable-)adjacent
Phonological status	Static pattern:	Yes, obligatory
	Active alternation:	Yes, obligatory
	Morphological conditioning:	No
	Post-lexical:	Yes
	Exceptions:	No

Table 4.21: Properties of Woleaian *a*-raising and *e*-backing/rounding

(143) Acehnese vowel inventory (Durie 1985: 16)

		Oral			*Nasal*	
a. Monophthongs:	i	ɨ →	u	ĩ	ɨ̃	ũ
	e	ə	o			
	ɛ	ɐ	ɔ	ɛ̃	ɐ̃	ɔ̃
		a			ã	
b. Diphthongs:	iᵊ	ɨᵊ	uᵊ	ĩᵊ	ɨ̃ᵊ	ũᵊ
	ɛᵊ		ɔᵊ	ɛ̃ᵊ		ɔ̃ᵊ

(144) Acehnese consonant inventory (Durie 1985: 19)

Labial	Alveolar	Palatal	Velar	Glottal
p	t	c	k	ʔ
b	d	ɟ	g	
m	n	ɲ	ŋ	
	s	ʃ		h
	r			
	l			
w		j		

When wedged between two immediately adjacent labial consonants in an unstressed (i.e. non-final) syllable, the high central vowel /ɨ/ is obligatorily rounded to /u/ (Durie 1985: 34, 36). This is illustrated in (145) below for all the labial consonant pairings allowed by the combination of the verbal prefixes /mɨ-/ and /pɨ-/ with nominal and verbal roots (B stands for any labial consonant).

(145) *BɨB → BuB

/pɨ-pagɨ/	[pu̲-pagɨ]	'to fence'
/pɨ-but/	[pu̲-but]	'to do, make a deed of'
/pɨ-mat/	[pu̲-mat]	'cause to hold'
/pɨ-wo/	[pu̲-wo]	'to bring home'
/mɨ-pɨnuteh/	[mu̲-pɨnuteh]	'a little bit white'
/mɨ-bino/	[mu̲-bino]	'being married (of man)'
/mɨ-mapo/	[mu̲-mapo]	'to call someone aunt'
/mɨ-wie/	[mu̲-wie]	'to go to the left'

Contrary to the Laal doubly-triggered rounding harmony, it is thus strictly double-sided. The examples in (146) show that this assimilation is not triggered when the target vowel is adjacent to only one labial consonant on either side.

(146) a. BɨC

pɨtak	'go'
bɨkem	'bruise'
mɨnimaŋ	'be honest'
wɨk	'ape sp.'

b. CɨB

tɨpaŋ	'bar'
kɨbit	'correctly'
gɨma	'excited'

A round vowel in an adjacent syllable (including /u/, the most rounded vowel) does not have any effect on /ɨ/, as shown by (147).

(147) ɨCu and uCɨ (C = non-labial)

kɨtupɨŋ	'clown'
runɨ	'plant sp.'
tɨ-ʔule	'vomit'

Additionally, contrary to Laal, a round vowel and a labial consonant may not gang up to trigger labial/rounding assimilation, as shown in (148).

(148) BɨCu and CɨBu: no rounding (C = non-labial)

mɨ-tuto	'to speak'
mɨ-juntɛɛ	'to sit on and on with legs hanging down'
mɨ-guda	'to ride a horse'
pɨ-ʔunɨn	'to turn right'
cɨmuru	'jalous'
kɨpula	'tree sp.'

Note that vowel sequences do not exist in Acehnese, where every syllable must have an onset, including default /ʔ/ for onset-less syllables. It is thus impossible for /u/ (or any other round vowel) to be adjacent to a /ɨ/, i.e. the following contexts that could be thought to be conducive to inter-labial rounding are not attested: *uɨu, *Buɨ, *uɨB. However, contrary to Laal, a following

/w/ does not prevent rounding of /ɨ/, as shown by the last example in (145) above: /mɨ-wie/ [mu̲-wie] ‘to go to the left’.

The impossibility for /ɨ/ to surface faithfully between two labial consonants in an unstressed syllable (*BɨB) is also a general morpheme structure constraint in Acehnese, with very few exceptions. In Aboe Bakar et al.’s Aceh-Indonesian dictionary, only seven words of two or more syllables (i.e. with at least one unstressed syllable) beginning with the sequence BɨB are attested, all listed in (149).

(149) words starting with BɨB…

bɨpak	‘stupid’		
bɨbe	‘bold’	∼[bbe]	
bɨmkirɛ	‘prickly heat’	∼[bɨnkirɛ]∼[bɨŋkirɛ]	
pɨbula	‘lie’	∼[pɨrɨbula]	
pɨmupah	‘added, appended’	∼[pumɨʔupah]∼[pumupah]	
pɨmata	‘jewel’	∼[pɨr(ɨ)mata]∼[pumata]	< Ind. *permata*
bɨmbam	‘roast (fish?)’		< Ind. *bembam*

Out of these seven words, two (*bɨmbam* and *pɨmata*) are direct loans from Indonesian, in which /ə/ (orthographic “e”) is regularly replaced by /ɨ/ in Acehnese. Note that the violation of *BɨB seems to be corrected in at least two variants: *pɨmata∼pumata* and *pɨmupah∼pumupah.* Five of these words have alternate forms that do not violate the constraint: *bɨbe∼bbe*, *bɨmkire∼bɨnkire ∼bɨŋkirɛ*, *pɨbula∼pɨrɨbula*, *pɨmupah∼pumɨʔupah∼pumupah* and *pɨmata∼pɨr(ɨ)mata∼pumata*. Only one, *bɨpak*, does not seem to be a loanword, and does not have an alternate form. I have not inventoried words with a non-initial unstressed syllable violating *BɨB in the dictionary, but such syllables are likely to be equally rare. Violations of *BɨB are thus only very marginally attested, and can be considered virtually non-existent.

The phonetic basis of this double-sided teamwork effect is very similar to that of Woleaian: labial consonants are known to affect an immediately adjacent unrounded vowel by imposing labial formant transitions that make the affected edge of the vowel sound more round/labialized. The effect of one labial consonant on an unrounded vowel in Acehnese is negligeable, i.e. insufficient to prevent the affected vowel from being perceived accurately. But when both edges are affected by transitions from labial consonants on each side of the vowel, if the coarticulatory effect is strong enough, the unaffected part of the unrounded vowel might be reduced to the point that the vowel is likely to be perceived as round. The perceptual confusability resulting from the double-sided coarticulatory effect depends both on the extent of labial coarticulation on the language (in Acehnese, this effect is not sufficient to trigger rounding with one labial consonant, two labial consonants are required), and on the phonological or intrinsic length or strength of the affected vowel. If the vowel is long or strong enough, its unaffected core might be sufficiently salient to trump the coarticulatory effect and still be perceived accurately. On the other hand, a short or weak vowel might not have enough unaffected material left not to be mis-perceived as a round vowel (a case of hypocorrection in Ohala’s (1981) terms; cf. Flemming 2002: 85).

This explains why only unstressed, short /ɨ/ is affected by this double-sided effect in Acehnese: /ɨ/ is a high vowel, and as such is expected to have a relatively short intrinsic duration compared to other vowels in the system (cf. Maddieson 1997 and references therein). Additionally, Durie (1985: 17) notes that “in unstressed syllables vowels are considerably shorter and less distinct than in stressed syllables.” Finally, due to their position in the vowel space, central vowels are close

Rounding scale	a. /C ɨ C/ [C ɨ C]	b. /C ɨ B/ [C ɨ B]	c. /B ɨ C/ [B ɨ C]	d. /B ɨ B/ [B u B]
[+round]				u
↑				~~$^{\text{u}}$ɨ$^{\text{u}}$~~
|		ɨ$^{\text{u}}$	$^{\text{u}}$ɨ	
[–round]	ɨ			

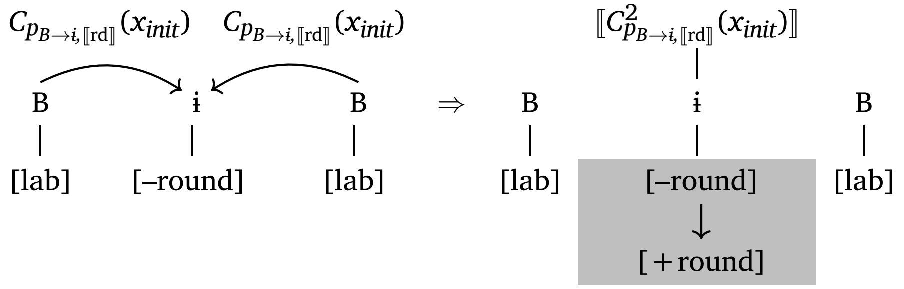
Table 4.22: Subphonemic threshold effect in Acehnese interlabial rounding

to both front unrounded and back rounded vowels, which makes them particularly susceptible to being misperceived as one or the other under coarticulation. In sum, the short high central vowel /ɨ/ in unstressed syllable is both one of the shortest vowels in the system, and one of the most susceptible to coarticulatorily driven misperception, i.e. an excellent target of subphonemic teamwork.

The threshold effect involved in Acehnese interlabial rounding is illustrated in Table 4.22 (were C = non-labial consonant, B = labial consonant; I use the feature [round] out of mere convenience: the feature [labial] would have worked as well). Note that /ɨ/ is the "least marked and commonest vowel" in unstressed syllables (Durie 1985: 21), where the other two non-low central vowels /ə/ and /ɐ/ are virtually unattested: it is thus impossible to know whether they would undergo the same alternation in similar conditions.

The subfeatural analysis of this typical self-additive teamwork effect can very easily be represented as follows. Each labial consonant contributes a some partial coarticulatory rounding by application of the function $C_{p_{B\to i,[\![\mathrm{rd}]\!]}}(x_{init})$. The cumulative effect of two triggers yields a $[\![C^{2}_{p_{B\to i,[\![\mathrm{rd}]\!]}}(x_{init})\ \text{round}]\!]$ [$^{\text{b}}$ɨ$^{\text{b}}$], which the phonology changes to [u], to which it would otherwise be perceptually too close.

(150)



Interestingly, Durie (1985: 35) notes that inter-labial rounding of /ɨ/ is optional if the vowel of the following (non-final) syllable is /ɨ/, i.e. identical to the target, as in the word in (151). The perceptual similarity between the target and the following vowel seems to optionally trump the teamwork-driven assimilation, as if the echo effect thus created made the limited unlabialized core of the target vowel salient enough to be preserved, despite the strong labialization of its edges.

(151) /pɨ-mɨʔãh/ → [pɨmɨ̃ʔãh]~[pu̲umɨ̃ʔãh] 'forgive'

Finally, inter-labial rounding is also optional when applying across a clitic boundary, as shown in the examples in (152).

Teamwork	Type:	Self-additive
	Phonological process:	Assimilation
	Property(ies):	Rounding/labiality
Target	Type:	V
	Weak/strong:	weak (short, unstressed)
Triggers	Number:	2
	Type:	C
	Hierarchy:	Equal co-triggers
	Position w.r.t. target:	Double-sided
	Locality w.r.t. target:	Strictly adjacent
Phonological status	Static pattern:	Yes, obligatory
	Active alternation:	Yes, obligatory (affix boundary) or optional (clitic boundary)
	Morphological conditioning:	No
	Post-lexical:	No (?)
	Exceptions:	Marginal

Table 4.23: Properties of Acehnese interlabial rounding

(152) Optional interlabial rounding across clitic boundary (Durie 1985: 36)

a. /lon = mɨ = poh/ → [lon = mɨ̄ = ˈpoh] ∼ [lon = mũ = ˈpoh]
I = want = hit
‘I want to hit.’

b. /bɨ = patah/ → [bɨ̄ = paˈtah] ∼ [bu = paˈtah]
ILLOC = break
‘May (it) break.’

c. /mɨ = wɔᵊ/ → [mɨ̄ = ˈwɔᵊ] ∼ [mũ = ˈwɔᵊ]
we = go.home
‘We go home.’

This shows that inter-labial rounding is partly morphologically conditioned: it is compulsory (with only the handful of exceptions in (149) above) as a morpheme structure constraint, and as an active process between the tight bond between roots and affixal material, but it is only optional between the looser bond that clitic boundaries represent. Inter-labial rounding is furthermore not reported to apply across word boundaries, and is thus not a postlexical process. Table 4.23 summarizes the characteristics of Acehnese inter-labial rounding.

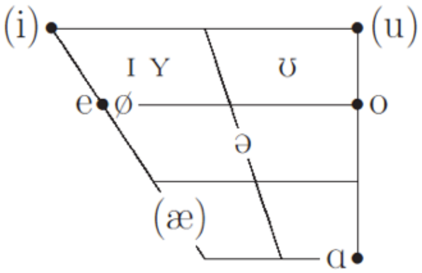
4.2.4.2 Kazakh

Rounding harmony in Kazakh exhibits an interesting case of self-additive teamwork. The data presented here all comes from McCollum's (2015) analysis of the status of this harmony in contemporary Kazakh.

The Kazakh vowel system is presented in (153) below. The role of the three vowels in parentheses /i, u, æ/ in the harmony is not addressed by McCollum, and will thus be ignored here as well. A featural analysis of the remaining vowels is presented in the table in (153b), with arrows indicating the vowel changes incurred by the teamwork pattern described in this section.

(153) Kazakh vowel system (McCollum 2015: 330)[45]

a.



b.

	[–back]		[+back]	
	[–rd]	[+rd]	[–rd]	[+rd]
[+high]	ɪ ⟶	ʏ	ɯ ⟶	u
[–high]	e	ø	ɑ	o

Kazakh exhibits two types of vowel harmony typical of Turkic languages: backness and rounding harmony. Both harmonies are perseverative, and triggered by the root-initial vowel. McCollum (2015: 331), summarizing past research on Kazakh rounding harmony, shows that "previous studies on Kazakh, if viewed longitudinally, display a diminution in labialization post-initially." Based on a thorough acoustic study, McCollum (2015: 341-344) proposes an updated description of contemporary rounding harmony in Kazakh: rounding harmony targets only root-internal high vowels, i.e. /ɪ, ɯ/ → [ʏ, ʊ]. This can be seen in all the examples in (154) below, where vowels rounded through rounding harmony are underlined, and the domain of rounding harmony is highlighted in light gray. Korn's (1969) analysis is given alongside McCollum's, to illustrate the decay of the harmony over the last forty decades or so. Capital letters in underlying forms indicate underspecified vowels subject to harmony: /I/ = [ɪ∼ʏ∼ɯ∼ʊ], /A/ = [e∼ø∼a∼o], U = [ʏ∼u]. Following McCollum (2015), Vajda (1994) and Harrison and Kaun (2000), I assume that non-initial root vowels are targets for harmony.

(154)		McCollum (2015)	Korn (1969)	
a.	1σ roots:			
	/øt-tI-ŋ-lAr/	øt -tɪ-ŋ-der	øt-tʏ̲-ŋ-dø̲r	'pass-PST-2-PL'
	/kʏn-lAr/	kʏn -der	kʏn-dø̲r	'day-PL'
	/kʏl-nI/	kʏl -dɪ	kʏl-dʏ̲	'laugh-PST.3'
	/qʊs-nI/	qʊs -tɯ	qʊs-tʊ̲	'bird-ACC'
	/qʊs-dA/	qʊs -tɑ	qʊs -tɑ	'bird-LOC'
b.	2σ roots /ʏ…ɪ/:			
	/ʒʏzIm-lAr/	ʒʏzʏ̲m -der	ʒʏzʏ̲m-dø̲r	'grape-PL'
c.	2σ roots /ø…ɪ/:			
	/kømIr-nI	kømʏ̲r -dɪ	kømʏ̲r-dʏ̲	'coal-ACC'
d.	2σ roots /ʊ…ɯ/:			
	/qʊłIp-nI/	qʊłʊ̲p -tɯ	qʊłʊ̲p-tʊ̲	'lock-ACC'

---

[45] McCollum, following Dzhunisbekov (1972) and Vajda (1994), transcribes the high back unrounded vowel as [ə]. I have decided to change it to [ɯ] here, for the sake of clarity (in accordance with most Turkologists).

e.	2σ roots /ø…e/:			
	/tøbA-lAr	tø be-ler	tøbø̱-lø̱r	‘hill-PL’
f.	2σ roots /o…ɯ/:			
	/qozI-nI/	qo zɯ-nɯ	qozʊ̱-nʊ̱	‘lamb-ACC’
	/qozI-lAr-dɯ/	qo zɯ-łɑr-dɯ	qozʊ̱ -łɑr-dɯ	‘lamb-PL-ACC’

As can be seen, the rounding domain is strictly limited to the root and never extends to suffixes in McCollum’s data. Within roots, only high vowels are ever rounded through harmony, as shown in (154e). Finally, (154f) illustrates an asymmetry between front and back vowels: back /ɯ/ may only be fronted by high /ʊ/, i.e. among back vowels, rounding harmony applies only if both vowels are high. A few marginal exceptions to this general pattern are observed (e.g. rounding of non-high vowels). Rounding harmony is thus still an active process in the language, but it has lost much of its strength, as a brief comparison with Korn’s (1969) data in (154) demonstrates: it now applies in a more restricted domain (root internally only) and to a more restricted set of targets.

McCollum (2015: 342; p.c. 26 Apr. 2015) further notes that harmony sometimes extends beyond the root, targeting suffix vowels, in which case it is variable and gradient, and applies with a frequency that is “inversely proportioned to the duration of the intervening consonant, where the most likely consonants to allow the spreading of the lip rounding gesture are the shortest:” post-radical rounding is most frequent across intervening liquids (the shortest consonants), unattested across intervening fricatives (the longest consonants), and applies with varying degrees across intervening stops and nasals (consonants of intermediate lengths). This restriction is limited to post-radical targets: root-internally, intervening consonants are entirely transparent to the harmony (cf. 154b-c). This is illustrated (155) below.

(155)	a.	/øl-Ip/	øl -ɪp	∼	øl-ʏ̱p	‘die-CVB’
		/qʊɾ-Ip/	qʊɾ -ɯp	∼	qʊɾ-ʊ̱p	‘construct-CVB’
	b.	/qʊɾ-Il-Ip/	qʊɾ -ɯł-ɯp	∼	qʊɾ-ʊ̱ł -ɯp	‘construct-PASS-CVB’
				∼	qʊɾ-ʊ̱ł-ʊ̱p	
	c.	/qʊs-Ip/	qʊs -ɯp		(*qʊs-ʊp)	‘vomit-CVB’
		/kʏl-Ip-dI/	kʏl -ɪp-tɪ	∼	kʏl-ʏ̱p -tɪ	‘laugh-PTCP-PST.3’
		/kʏl-A-dI/	kʏl -e-dɪ	∼	kʏl-ø̱ -dɪ	‘laugh-NPST-3’

As seen, rounding harmony variably applies only within the root (first variant in each example), or extends to the suffixes through [ɾ, l], as in (155a-b). Note that in this case it is not limited to the immediately post-radical suffix vowel, but may extend to the next suffix if the intermediate consonant is a liquid, as in (155b). The examples in (155c) show that other intervening consonants block the harmony from spreading beyond the root. Additionally, McCollum notes that, similarly to the root-internal pattern, non-high vowels are only exceptionally targeted post-radically. In all cases, the target is non-high front /e/ (never back /ɑ/), and the intervening consonant is always a liquid: post-radical non-high vowels are never targeted across any other consonants.

After this overview of rounding harmony in contemporary Kazakh, I now come to the main point of this section: the double-sided rounding of post-radical vowels. We have seen that post-radical high vowels could be targeted by the harmony on the condition that the intervening consonant be short. There is a second environment that allows quasi-systematic rounding outside the root: when a post-radical high vowel is surrounded by two round or labial segments. This occurs in two cases, illustrated in (156) and (157) below, which both involve the gerund suffix /-Uw/ [-uw∼-ʏw], the only suffix with an underlying [+round] vowel.

(156)	$\text{Root}_{[\text{rd}]}$-__-Uw					
	a.	/kʏl-DIr-Uw/	kʏl-dʏr-ʏw			‘laugh-CAUS-GER’
		/øl-DIr-Uw/	øl-dʏr-ʏw			‘die-CAUS-GER’
		/qʊr-Iɫ-Uw/	qʊr-ʊɫ-ʊw			‘construct-PASS-GER’
		/qos-Iɫ-Uw/	qos-ʊɫ-ʊw			‘add-PASS-GER’
	b.	/qos-DIr-Uw/	qos-tur-uw	∼	qos-tɯr-uw	‘add-CAUS-GER’
	c.	/qɯs-Il-Uw/	qɯs-ɯl-uw		(*qɯs-ʊl-ʊw)	‘press-PASS-GER’
		/qɯs-DIr-Uw/	qɯs-tɯr-uw		(*qɯs-tʊr-uw)	‘vomit-CAUS-GER’

(157)	a.	…-Uw-__-m			
		/qɑs-Uw-I-m/	qɑs-ʊw-ʊ-m		‘scratch-GER-POSS-1S’
		/kel-Uw-I-m/	kel-ʏw-ʏ-m		‘come-GER-POSS-1S’
	b.	…-Uw-__-{Ø, $C_{\text{non–labial}}$}			
		/qɑs-Uw-I/	qɑs-ʊw-ɯ	(*qɑs-ʊw-ʊ)	‘scratch-GER-POSS.3’
		/kel-Uw-I-ŋ/	kel-ʏw-ɪ-ŋ	(*kel-ʏw-ʏ-ŋ)	‘scratch-GER-POSS-2S’

As seen in (156), when a post-radical second-syllable high vowel occurs between a round root and the round suffix /-Uw/, it is quasi-systematically rounded. Even the weak trigger /o/ rounds a following /ɯ/ in this context ((156a) /qos-Iɫ-Uw/ → [qos-ʊɫ-ʊw]), which we saw was not possible root-internally. Note that distance still plays a role here, since when more than one consonant intervenes between the target and one of the triggers, as in (156b), rounding is variable. The examples in (157) show that this double-sided rounding is separate from root-internal rounding harmony, since it applies even when the root does not have a round vowel. Finally, rounding is not attested when only one of the two round/labial triggers is present, as shown in (156c) and (157b).

To summarize, Kazakh is characterized by several patterns of vowel rounding assimilation. Root-internally, perseverative rounding harmony targets high vowels. Beyond the root, high vowels are rounded only in two cases: 1) the target vowel is adjacent to a round root and the intervening consonant is short (most often a liquid, less frequently a stop or a nasal, never a fricative); 2) the post-radical target vowel occurs between two round or labial segments: Vrd__Vrd, m. Teamwork is involved only in the latter post-radical context. The rounding assimilatory effect of the root initial vowel is strong within roots, where it does not need the help of another round or labial segment. This effect is less strong across a morpheme boundary (extending beyond the root), where it is blocked by long intervening consonants, and only optional and variable across short intervening consonants. Post-radical round triggers presumably exert a weak coarticulatory rounding effect on adjacent high vowels that is insufficient to lead to full categorical rounding. However, the cumulative coarticulatory effects of two such triggers on the same target breaks the threshold for full rounding. The co-triggers at work in post-radical double-sided rounding may be: the root vowel (as in (156a-b)), the round vowel of the gerund suffix /-Uw/ (as in (156a-b) and (157a)), or the labial suffix -m (as in (157a)). Note that the labial glide in /-Uw/ is likely to participate in the cumulative rounding coarticulation at work in this assimilation, in particular when

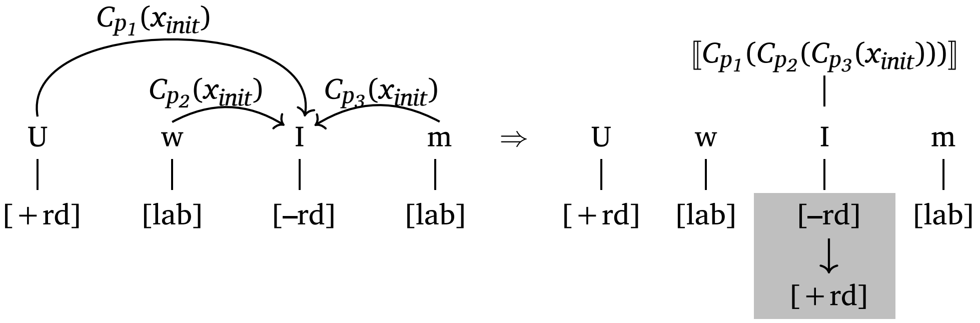
Teamwork	Type:	Self-additive
	Phonological process:	Assimilation
	Property(ies):	Rounding/labiality
Target	Type:	V
	Weak/strong:	weak (post-radical, partly underspecified)
Triggers	Number:	Up to 3
	Type:	C, V
	Hierarchy:	Root co-trigger > post-radical
	Position w.r.t. target:	Double-sided
	Locality w.r.t. target:	Adjacent (string or tier)
Phonological status	Static pattern:	Yes, quasi-systematic
	Active alternation:	Yes: post-radical, across morpheme boundary
	Morphological conditioning:	No
	Post-lexical:	No
	Exceptions:	Marginal

Table 4.24: Properties of Kazakh double-sided rounding

it immediately precedes the target vowel, as in the context /…-Uw__-m/ illustrated in (157a). In this case, teamwork is thus driven by up to three co-triggers.

A subfeatural analysis of this teamwork effect is sketched in (158) below, making use of the coarticulatory functions $Cp_{U\rightarrow I,[\![\mathrm{rd}]\!]}(x_{init})$, $Cp_{w\rightarrow I,[\![\mathrm{rd}]\!]}(x_{init})$, and $Cp_{m\rightarrow I,[\![\mathrm{rd}]\!]}(x_{init})$, represented by p_1, p_2, and p_3 respectively.

(158)

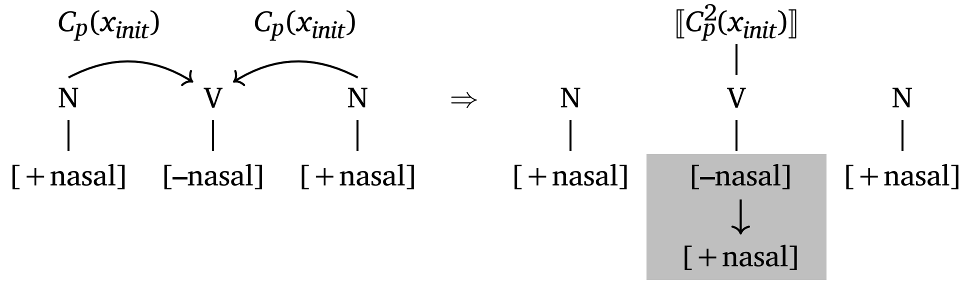


4.2.5 Vowel nasalization: Maléku Jaíka

A case of doubly triggers vowel nasalization is reported in the Chibchan language Maléku Jaíka (also known as Guatuso). In this language, vowels do not contrast for nasality. However, “when occurring between nasal consonants, vowels present nasalized allophones” (Constenla 1981: 94), i.e. V → Ṽ / N_N. Unfortunately, the author does not provide any example in his very brief sketch of the phonology of the language. While this example cannot be explored further, I have decided to include it in the typology because it is the only case of subphonemic teamwork involving nasal assimilation, and can thus serve as (tentative) evidence that such a teamwork effect is possible, despite its apparent rarity (which could be due to the fact that one nasal trigger is usually sufficient to trigger vowel nasalization).

Based on this very brief generalization, a subfeatural analysis using the ⟦nasal⟧ subfeature and the coarticulation function $C_{p_{N\rightarrow V,[\![\text{nas}]\!]}}(x_{init})$ scale is sketched in (159) below (with $p = p_{N\rightarrow V,[\![\text{nas}]\!]}$)

(159)



4.3 Mutually enhancing teamwork (vowel target)

4.3.1 Vowel rounding

4.3.1.1 Wergaia

Wergaia is an extinct Pama-Nyungan language formerly spoken in Western Victoria. The Djadjala dialect has the consonant and vowel inventories presented in (160) and (161) below.

(160) Wergaia consonants (Djadjala dialect; Hercus 1986: 73)

	Labial (B)	Alveolar (D)	Retroflex (Ḍ)	Palatalized alveo-dental (Dʲ)	Velar (G)
Plain	b∼[p]	d∼[t]	ɖ∼[ʈ]	d̪ʲ∼[t̪ʲ]	g∼[k]
Nasal	m	n	ɳ	n̪ʲ	ŋ
Rhotic		r	ɽ		
Lateral		l			
Glide	w			j	(w)

(161) Wergaia vowels (Djadjala dialect; Hercus 1986: 78)

a. Inventory:

i u
e
a

b. Realization:

	stressed	unstressed
/i/	[i]	[ɪ], [ə]
/e/	[e] [ɛ]	[ə]
/a/	[a] [ɑ]	[ʌ]
/u/	[u]	[ʊ], [ɔ]

Primary stress falls on the word-initial syllable, and every other syllable to the right carries secondary stress, unless it is the final open syllable of a trisyllabic word. Vowels tend to be reduced in unstressed syllables, as indicated in (161b) (Hercus 1986: 79-81).

The mid front vowel /e/ is the target of an enhancing teamwork effect: it is realized as rounded [ø] when immediately preceded by a labial or velar consonant AND followed by a retroflex consonant, as [e] elsewhere, as illustrated in (162). The exhaustive of relevant Wergaia examples is taken from Hercus' (1986: 198-214) lexicon.

(162) /e/ → [ø] / {B,G}_Ḍ in Wergaia (Hercus 1986)

a.	b_Ḍ	/be̱ɳeɽ/	[ˈbø̱ɳɽ]	'teal duck'
		/gurumbe̱ɖ/	[ˈgurʊmˌbø̱ʈ]	'water-rat'
		/be̱ɽm-be̱ɽm/	[ˈbø̱ɽm-ˌbø̱ɽm]	'red-kneed dotterel'
		/be̱ɽŋga/	[ˈbø̱ɽŋgʌ]	'to make or set (a fire)'
		/be̱ɽŋgun̪ʲa/	[ˈbø̱ɽŋgʊn̪ʲʌ]	'to be thirsty'
b.	m_Ḍ	/meɖ-meɽel/	[ˈmø̱ːʈ ˈmø̱ˌɽel]	'large black cormorant'
		/me̱ɽb/	[ˈmø̱ɽp]	'cousin'
		/me̱ɽeŋ/∼/me̱ɽŋ	[ˈmø̱ˑɽeŋ]∼[ˈmø̱ˑɽŋ]	'cloud'
		/me̱ɽg/	[ˈmø̱ˑɽk]	'ankle'
		/me̱ɽɳɖaɽ/	[ˈmø̱ɽɳɖʌɽ]	'thunder'
c.	w_Ḍ	/weɖug/	[ˈwø̱ʈʊk]	'(his) shoulder'
		/we̱ɽbil/	[ˈwø̱ɽpɪl]	'eagle hawk'
		/we̱ɽbug/	[ˈwø̱ɽpʊk]	'(its) trunk'
		/we̱ɽga/	[ˈwø̱ɽkʌ]	'not'
		/we̱ɽgaia/	[ˈwø̱ɽkaijʌ]	'no'
		/we̱ɽwa/	[ˈwø̱ɽwʌ]	'to swell up'
d.	g_Ḍ	/wila-geɖ/	[ˈwillʌ ˌgø̱ːʈ]	'bird sp.'
		/ge̱ɖia/	[ˈgø̱ʈɪʌ]	'umbrella wattle'
		/ge̱ɖug/	[ˈgø̱ʈʊk]	'owl'
		/ge̱ɽem/	[ˈgø̱ɽəm]	'spear shield'
		/ge̱ɽga/	[ˈgø̱ɽkʌ]∼[ˈgaɽkʌ]	'to grab, to catch'
		/ge̱ɽɳɖa/	[ˈgø̱ɽɳɖʌ]	'to shout, to yell'

There is only one exception to this pattern: /ŋeri/ [ˈŋɜɽɪ] 'black duck', where /e/ is centralized to [ɜ] under the effect of the following retroflex consonant (cf. (163) below), but not rounded to [ø]. Since this is the only attestation of the sequence /ŋeḌ/, it is possible that among velar consonants, only the stop /g/ [g ∼k] is able to co-trigger the teamwork-driven rounding of /e/.

That velars and labials should contribute to the retraction or rounding of an adjacent vowel is not surprising, as we already saw (cf. Fe'fe' Bamileke, § 4.3.2). While rounding by retroflex consonants may seem less natural –and is less frequent, as noted by Flemming (2002: 99)– it is nonetheless phonetically grounded. Indeed, retroflexion results in a general lowering of higher formant transitions (F2, F3, F4) going from a preceding vowel, particularly F3, whose amplitude it also decreases noticeably (cf. Fant 1968, Stevens and Blumstein 1975, and Dave 1977, Ladefoged and Maddieson 1996: 28; Stevens 1998: 535-542; see also Flemming 2002: 90-91). This lowering effect is very similar to that exerted by labials. In fact, lip rounding is known to enhance retroflexion, as is the case for the English retroflex approximant [ɻ], by reinforcing higher formant lowering, a crucial acoustic cue to retroflexion. While velars do not lower all formants (they tend to raise F2), they significantly lower F3, an effect they have in common with both labials and retroflexes. Labial, velar, and retroflex are thus all characterized as acoustically [+grave].

The teamwork effect illustrated by the Wergaia examples above is thus a clear case of enhancing teamwork: two articulatorily different triggers (labial/velar vs. retroflex) contributing the same acoustic effect (F3 lowering) team up to assimilate the target segment. The cumulative F3 lowering effect is realized as full rounding of the target vowel.[46]

The fixed position of each co-trigger with respect to the target is most probably not fortuitous, in particular the fact that the retroflex co-trigger systematically follows the target, and never precedes it. The formant transitions typical of retroflexion are indeed much greater in the vowel preceding the retroflex consonant than in the vowel following it (Dave 1977, Stevens 1998: 538). Two predictions can be drawn from this fact. Firstly, vowel rounding by a retroflex consonant is much more likely to take place when the vowel precedes the consonant. Secondly, if a retroflex consonant needs to team up with another consonant in order to round a vowel, this second consonant is likely to precede the target vowel, and is thus unlikely to be a retroflex consonant, which in this position is not expected to have much of an effect on the target vowel. The only F3-lowering consonants left are labials (and their "relatives": labial-velars and labialized consonants) and velars. As we will see, these predictions are borne out in all three of the languages presented in this section (Wergaia, Wemba Wemba, Tamil).

Interestingly, the teamwork effect at work in Wergaia can be further decomposed into two steps: the retroflex consonant retracts the preceding /e/ to [ɜ], and teams up with the preceding labial or velar consonant to further change it into front rounded [ø]. The retracting effect of retroflex consonants on /e/ is independently observed, as shown shown in (163), with the three of the four words in Hercus' Wergaia lexicon where /e/ precedes a retroflex and does not follow a labial or velar consonant.

(163) /e/ → [ɜ] / C_Ḍ in Wergaia (C ≠ B,G)

D_Ḍ	/le̠ɽble̠ɽbmala/	[ˈlɜ̠ɽplɜ̠ɽpˌmalʌ]	'to bark'
Ḍ_Ḍ	/peɳe̠ɽ/	[ˈbøɳɜ̠ɽ]	'teal duck'
Dʲ_Ḍ	/d̪ʲid̪ʲe̠ʈ/	[ˈt̪ʲit̪ʲɜ̠ʈ]	'grass parrot'
	/je̠ɽga/	[ˈjɜ̠ɽkʌ]	'to search'

The only attestation of a ḌeḌ sequence in Hercus' Wergaia data is in the word /waɽeɽeŋ/, whose phonetic transcription is given as [ˈwɔɽə̠ˌɽeŋ], with the unstressed allophone [ə] of /e/, and not [ˈwɔɽɜ̠ˌɽeŋ], with the expected pre-retroflex [ɜ] allophone. This could be a typographical or transcription error: the distinction between unstressed [ɜ] and [ə] is after all pretty tenuous. Additionally, there is one exception to the last pattern in (163): /d̪ʲeɖawa/ [ˈt̪ʲøɽawa] 'to stop, to be stationary'. Once again, it might be a typographical or transcription error, given the perceptual similarity between [ɜ] and [ø] (often realized as open [œ], Hercus: 1986: 80).

This effect is also attested in closely related Wemba Wemba, where /e/ is always realized [ɜ] before a retroflex, irrespective of the nature of the preceding consonant, (Wemba Wemba does not have the doubly triggered rounding of /e/ attested in Wergaia).[47] This is shown in (164) below.

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[46] If retroflex consonants are articulated in Wergaia with redundant lip rounding, as is cross-linguistically frequent, the two co-triggers in the B_Ḍ environment might even be considered to have the lip rounding articulation in common. This is purely speculative, however, since Hercus (1986) does not give any information on this –and will unfortunately have to remain so, since Wergaia is now extinct.

[47] "[In Wemba Wemba,] after labial consonants there was a slight tendency towards lip-rounding in the articulation of [ɜ], but this was so variable that it des not warrant inclusion in the phonetic notation" (Hercus 1986: 17).

(164) /e/ → [ɜ] / C_Ḍ in Wemba Wemba (C = any consonant; NB: GeḌ is unattested)

B__Ḍ	/be̠ɳe̠ɽ/	[ˈpɜ̠ɳɜ̠ɽ]	‘teal duck’	cf. (162b)
	/me̠ɖ-me̠ɽil/	[ˈmɜ̠ʈ ˈmɜ̠ˌɽɪl]	‘cormorant sp.’	cf. (162c)
	/we̠ɽbug/	[ˈwɜ̠ɽpʊk]	‘(its) trunk’	cf. (162d)
D__Ḍ	/le̠ɽeb/	[ˈlɜ̠ɽəp]	‘manna sp.’	
Ḍ__Ḍ	/pe̠ɳe̠ɽ/	[pɜ̠ɳɜ̠ɽ]	‘teal duck’	cf. (162b)
Dʲ__Ḍ	/d̪ʲe̠ɖa/	[ˈt̪ʲɜ̠ʈa]	‘to finish’	

In keeping with the articulatory and acoustic characteristics of the release of retroflex consonants mentioned above, post-retroflex /e/ is not affected, even when followed by a labial or velar, as shown in (165) below for Wergaia. Note that retroflex consonants are not attested word-initially.

(165) Post-retroflex /e/ in Wergaia (NB: ḌeD and ḌeDʲ are unattested)

Ḍ__B	/waɽewa/	[ˈwaɽə̠wʌ]∼[ˈwɔɽə̠wʌ]	‘to go away’
Ḍ__G	/biɽe̠ŋga/	[ˈbyɽə̠ŋgʌ]	‘to cut’
	/baɽe̠ŋ/	[ˈbaɽɛ̠ŋ]	‘river’

The retroflex consonant thus retracts the preceding /e/ to [ɜ], and teams up with the preceding labial or velar consonant to further change it into front rounded [ø]. This teamwork effect does not exist in Wemba Wemba, and it is only attested with /e/ in Wergaia. Notably, the high front vowel /i/ is systematically realized as rounded [y] whenever it is immediately followed by a retroflex consonant, the nature of the preceding consonant being irrelevant, as exhaustively illustrated in (166). Note that this distributional constraint is attested in both Wergaia and Wemba Wemba.

(166) /i/ → [y] / _Ḍ in Wergaia (ḌiḌ is unattested)

B__Ḍ	/bi̠ɽbin̪ʲ/	[ˈby̠ɽpɪn̪ʲ]	‘spear-point waddy’
	/mi̠ɽ /	[ˈmy̠ɽ]	‘eye’
	/wi̠ɽimbul/	[ˈwy̠ɽɪmˌbʊl]	‘ears’
G__Ḍ	/gi̠ɽe/	[ˈgy̠ɽə]	‘urine’
D__Ḍ	/ni̠ɳag/	[ˈny̠ɳʌk]	‘frog’
Dʲ__Ḍ	/d̪ʲi̠ʈug/	[ˈd̪ʲy̠ʈuk]	‘end’

Interestingly, Hercus (1986: 17, 79) notes that in both languages, the rounding effect is more pronounced when the target vowel is also preceded by a labial consonant, as in (166a) above. That is, even if the presence of the labial consonant is not necessary for rounding to take place, the phonetic cumulative effect of the labial and retroflex consonants is still perceptible.

Like for the mid-vowel /e/, a retroflex consonant has no effect on a following /i/, even if the following consonant is labial or velar, as shown in (167) below.

(167) Post-retroflex /i/ in Wergaia (exhaustive list)

a.	Ḍ__B	/gaɽi̠bug/	[ˈgaɽɪ̠ˌpʊk]	‘(his) thigh’
		/wiɽi̠mbul/	[ˈwyɽɪ̠mˌbʊl]	‘ears’
		/wiɽi̠mal/	[ˈwyɽɪ̠ˌmʌl]	‘big light-coloured owl’
		/wiɽi̠ba/	[ˈwyɽɪ̠ˌpʌ]	‘to stay, to remain’
		/wuɽi̠b/	[ˈwʉɽɪ̠p]	‘cuckatoo parrot’

	/CeC/					/CiC/				
	__B	__D	__Ḍ	__Dʲ	__G	__B	__D	__Ḍ	__Dʲ	__G
B__	e	e	ø	e	e	i	i	y	i	i
G__	e	e	ø	e	e	i	i	y	i	i
D__	e	e	ɜ	e	e	i	i	–	i	i
Ḍ__	e	–	ɜ	e	e	i	i	y	i	i
Dʲ__	e	e	ɜ	–	–	i	i	y	i	i

Table 4.25: Realization /CeC/ in Wergaia

b.	Ḍ__G	/baɽi̠ŋgug/	[ˈbaɽɪ̠ŋˌgʊk]	‘(his) track ,road’
		/gaɽi̠ŋa/	[ˈgaɽɪ̠ŋʌ]	‘to grow’
c.	Ḍ__D	/daɖi̠daɖi̠/	[ˈdaʈɪ̠ˌdaʈɪ̠]	tribe name
		/daɖi̠dan̪ʲa/	[ˈdaʈɪ̠ˌdan̪ʲʌ]	place name
d.	Ḍ__D̪ʲ	/baɽi̠n̪ʲug/	[ˈbaɽɪ̠ˌn̪ʲʊk]	‘(his) lower leg’
		/buɽi̠n̪ʲ/	[ˈbʉɽɪ̠n̪ʲ]	‘smoke’
		/wiɽi̠n̪ʲ/	[ˈwyɽɪ̠n̪ʲ]	‘hot coals’
		/wuɽi̠n̪ʲug/	[ˈwʉɽɪ̠ˌn̪ʲʊk]	‘back of (his) knees’
e.	Ḍ__#	/ŋeɽi̠/	[ˈŋɜɽɪ̠]	‘black duck’

Table 4.25 presents a simplified summary of the effect of consonants on the realization of adjacent /e/ and /i/ in Wergaia. The letters “e” and “i” stand for all allophones of /e, i/ that are independent of the nature of adjacent consonants: [e, ɛ, ə] and [i, ɨ] respectively. Minor exceptions are excluded.

There is thus a discrepancy between high and mid vowels. The effect of the retroflex consonant is stronger on /i/ (full rounding) than on /e/ (retraction in both languages), making teamwork with a labial consonant necessary only for the mid vowel (in Wergaia only). Flemming (2002: 90) ascribes this discrepancy to

> an articulatory incompatibility between tongue tip retroflexion and a high front tongue body. The articulatory difficulty arises from an articulatory incompatibility between tongue tip retroflexion and a high front tongue body. A retroflex involves a constriction formed by the tongue tip against the hard palate, but the tongue body approximates to the palate when it is high and front, so it is not possible to form both constrictions simultaneously. So the tongue body must be retracted and lowered during a retroflex, consequently rapid tongue body movement is required where a high front vowel precedes a retroflex. More generally, it appears that any front tongue body position is problematic during a retroflex, even if non-high, and that a high tongue body position is problematic, unless it is also back (i.e. it is problematic for the front of the tongue to be high).

In other words, the coarticulatory effect of a retroflex consonant on a preceding /e/ is weaker than on a preceding /i/, which explains why teamwork with a labial or velar consonant, i.e. cumulative coarticulation, is needed for the rounding of /e/.

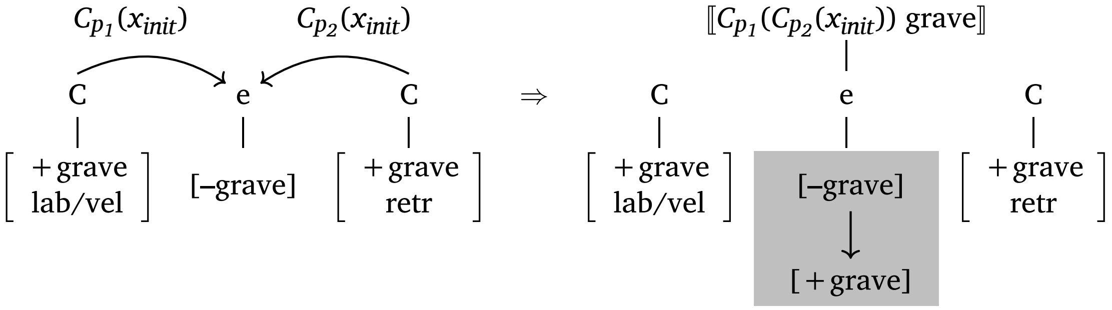
Teamwork	Type:	Self-additive
	Phonological process:	Assimilation
	Property(ies):	Rounding
Target	Type:	V
	Weak/strong:	n/a
Triggers	Number:	2
	Type:	C
	Hierarchy:	Retroflex > labial
	Position w.r.t. target:	Double-sided
	Locality w.r.t. target:	Adjacent
Phonological status	Static pattern:	Yes
	Active alternation:	No
	Morphological conditioning:	No
	Post-lexical:	No
	Exceptions:	No?

Table 4.26: Properties of Wergaia double-sided /e/ rounding

Finally, let us note that the retroflex consonant seems to be the stronger of the two co-triggers here, for two reasons, since it is strong enough to round high /i/, contrary to labials or velars, and it always has a perceptible coarticulatory effect on the preceding vowel, whereas labials and velars are not said to have any independent effect on a following vowel in Hercus (1986). The labial thus seems to play an auxiliary role in the process.

This slight discrepancy between labials and retroflexes is simply accounted for in subfeatural theory by assigning to each type of trigger a different coarticulatory coefficient: $p_{B/G\to V,[\![\mathrm{gr}]\!]} < p_{\underset{\cdot}{D}\to V,[\![\mathrm{gr}]\!]}$. The teamwork effect yields a $[\![C_{p_{B/G\to V,[\![\mathrm{gr}]\!]}}(C_{p_{\underset{\cdot}{D}\to V,[\![\mathrm{gr}]\!]}}(x_{init}))\ \mathrm{grave}]\!]$ [e] that the phonology changes to [+grave] [o]. This is schematized in (168), where $p_1 = p_{B/G\to V,[\![\mathrm{gr}]\!]}$, and $p_2 = p_{\underset{\cdot}{D}\to V,[\![\mathrm{gr}]\!]}$. Table 4.26 summarizes the properties of the Wergaia double-sided /e/ rounding.

(168)



4.3.1.2 Tamil

An ongoing sound change in Standard Spoken Tamil illustrates a very similar enhancing teamwork effect: the front vowels /i(ː)/ and /e(ː)/ are backed and rounded into [u(ː)] and [o(ː)] respectively when preceded by a labial consonant, i.e. {m,ʋ,p} and followed by a retroflex consonant, i.e. {ʈ ɳ ɽ ɻ ɭ}. This is schematized and illustrated in (170)-(171) below, after a presentation of the vowel system of Standard Spoken Tamil in (169).

(169) Tamil vowel inventory (Schiffman 1999)

$$\begin{tikzcd} i \arrow[r] & u \\ e \arrow[r] & o \\ a & \end{tikzcd}$$

(170) $V_{[+\text{front}]} \rightarrow V_{[+\text{back}, +\text{round}]} \,/\, C_{\text{labial}} \_\_ C_{\text{retroflex}}$

(171)		Literary Tamil	Spoken Tamil [48]	
	a.	pe̱ɳ	[po̱ɳɳu]	‘girl, daughter’
	b.	pi̱ɖi	[pu̱ɖi]	‘like’
	c.	ʋi̱ːɖu	[ʋu̱ːɖu]	‘house’
	d.	ve̱ɳɖum	[ʋo̱ːɳum]	‘want, need, must’
	e.	pe̱ʈʈi	[po̱ʈʈi]	‘box’

Schiffman (1999: 19) describes this process as an ongoing sound change, which explains why it is not fully regular, as shown. He also says that it sociolinguistically marked: “some forms that have undergone this change are socially quite acceptable, but others are considered to be somewhat substandard or casual (or even ‘vulgar’) so many speakers avoid this kind of rounding, or deny that they do it even when it is observed in their speech.”

This change is sometimes attested even when the rightmost co-trigger is alveolar, as in the following two examples (although the [ɾ] in (172a) is historically derived from a retroflex rhotic /ɽ/, as still indicated in the Literary Tamil orthography, faithfully transcribed to the left of the phonetic transcription.

(172)			
	a.	pi̱ɽandadu	[po̱ɾandadu]
	b.	mi̱dakkum	[mo̱dakkum]

The phonetic underpinnings of the Tamil facts are presumably the same as in Wergaia above, except that velar consonants are not involved. This difference is not unexpected, given that velars tend to have a less strong higher-formant lowering effect than labials and retroflexes.

The subfeatural analysis sketched for Wergaia in the previous chapter can be applied to Tamil as well. Note that there is no information in the data I had access to about the relative strength of the two triggers with respect to each other. This case of teamwork could thus be analyzed as resulting from the double application of the same coarticulatory function. It should not be too surprising if the retroflex consonant turned out to have a stronger effect than the labial consonant, given the general cross-linguistic properties of retroflex consonants.

The characteristics of Tamil double-sided rounding are summarized in Table 4.27 below.

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[48] (171a) shows gemination of the final sonorant and u-epenthesis after a word-final consonant; (171d) illustrates ɳɖ > ɳ cluster reduction and compensatory lengthening.

Teamwork	Type:	Self-additive
	Phonological process:	Assimilation
	Property(ies):	Rounding
Target	Type:	V
	Weak/strong:	n/a
Triggers	Number:	2
	Type:	C
	Hierarchy:	n/a
	Position w.r.t. target:	Double-sided
	Locality w.r.t. target:	Adjacent
Phonological status	Static pattern:	Yes (ongoing sound change)
	Active alternation:	No
	Morphological conditioning:	No
	Post-lexical:	No
	Exceptions:	Yes (ongoing sound change)

Table 4.27: Properties of Tamil double-sided rounding

4.3.1.3 Iaai

A similar case of teamwork-driven vowel rounding is attested in Iaai (Oceanic, Loyalty Islands; Ozanne-Rivierre 1976), this time involving labials and velars (at least in the hypothesis tentatively adopted here).[49]

(173) Iaai vowels (Ozanne-Rivierre 1976: 81, Ozanne-Rivierre 1984)

i	y			u
e	ø		ɤ	o
æ	[œ]			ɔ
		a		

The vowel /ø/ (and its long counterpart /øø/) is attested in only nine words, where it always occurs in a CVC syllable, wedged between a labial and a velar consonant in that order, as shown in (174a). There are only two minor exceptions: (174b) where the velar consonant following /ø/ is not tautosyllabic, and (174c) where the consonant preceding /øø/ is palatal.

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[49] I follow Maddieson and Anderson's (1995) phonetic transcription here rather than Ozanne-Rivierre's practical orthography. Note that vowel length is distinctive for all vowel qualities.

(174) /ø/ in Iaai (Ozanne-Rivierre 1976: 65, 71; 1984)

a.	bebøŋ	‘rotten’
	møk	‘illness, be sick, die’
	ɲ̊aamøk	‘mourning cries’ (likely related to møk ‘die’)
	eekemøk	‘cemetery’ (likely related to møk ‘die’)
	møxon	‘shortness of breath’
	omøk	‘fish sp.’
	om̥ɤm̥øk	‘plant sp.’
b.	liamøkon	‘parent with his/her children’ (< liame-ko-n, cf. below)
c.	ɲ̊øøk	‘dedicate’

This vowel never occurs elsewhere, even phonetically, and is contrastive in the restricted context where it is found, since all vowels are attested in that environment (B__G]$_\sigma$). This very restricted distribution suggests that /ø/ is likely to have resulted historically from the phonologization and phonemicization of the coarticulatory effects of the labial and velar consonants on the vowel they flank. One possible hypothesis is that the precursor of /ø/ was a front vowel (e.g. /e/), tending toward the phonetic realization [ø] under the rounding effect of the preceding labial consonant, an effect reinforced by probable F2’ lowering caused by the grave velar consonant immediately following it.[50] In this hypothesis, the labial was the main co-trigger and the velar an auxiliary co-trigger in a teamwork-driven sound change. The existence in the inventory of the high front rounded vowel /y/ may also have played a role in the sound change, by making the front rounded “area” in the vowel space more easily accessible to potential sound changes, increasing the likelihood that a vowel sounding like a front rounded vowel be reinterpreted as such, by analogy with /y/. The exact conditions of this sound change cannot be determined (e.g. if BeG]$_\sigma$ changed to BøG]$_\sigma$, where do the attested cases of BeG]$_\sigma$ come from?), and other hypotheses are of course possible.

It is worth noting that the possessed form of *møk* ‘illness, be ill, die’ is *meki-*, with an unrounded mid front vowel (e.g. *meki-ɲ* ‘his illness’). This could be seen as evidence in favor of the hypothesis just proposed (i.e. *e > ø / B__G]$_\sigma$): when the velar co-trigger is not tautosyllabic, as in *me.ki-*, the e → ø change does not occur. It is, however, difficult to view this single occurrence of an e/ø correspondence as a regular morpho-phonological process, in particular given the fact that many Iaai verbs are characterized by unpredictable umlaut (and consonant mutation) processes marking various inflectional and derivational categories. Note, additionally, that in the word *komok* ‘ill person, corpse’, very likely related to *møk*, the same root appears with an [o] (perhaps historically through harmony with the preceding vowel?).

A second case of morpho-phonological e/ø alternation is illustrated in the word *liamø-ko-n* ‘parent with his/her children’ (174b above), from the classificatory prefix *liame-* referring to persons in a kinship relation, and *ko-n* ‘his/her child’ (note that the velar co-trigger and the target are not tautosyllabic). Once again, this alternation seems to be an isolated case: there is no vowel rounding in the same environment in *liame-kei-ɲ* ‘two brothers’. The vowel difference in the immediately following syllable (*ko* vs. *e*) might have something to do with this difference: the articulatorily back/rounded and acoustically grave vowel /o/ in /liame-ko-n/ may have participated alongside

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[50] F2’ is defined as the center of gravity of higher formant frequencies, mainly F2, F3 and F4, cf. Carlson et al. (1970), Stevens (1998: 288-290).

Teamwork	Type:	Enhancing
	Phonological process:	Assimilation
	Property(ies):	Backness & rounding
Target	Type:	V
	Weak/strong:	n/a
Triggers	Number:	2
	Type:	C
	Hierarchy:	Labial > velar
	Position w.r.t. target:	Double-sided, tauto-syllabic
	Locality w.r.t. target:	Adjacent
Phonological status	Static pattern:	Yes (distributional restriction)
	Active alternation:	No (completed sound change)
	Morphological conditioning:	No
	Post-lexical:	No
	Exceptions:	?

Table 4.28: Properties of Iaai doubly triggered rounding

the two consonants in the teamwork effect leading to the e > ø change, while the front/acute vowel /e/ is not unlikely to have counteracted their cumulative F2' lowering effect.

Table 4.28 summarizes the characteristics of this case of enhancing teamwork.

4.3.2 Gravity: acute vs. grave competition in high vowel reduplication

I now turn to a case of team competition involving additive teamwork, found in "high vowel reduplication" (Hyman 1970). This morpho-phonological process is commonly used to mark various functions in many West African languages, in particular Benue-Congo languages of Nigeria and Cameroon. In all these languages, the reduplicated form is obtained through reduplication of the initial consonant of the stem and epenthesis of a high vowel between the reduplicated consonant and the root-initial consonant, as schematically illustrated in (175).

(175) High vowel reduplication:

$[C_1V\ldots]_{stem} \quad [C_1V_{[+high]}]_{RED} + [C_1V\ldots]_{stem}$

In many languages, the realization of this high vowel is determined by the stem-initial consonant and/or vowel, and varies between [i] and [u] (or between [i], [ɨ], and [u], depending on the vowel inventory). Such is the case in Fe'fe' Bamileke, where the realization of the epenthetic vowel as [i], [ɨ], or [u] depends on the winner of a competition between acute and grave assimilation triggers, a competition that involves teamwork within each team. The rest of this section is devoted to a thorough description of the Fe'fe' Bamileke facts, based on Hyman's (1972) description of the phonology of the language, as well as his unpublished field notes.[51]

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[51] Similar assimilatory effects are also attested, with slightly different properties, in high vowel reduplication in Akan (Schachter and Fromkin 1968), Igbo (Hyman 1973), Nupe (Smith 1967; Hyman 1970), Tarok (Robinson 1976; Sibomana 1980; Longtau 1993), and Mungbam (Lovegren 2013), but they don't all constitute as clear cases of teamwork as Fe'fe' Bamileke.

The consonant and vowel systems of Fe’fe’ Bamileke are presented in (176) and (177) below, with arrows indicating the vowel changes incurred by the teamwork process.[52]

(176) Fe’fe’ Bamileke consonants (Hyman 1972: 38-39)

Labial	Alveolar	Palatal	Velar	Glottal
	t	c [t͡ʃ], cw [t͡ʃʷ]	k, kw	ʔ[53]
b, bw	d	j [d͡ʒ], jw [d͡ʒʷ]	g, gw	
f	s			h
v	z			
m	n		ŋ	

(177) Fe’fe’ Bamileke vowels (Hyman 1972: 30)

Front	Central	Back
i ⟵	ɨ ⟶	u
e∼[ɛ]	ə	[ɔ]∼o
	a ɑ	

Note that word-initial /b/ is regularly realized [p], and will be transcribed as such. Additionally, the mid vowels /e/ and /o/ are realized [ɛ] and [ɔ] respectively in the contexts given in (178) and (179) below. Since the distinction between [e] and [ɛ] is important for the understanding of the assimilation processes at work in high vowel reduplication, as we will see, it will be systematically kept in the transcriptions.

(178) /e/ → [ɛ] / _{n,h,ʔ}#
/fen/ [fɛn] ‘sell’
/ceh/ [cɛh] ‘read’
/sė ʔ/ [sɛ̇ʔ] ‘tooth’

(179) /o/ → [ɔ] / _{b,h,g}#
/vǒb/ [vɔ̌p] ‘dust’ (+ final devoicing)
/tog/ [tɔk] ‘ear’
/sȯh/ [sɔ̇h] ‘wash’

High vowel reduplication in Fe’fe’ is used to derive restrictive (do only) or insistive/repetitive (do nothing but) verb forms. Verb stems can only be of one of the four forms CV, CVV, CVC or CVVC. The epenthetic vowel of the reduplicant is the central vowel /ɨ/:

(180) C_1V(V)(C) → C_1ɨ + C_1V(V)(C)
za ‘eat’ → zɨ + za
koo ‘carve’ → kɨ + koo
tɛn ‘stand up’ → tɨ + tɛn

---

[52] Hyman’s original /ʉ/ ([ɯ] [ɨ]) and /ɤ/ are reanalyzed here as /ɨ/ and /ə/ respectively. Whether /Cw/ sequences should be treated as labialized segments or as a /C/ + /w/ sequences is unclear. Hyman (1972) chooses the latter option, recognizing /w/ as a separate phoneme with a highly constrained distribution (only post-consonantal, only before a non-back vowel etc.).

[53] /ʔ/ is only attested in coda position.

Hyman (1972) notes that there is much dialectal and idiolectal variation with respect to the realization of the epenthetic vowel in the reduplicant. In all dialects, the epenthetic vowel /ɨ/ systematically fully assimilates to the high vowels /i/ and /u/ of the stem, as shown in (181). In the speech of the Bafang dialect speaker Hyman worked with, this is the full extent of the assimilation: elsewhere, the vowel is realized [ɨ], as shown in the examples below.

(181) sii ‘spoil’ → si̲ + sii
kuu ‘carve’ → ku̲ + kuu

Additionally, the epenthetic vowel is systematically realized [u] when the stem-initial consonant is a labialized labial or dorsal consonant. Note that labialized palatals do not have the same effect: they behave like regular palatals, as shown in (182c).

(182) a. pwɛn → pu + pwɛn (+ *Cwu > Cu)
b. kwɛn → ku + kwɛn (+ *Cwu > Cu)
c. jwɛn → jɨ + jwɛn (+ *Cwɨ > Cɨ)

Table 4.29 summarizes the realization of the vowel of the reduplicant in the Bafang speaker’s idiolect, according to the stem vowel and the stem-initial consonant (“–” indicates a phonotactically prohibited sequence).[54]

		Stem Vowel								
C1		i	e	[ɛ]	a	ɨ	ɑ	[ɔ]	o	u
Alv	D	i	ɨ	ɨ	ɨ	ɨ	ɨ	ɨ	ɨ	u
Pal	J	i	ɨ	ɨ	ɨ	ɨ	ɨ	ɨ	ɨ	u
Pal +lab	Jw	i	ɨ	ɨ	ɨ	–	–	–	–	–
Lab	B	i	ɨ	ɨ	ɨ	ɨ	ɨ	ɨ	ɨ	u
Vel	G	i	ɨ	ɨ	ɨ	ɨ	ɨ	ɨ	ɨ	u
Lab + lab	Bw	–	–	u	–	–	–	–	–	–
Vel +lab	Gw	–	u	u	u	–	–	–	–	–

Table 4.29: High vowel reduplication in Bafang

In the speech of the Petit Diboum dialect speaker that Hyman worked with, the realizations [i] and [u] of the epenthetic vowel are also attested in other contexts. The realization [i] extends to the stem vowels [e, ɛ, a], if the stem-initial C is alveolar or palatal, as shown by examples a-b vs. c-d in (183)-(186).

(183) a. tee ‘remove’ → ti + tee
b. jee ‘see’ → ji + jee
c. pėė ‘hate’ → pɨ + pėė
d. kėė ‘refuse’ → kɨ + kėė

---

[54] + Add note on the fact that the cells corresponding to unattested combinations (e.g. Jw + ɨ, Bw + o, etc.) are shaded in order to devise two continuous i- and u-zones respectively. Their shading is based on an implicational reasoning: if Bw and Gw are grave enough to change /ɨ/ to [ɨ] despite the counteracting effect of a following /e/, then it would most probably have the same effect with any vowel with lower acuteness (ɛ ... u) if the relevant combinations were attested. The only two cases where the outcome is unpredictable are the combinations of Bw and Gw with /i/, which are thus left blank in Tables 4.29 to 4.32.

(184) a. tɛn ‘stand up’ → ti + tɛn
b. cɛn ‘moan’ → ci + cɛn
c. pɛn ‘accept’ → pɨ + pɛn
d. ɣɛ̇n ‘go’ → ɣɨ + ɣɛ̇n

(185) a. taʔ ‘bargain’ → ti + taʔ
b. caʔ ‘trample’ → ci + caʔ
c. paʔ ‘commit suicide’ → pɨ + paʔ
d. kaʔ ‘fry’ → kɨ + kaʔ

Labialized labials and velars, like for the Bafang speaker, systematically trigger assimilation to [u] ((118)a-b). Note that labialized palatals behave like their non-labialized counterparts, and not like either labials or labialized labials or velars, as shown in (187c-d) below.

(186) a. kwėe ‘join’ → ku-kwėe
b. pwɛn ‘howl’ → pu-pwɛn
c. cwee ‘cut’ → cwi-cwee
d. cwɛʔ ‘fuck’ → cwi-cwɛʔ

Additionally, the realization [u] is extended to all round stem vowels, on the condition that the stem-initial consonant be labial or dorsal, as shown in (187)-(188 (compare a-b vs. c-d). The Petit Diboum data is summarized in Table 4.30.

(187) a. mo ‘kill time’ → mu + mo
b. ko ‘take’ → ku + ko
c. to ‘punch’ → tɨ + to
d. co ‘fall’ → cɨ + co

(188) a. pɔh ‘be afraid’ → pu + pɔh
b. kɔh ‘be small’ → ku + kɔh
c. tɔh ‘pass’ → tɨ + tɔh
d. cɔh ‘be severe’ → cɨ + cɔh

		Stem Vowel								
C1		i	e	[ɛ]	a	ɨ	ɑ	[ɔ]	o	u
Alv	D	i	i	i	i	ɨ	ɨ	ɨ	ɨ	u
Pal	J	i	i	i	i	ɨ	ɨ	ɨ	ɨ	u
Pal + lab	Jw	i	i	i	i	–	–	–	–	–
Lab	B	i	ɨ	ɨ	ɨ	ɨ	ɨ	u	u	u
Vel	G	i	ɨ	ɨ	ɨ	ɨ	ɨ	u	u	u
Lab + lab	Bw	–	–	u	–	–	–	–	–	–
Vel + lab	Gw	–	u	u	u	–	–	–	–	–

Table 4.30: High vowel reduplication in Petit Diboum

Hyman (1972, 1973) uses these facts to argue in favor of reinstating the acoustic feature [grave] (first proposed by Jakobson et al. 1952) in phonological representations. The main argument in support of this claim is the fact that front unrounded vowels pattern with alveolar and palatal consonants, whereas back rounded vowels pattern with labials and velars, which do not form a natural class unless gravity is taken into account. As noted by Ladefoged (1971)44:

> The acoustic (and hence auditory) similarities between corresponding sounds made in the labial and velar regions is often considerable. The reasons for this acoustic similarity are complex and cannot be given here. It must suffice to say that sounds made with a constriction in either of these areas often have an overtone structure in which most of the acoustic energy is at a lower pitch than in the corresponding sounds made in the alveolar or palatal regions... Following Jakobson (Jakobson et al. 1952; Jakobson 1962) we will refer to this feature as gravity.

Front unrounded vowels, alveolar, and palatal consonants are thus acute, whereas back rounded vowels, velar and labial consonants are grave. The epenthetic vowel /ɨ/ in Fe'fe' is thus subject to gravity/acuteness assimilation. Gravity and acuteness can be seen as two forces competing to assimilate the epenthetic vowel. Assimilation occurs when the sum of the coarticulatory effects of the neighboring segments is acute or grave enough, i.e. if a threshold of acuteness or gravity (subject to dialectal and/or idiolectal variation) is reached.

> The assimilation of [ɨ] to [i] will take place if there is “enough” fronting (or non-gravity); the assimilation of [ɨ] to [u] will take place if there is “enough” gravity of roundness (i.e. “enough” frequency lowering). The content of the term “enough” will vary from village to village and from speaker to speaker… (Hyman 1972: 125)

In the speech of the Bafang dialect speaker, only the vowels [i] and [u] are acute or grave enough to trigger assimilation unconditionally. No simple consonant reaches the threshold of gravity or acuteness necessary to trigger assimilation. However, grave consonants may gang up to trigger gravity assimilation, as is the case with the labialized velars and labials: labial and velar consonants are not grave enough, unless they are combined with /w/. Note that /w/ cannot be said to be grave enough, since labialized palatal consonants do not trigger gravity assimilation (the palatal consonant seems to be “stronger” than /w/, thus cancelling its effect). In Petit Diboum, more segments team up. While the non-high front vowels [e, ɛ, a] and the alveolar and palatal consonants are not acute enough to trigger acuteness assimilation on their own, their cumulative effect does break the threshold, forcing neutral /ɨ/ to go to acute [i]. The same phenomenon is observed with non-high back rounded vowels and labial and velar consonants: only their cumulative effects yield enough gravity to trigger harmony. It thus appears that the threshold for gravity and acuteness assimilation is slightly lower in Petit Diboum than in Bafang.

The threshold for acuteness assimilation is further lowered in the Bassap speaker's variant, where not only [i], but also [e] unilaterally break the threshold of acuteness, as illustrated in (189) and summarized in Table 4.31 (compare with (183) and Table 4.30 above). Interestingly, [ɛ] is not acute enough, which, as Hyman (1972: 113) noted, shows that “the choice of the reduplicated vowel depends more on the phonetic vowel [i.e. contextual allophone], than on the underlying vowel”, which shows that this assimilation process is sensitive to purely allophonic information (as in Kaska back harmony, § 4.4).

(189)

				Bassap	Pt Diboum	Bafang
a.	tee	‘remove’	→	ti + tee	ti + tee	tɨ + tee
b.	jee	‘see’	→	ji + jee	ji + jee	jɨ + jee
c.	pėė	‘hate’	→	pi + pėė	pɨ + pėė	pɨ + pėė
d.	kėė	‘refuse’	→	ki + kėė	kɨ + kėė	kɨ + kėė

		Stem Vowel								
C1		i	e	[ɛ]	a	ɨ	ɑ	[ɔ]	o	u
Alv	D	i	i	i	i	ɨ	ɨ	ɨ	ɨ	u
Pal	J	i	i	i	i	ɨ	ɨ	ɨ	ɨ	u
Pal +lab	Jw	i	i	i	i	–	–	–	–	–
Lab	B	i	i	ɨ	ɨ	ɨ	ɨ	u	u	u
Vel	G	i	i	ɨ	ɨ	ɨ	ɨ	u	u	u
Lab + lab	Bw	–	–	u	–	–	–	–	–	–
Vel +lab	Gw	–	u	u	u	–	–	–	–	–

Table 4.31: High vowel reduplication in Bassap

Finally, the Bakou variety of Petit Diboum shows no lowering of the acute threshold compared to Petit Diboum, but does show a slight lowering of the gravity threshold: additionally to [u], [o] is grave “enough” to trigger gravity assimilation on its own, as illustrated in (190 and summarized in Table 4.32.

(190)

				Bakou	Pt Diboum	Bafang
a.	mo	‘kill time’	→	mu + mo	mu + mo	mɨ + mo
b.	ko	‘take’	→	ku + ko	ku + ko	kɨ + ko
c.	to	‘punch’	→	tu + to	tɨ + to	tɨ + to
d.	co	‘fall’	→	cu + co	cɨ + co	cɨ + co

		Stem Vowel								
C1		i	e	[ɛ]	a	ɨ	ɑ	[ɔ]	o	u
Alv	D	i	i	i	i	ɨ	ɨ	ɨ	u	u
Pal	J	i	i	i	i	ɨ	ɨ	ɨ	u	u
Pal +lab	Jw	i	i	i	i	–	–	–	–	–
Lab	B	i	ɨ	ɨ	ɨ	ɨ	ɨ	u	u	u
Vel	G	i	ɨ	ɨ	ɨ	ɨ	ɨ	u	u	u
Lab + lab	Bw	–	–	u	–	–	–	–	–	–
Vel +lab	Gw	–	u	u	u	–	–	–	–	–

Table 4.32: High vowel reduplication in Bakou

Note that in all three Petit Diboum varieties (Petit Diboum proper, Bassap and Bakou), labialized grave consonants are always grave enough to counterbalance the effect of acute [e,ɛ,a], including in Bassap, where [e] is acute enough to trigger acute assimilation. Labialized palatals, on the other hand, systematically pattern with regular palatals.

The gravity/acuteness assimilation affecting the epenthetic vowel in cases of high vowel reduplication in Fe'fe' is thus a clear case of a cumulative subphonemic effect: categorical assimilation in gravity or acuteness occurs when a certain quantitative threshold of coarticulation-induced subphonemic gravity or acuteness is reached. Only the coarticulatory effects of maximally grave /u/ and maximally acute /i/ are strong enough to break the threshold in Bafang. In the three Petit Diboum variants (Petit Diboum, Bassap and Bakou), the threshold is lowered, and phonological teamwork is allowed: several "mildly" grave/acute segments may join forces to trigger an assimilation which they could not trigger on their own.

Table 4.33 presents a tentative scale of grave/acute coarticulation in Fe'fe'. The segments are presented either alone (separated by a comma), indicating that the effect they exert (if any) is strong enough to apply across the board, or as teams (with a "+" sign), indicating that only a combination of the segments in question may trigger the effects indicated. The highlighted cells represent the subphonemic levels of gravity/acuteness that are beyond the two (acute and grave) thresholds at work in each one of the four variants (PD = Petit Diboum; [$ɨ^{g}$] = grave coarticulation; [$ɨ^{a}$] = acute coarticulation).

					Effect on epenthetic /ɨ/			
Scale			Segments (+ teams)		Bafang	PD	Bassap	Bakou
Max grave	↑	4	u, Gw, Bw	$ɨ^{gggg}$	→ u	→ u	→ u	→ u
		3	o, ɔ + G, B	$ɨ^{ggg}$	ɨ	→ u	→ u	→ u
		2	o	$ɨ^{gg}$	ɨ	ɨ	ɨ	→ u
		1	ɔ, G, B	$ɨ^{g}$	ɨ	ɨ	ɨ	ɨ
Neutral		0	ɨ, ə, ɑ	ɨ	ɨ	ɨ	ɨ	ɨ
		–1	ɛ, a, D, J(w)	$ɨ^{a}$	ɨ	ɨ	ɨ	ɨ
		–2	e	$ɨ^{aa}$	ɨ	ɨ	→ i	ɨ
		–3	e, ɛ, a + D, J(w)	$ɨ^{aaa}$	ɨ	→ i	→ i	→ i
Max acute	↓	–4	i	$ɨ^{aaaa}$	→ i	→ i	→ i	→ i

Table 4.33: Tentative quantification of coarticulatory grave/acute effect in Fe'fe' Bamileke

One of the characteristics of this process that sets it apart from the cases of teamwork we have seen so far, is the fact that there are actually two (related) assimilation processes at work here, which are the result of the competition between two opposing forces. The actual coarticulatory effects at work are consequently always the (positive or negative) difference between the coarticulatory effects contributed by the neighboring grave and acute segments (which makes a precise evaluation of such effects rather difficult). For instance, in a form like /sɨ+suu/ [su̲suu] 'lie in wait' (all dialects), /u/ is strong enough to trigger [+grave] assimilation, despite the acuteness of the flanking /s/'s, i.e. /u/ contributes more coarticulatory gravity than /s/ does acuteness. In the Petit Diboum form /tɨ+tɔh/ [tɨtɔh] 'pass', the coarticulatory effects of grave /ɔ/ and acute /t/ cancel each other out, and the target vowel does not assimilate with either.

Table 4.34 summarizes the characteristics of the teamwork-driven grave/acute assimilation involved in Fe'fe' high-vowel reduplication.

Teamwork	Type:	Self-additive
	Phonological process:	Assimilation
	Property(ies):	Acute vs. grave
Target	Type:	V
	Weak/strong:	weak (epenthetic)
Triggers	Number:	3
	Type:	C and V
	Hierarchy:	Assimilatory strength hierarchy
	Position w.r.t. target:	Double-sided
	Locality w.r.t. target:	Adjacent segment or nucleus
Phonological status	Static pattern:	No
	Active alternation:	Yes
	Morphological conditioning:	Yes: epenthetic vowel in reduplication
	Post-lexical:	No
	Exceptions:	No

Table 4.34: Properties of Fe'fe' acute/grave assimilation

4.4 Coincidental teamwork: Kaska back harmony

Subphonemic teamwork is coincidental when the two partial coarticulatory effects at work are articulatorily and perceptually unrelated, but team up to trigger a categorical effect nonetheless (cf. § 4.1.2.1.3). I have found only one case of coincidental teamwork so far: Kaska back harmony.

4.4.1 Kaska back harmony

In the Pelly Banks dialect of Kaska (Athabaskan; Hansson and Moore 2011), the vowel *e(:)* in certain preverbal elements (prefixes, preverbs, etc.) changes to *a(:)* when the stem vowel is *o(:)* or *a(:)*, i.e. a non-high back vowel. This is illustrated in (192) with long *e:*. The vowel inventory of Kaska is given in (88), in standard orthography (a more detailed phonetic transcription will be given later). Additionally, all eight vowels may be nasalized (nasalization is represented by a subscript hook in the orthography, e.g. *a* vs. *ą*).

(191)	Short vowels			Long vowels	
				ī	ū
	e		o	ē	ō
		a		ā	

(192) Long *ē* : perfect *ē*-
a. /ē-d = jen/ *ējen* '(s)he sang'
/ē-l = lį̄h/ *ēlį̄h* '(s)he danced'
/ē-s-h = t'ū́t/ *ēst'ū́t* '(s)he sucked'
b. /ē-d = k'as/ *āk'as* '(s)he ate quickly'
/ē-d = dān/ *ādān* '(s)he drank'

Interestingly, short *e* can only be targeted when it is followed by a coda *h*, as shown in (193b) and (194b), where the harmony applies, vs. (193c) and (194c), where it does not, despite the fact that the stem vowel is /a(:)/.

(193) Short *e*: *se-* conjugation marker

a.	/se-h = tsū́ts/	*sehtsū́ts*		‘(s)he put (fabric) there’
b.	/se-h = tān/	*sahtān*		‘(s)he put (long object) there’
	/se-h = ɬa’/	*sahɬa’*		‘(s)he put (plural objects) there’
c.	/se-Ø = tān/	*setān*	(**satān*)	‘(long object) is there’
	/se-Ø = la’/	*sela’*	(*sala’)	‘(plural objects) are positioned’

(194) Short *e*: *de-* conjunct prefix

a.	/e-de´-h-Ø = ū́n/	*edéh’ū́n*		‘(s)he shot’
	/e-de-Ø = ū́n/	*ede’ū́n*		‘(s)he is shooting’
b.	/de´-h-Ø = ya’/	*dáhya’*		‘(s)he went’
c.	/de-Ø = yā́/	*deyā́*	(**dayā́*)	‘(s)he is going’

When the consonantal perfective marker *h-*∼*s-* is in coda position immediately after short *e*, back harmony applies only with the *h-* allomorph, as illustrated in (195). This shows both that the only coda consonant may co-trigger back harmony is *h*, and that it is not morpheme specific

(195) short *e* : perfective *h-*∼*s-* doublets

	s- allomorph		*h-* allomorph	
a.	*ejedáhya’*	∼	*ejedésya’*	‘(s)he went hunting’
	/eje#de-´h-Ø = ya’/		/eje#de-´s-Ø = ya’/	
b.	*ejegedáh’ā́ts*	∼	*ejegedés’ā́ts*	‘we (pl.) went hunting’
	/eje#ge-de-´h-Ø = ’ā́ts/		/eje#ge-de-´s-Ø = ’ā́ts/	

Note that short a is attested before coda *h*, whatever the quality of the following stem vowel, as in the directional *ah* = illustrated in (197), showing that the harmony changes e to a, rather than the opposite.

(196) Directional *ah* =

a.	/ah = degé/	*ahdegé*	‘up ahead, uphill, upstream’
b.	/ah = yegé/	*ahdegé*	‘there’
c.	/ah = tsā́/	*ahtsā́*	‘down there, downhill’

Finally, the harmony also operates at a distance: it may skip transparent intervening (non-target) vowels, as shown in the examples below.

(197) Transparency of *ī* and *ū*, and of *e* in non-*eh*C contexts:

a.	/neh = ké#ne-s-Ø = got/	*nahkénesgot*	‘I am digging you (du./pl.) out with a stick’
b.	/me = kḗ#ge-de-ī-Ø = k’ā́n/	*mekā́gedīk’ā́n*	‘they burned her/him up’
c.	/neh = yé#n-ū-Ø = kā́/	*nahyénūką́ sį́*	‘(s)he will give you (du./pl.) back (contained liquid)’

4.4.2 The phonetic underpinnings of the harmony

In order to properly characterize this harmony, the restrictions on both the targets (in particular the necessary presence of tautosyllabic *h* to make short *e* a target) and the triggers of the process (in particular the fact that long ū is not a trigger) need to be elucidated. Hansson and Moore (2011) show that these apparently problematic restrictions are actually rooted in phonetics. A rough phonetic representation of the short- and long vowels space of Kaska is given in (198).

(198) Short vowels Long vowels
ī [iː] *ū* [ʉː]
o [ʊ]
e [ɛ] *ō* [oː]
a [ɐ] *ē* [æː] *ā* [ɐː]

Two findings have important consequences for the characterization of Kaska vowel harmony. First, it appears that long *ū* is systematically realized as the central vowel [ʉː]. It is in fact significantly more front than both *o* [ʊ] (average $\Delta_{F2} = 169$ Hz; $t(144.72) = 6.91$, $p < 0.001$) and long *ā* [ɐː] (average $\Delta_{F2} = 337$ Hz; $t(138.01) = 11.11$, $p < 0.001$). There is however no significant F2 difference between long *ū* [ʉː] and short *a* [ɐ] ($\Delta_{F2} = 10$ Hz; $t(157.99) = 0.54$, $p = 0.59$). Hansson and Moore conclude from this fronted realization of *ū* that it should not be considered a back vowel. In other words, the set of harmony triggers can be simply characterized as the class of back vowels: *a*, *o*, *ā*, and *ō*.

The second important finding concerns the role of *h* as a co-trigger when the harmony targets short e, which, at first sight, is indeed somewhat perplexing: *h* and back vowels do not form a natural class, and it is difficult to see what property they could have in common that would explain their participation in a subphonemic teamwork process. The difference in terms of locality is also striking: both need to follow the vowel, but while the vowel co-trigger does not need to be adjacent to the target (and can actually be quite distant, cf. (197) above), *h* needs to immediately follow it, within the same syllable. Hansson and Moore show that the role of tautosyllabic *h* is actually secondary in the harmony. Indeed, short *e* has two non-contrastive allophones: low [æ] immediately before tautosyllabic *h*, and mid-low [ɛ] elsewhere. The two allophones are acoustically distinct: the average F1 difference between [ɛ] and [æ] is both great (732 Hz vs. 560 Hz respectively, i.e. $\Delta_{F1} = 172$Hz) and highly statistically significant ($t(52.48) = 7.49$, $p < 0.001$). Interestingly, long *ē*, which systematically undergoes the harmony, is consistently realized [æː], and there is no F1 difference between long ē [æː] and short e/__hC [æ] ($\Delta_{F1} = 37$Hz; $t(46.58) = 1.66$, $p = 0.10$). Additionally, both [æ] and [æː] are comparable in height to {a,ā} [ɐ(ː)]. It thus appears that the effect of Kaska vowel harmony is simply to retract the low front vowel [æ(ː)] to [ɐ(ː)]. The tautosyllabic *h* acts as an enabler: by lowering the preceding *e* to [æ], it makes it a possible target.

In conclusion, Kaska vowel harmony can be characterized as a case of backness harmony targeting the low front vowel [æ(ː)].[55] The basic properties of the harmony are schematized in the diagram in (4.10) (a slightly modified version of Hansson and Moore's diagram). The solid tilted line separates [+back] (trigger) vowels from [-back] (non-trigger) vowels, while the dashed

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[55] This is the "reasonable" hypothesis proposed by Hansson and Moore (2011)), who note that other dimensions than backness could be at work as well (e.g. tongue-root position).

line separates the [+low] and [-low] vowels. The target [æ(ː)] is to the left of the solid line and below the dashed one, in the bottom left corner.

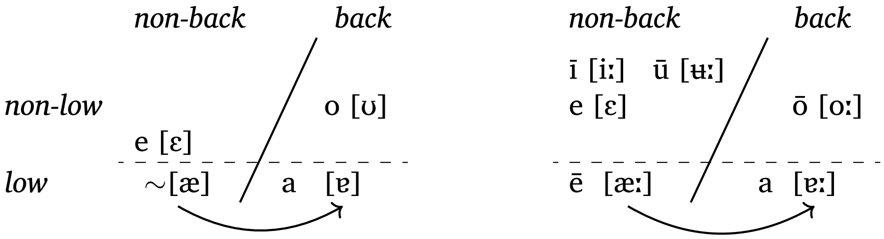


Figure 4.10: The phonetic underpinnings of Kaska back harmony

Hansson and Moore report another phonetic finding that sheds interesting light on the harmony. The non-low allophone [ɛ] of short e, when transparent (i.e. when intervening between the target and trigger of the harmony, as in ex. (197a) above) is significantly retracted towards [ə], both in the immediately pre-stem syllable (average $\Delta_{F2} = 415$ Hz; $t(43) = 8.16$, $p < 0.001$), and, although to a lesser extent, in the second syllable from the stem. The authors suggest that this coarticulatory backing effect could be part of the synchronic mechanism of the harmony, which could be "decomposed into two distinct interactive forces": *lowering* caused by following coda h, and backing caused by a back vowel in a following syllable. Both effects are allophonic, gradient, and rooted in coarticulation, i.e. the kind of effects that are typically seen as phonetic rather than phonological. However, when they both target the same vowel, they "team up" to cause a categorical, neutralizing process. The analysis sketched by Hansson and Moore (2011: 16), involves a purely abstract, predicted phonetic realization of the target vowel (cf. Figure 4.11) similar to that posited in the subfeatural account of subphonemic teamwork given in chapter 3.

> ...the unfilled square [on Figure 4.11] is intended to represent something like the (predicted) combination or sum of these two effects. The suggestion, then, is that this combination of allophonic effects pushes the phonetic realization of /ɛ/ very close to the pre-existing phonemic category of /ɐ/, close enough to cause such retracted-and-lowered instances of /ɛ/ to be recategorized as [ɐ] (identical to underlying /ɐ/). The outcome is a pattern in which short /ɛ/ is subject to backness harmony with an upcoming /ʊ oː ɐ ɐː/, but where this harmony only takes effect when the target /ɛ/ is immediately followed by an /h/ in the same syllable. (Hansson and Moore 2011: 15)

This is thus a case of *coincidental teamwork*: the cumulative effect at work does not involve two instances of the same process (contrary to Woleaian for example, cf. § 4.2.3), but two unrelated but complementary processes (here lowering and backing).

The subfeatural analysis sketched in § 4.1.2.1.3, using the ⟦low⟧ and ⟦back⟧ subfeatures, is repeated in (199) below. Any [ɛ] that is both $[\![C_{p_{a \to \varepsilon, [\![\mathrm{bk}]\!]}}(x_{init})\ \text{back}]\!]$ and $[\![C_{p_{h \to \varepsilon, [\![\mathrm{lo}]\!]}}(x_{init})\ \text{low}]\!]$ is changed to [ɑ].

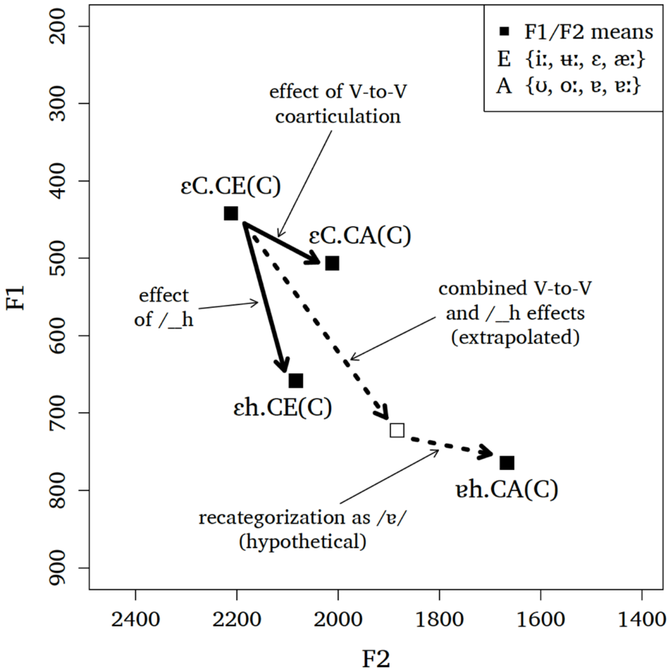
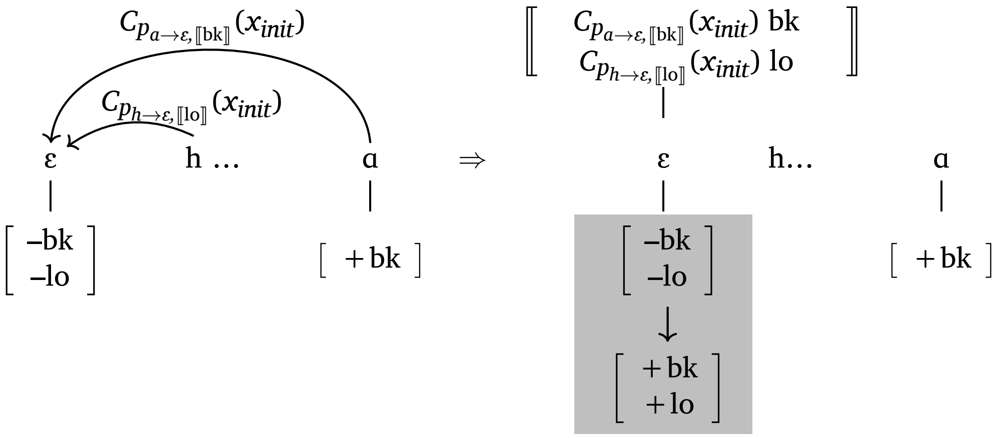


Figure 4.11: Harmony as combination of allophonic effects (Hansson and Moore 2011: 15)

(199)



Note, however, that Hansson and Moore do not provide all the necessary instrumental evidence to support the subphonemic nature of the effect of /a/ on a previous /e/: what they measure is the backing effect of the harmony on transparent /e/, i.e. what happens to its formants when harmony applies through it. It is thus impossible to determine whether this effect is caused by the coarticulatory effect of the co-trigger /a/ only, or by the complex articulatory effect of the harmony. What is crucially needed is instrumental mesaurements of the independent effect of /a/ on a preceding /e/ in words where the harmony does not apply, or at least outside of the harmony domain, as in the words in (193c), (194c), and (195) above. Only if an independent effect of /a/ is found will we have evidence that Kaska back harmony involves a purely subphonemic, additive effect. If not, then Kaska qualifies as subphonemic enabling, i.e. a case where a subphonemic effect feeds a categorical phonological process (cf. subphonemic enabling, § 4.1.2.2).

One particularly interesting property that Kaska backness harmony shares with other kinds of subphonemic teamwork effects is that it is conditioned by a non-contrastive property: the target is not the phoneme /e/, but only its non-contrastive, lowered allophone [æ]. As noted by Hansson and Moore (2011), this "has implications for phonological theory, given that contrast is often claimed to play a fundamental role in shaping the range of possible harmony processes". The theory of subfeatural representations proposed in chapter 3 is one possible response to the challenge this type of phenomenon poses to phonology.

Table 4.35 summarizes the characteristics of Kaska back harmony.

Teamwork	Type:	Coincidental
	Phonological process:	Assimilation
	Property(ies):	Back & low
Target	Type:	V
	Weak/strong:	n/a
Triggers	Number:	2
	Type:	V, C
	Hierarchy:	Equal co-triggers
	Position w.r.t. target:	Double-sided
	Locality w.r.t. target:	Adjacent
Phonological status	Static pattern:	Yes (distributional restriction)
	Active alternation:	Limited
	Morphological conditioning:	No
	Post-lexical:	No
	Exceptions:	?

Table 4.35: Properties of Kaska back harmony

4.5 Teamwork targeting consonants

As we noted at the very beginning of this chapter, all the cases of subphonemic teamwork inventoried so far target a vowel, except one: a multiple trigger sibilant palatalization attested in Capanahua. Among the 273 cases of "bidirectional" (i.e. double-sided) assimilation in P-base, 232 –i.e. the vast majority– target a consonant. However, out of these, only one case can convincingly be analyzed as involving subphonemic teamwork: the Capanahua case presented below. Additionally, I describe in § 4.5.2 the double-sided consonant nasalization attested in Kpan, and show that, despite having the appearance of subphonemic teamwork, it does not qualify as such.

4.5.1 Capanahua multiple-trigger sibilant harmony

Capanahua (Panoan, Loos 1967) is the only language in which I have been able to identify a bona fide case of teamwork targeting a consonant. The segment inventory of the language is presented in (200)-(201)below.

(200) Capanahua vowels (Loos 1967: 105)

i ɯ
o
a

(201) Capanahua consonants (Loos 1967: 105)

Labial	*Alveolar*	*Alveo-palatal*	*Retroflex*	*Palatal*	*Velar*	*Glottal*
p	t				k	ʔ
β						
	s ⟶	ʃ	⟵ ʂ			(h)
	ts	tʃ				
m	n					
w	ɾ			j		

In Capanahua, a root-final non palatal sibilant /s, ʂ/ is palatalized to [ʃ] when the following suffixal consonant is /ʃ/, if and only if it is also directly preceded and followed by the high front vowel /i/, as schematized in (202).

(202) {s,ʂ} → ʃ / i_-iʃ (Loos 1967: 105)

This process is only illustrated in Loos (1967) with verb roots combining with the past participle suffix /-aʂ/, after raising and fronting of the suffix vowel /a/ to [i], and palatalization of word-final /ʂ/ to [ʃ] through independent rules feeding this multiple trigger palatalization, as illustrated in (203).

(203) Ordered rules (Loos 1967: 173-174)[56]

	a. 'see-PST.PTCPL'	b. 'choose-PST.PTCPL'	c. 'see-PST'
	/his-aʂ/	/kais-aʂ/	/his-a/
a → ɯ / {w,s,ʂ,ʃ}_	his-ɯʂ	kais-ɯʂ	his-ɯ
ɯ → i / iC_	his-iʂ	kais-iʂ	[his-i]
ʂ → ʃ / i_#	his-iʃ	kais-iʃ	–
s,ʂ → ʃ / i_-iʃ	[hiʃ-iʃ]	[kaiʃ-iʃ]	–

This alternation seems to be a case of teamwork-driven palatalization involving the cumulative effect of three palatal segments on non-palatal /s,ʂ/. Although the author does not provide any example where the vowels surrounding the target /s,ʂ/ are not /i/ (i.e. a_-iʃ, i_-aʃ, etc.), his description of the pattern implies that palatalization would not take place in such contexts. Note, also, that the sequence /s-i/ does not palatalize to [ʃ-i] in /his-a/ → [hisi] in (203c).

Interestingly, Capanahua is characterized by a static pattern of strident harmony: sibilants and affricates within a morpheme always agree in place of articulation. Sibilants agree in all three places —i.e. alveolar /s/, alveo-palatal /ʃ/, and retroflex /ʂ/ are mutually exclusive morpheme internally— while affricates and sibilants agree only in what the author terms "compactness" (/s, ts/ are [–compact], [ʃ, ʂ, tʃ] are [+compact]). This static sibilant harmony is summarized in Table 4.36, where "✔" refers to attested combinations, "✔?"to combinations that are expected to be possible given Loos' (127-128) generalization, but are not illustrated in the examples he provides, and "*" to impossible combinations.

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[56] Loos gives only examples involving s → ʃ (no ʂ → ʃ).

	__s	__ts	__ʂ	__ʃ	__tʃ
s__	✔	✔?	*	*	*
ts__	✔	✔	*	*	*
ʂ__	*	*	✔	*	✔
ʃ__	*	*	*	✔	✔?
tʃ__	*	*	✔	✔	✔

Table 4.36: Strident harmony in Capanahua (Loos 1967: 127-128)

Strident harmony is only a morpheme structure constraint. Disharmony is indeed allowed across morpheme boundaries, as illustrated by the following two forms. Sibilant harmony can thus be said to be systematic within morphemes, but restricted to the teamwork effect in (200) across a morpheme boundary, as shown in (204).

(204) a. /his-noʂon/ [hisnoʂon] 'in order to see' (Loos 1967: 73)
see-PURPOSIVE
b. /biʃt(?)-a-ʂ-kin/ [biʃtaʂkin] 'while squashing' (Loos 1967: 76)
squash-PST-3PERS-SIMULTANEOUS

This case of teamwork seems to involve both a cumulative subphonemic effect, and subphonemic enabling (cf. § 4.1.2.2). One could indeed hypothesize that the targeted /s,ʂ/ undergoes categorical assimilation to the following /ʃ/, only if it is made articulatorily and perceptually similar enough to an [ʃ] sound by the cumulative palatalizing effect of the previous and following /i/. In a word, trans-morphemic regressive palatalization is a categorical process that targets only the doubly palatalized [^{i}s^{i}, ^{i}ʂ^{i}] allophone of /s, ʂ/, as schematized in (205). This is of course only a hypothesis, which needs to be tested against actual instrumental measurements, unavailable at present.

(205) /s, ʂ/
↓
a. Subphonemic teamwork: [^{i}s^{i}, ^{i}ʂ^{i}] / i__i
↓
b. Sibilant harmony: [ʃ] / __-ʃ

The properties of Capanahua double-sided palatalization are summarized in Table 4.37.

4.5.2 Kpan double-sided consonant nasalization: no teamwork

The Kente dialect of Kpan (Shimizu 1972, 1980: 70-71), whose segment inventory is given in (206), has a complex double-sided consonant nasalization that, on the surface, looks like subphonemic teamwork. I will show here that it isn't the case.

(206) Kpan segment inventory (Shimizu 1980b: 70)

a. Vowels:
i ĩ u ũ
e ẽ o õ
a ã

Teamwork	Type:	Self-additive
	Phonological process:	Assimilation
	Property(ies):	Front/palatal
Target	Type:	C
	Weak/strong:	n/a
Triggers	Number:	2
	Type:	V
	Hierarchy:	equal co-triggers
	Position w.r.t. target:	double-sided
	Locality w.r.t. target:	strictly adjacent
Phonological status	Static pattern:	No?
	Active alternation:	Yes
	Morphological conditioning:	across morpheme boundary
	Post-lexical:	No?
	Exceptions:	No?

Table 4.37: Properties of Capanahua double-sided palatalization

b. Consonants:

p		t		ts	k	
b		d		dz	g	
f		s			h	
v		z			ɣ	
m	[m] / __Ṽ	n	[n] / __Ṽ		ŋ	[ŋ] / __Ṽ
	[mb] / __V		[nd] / __V			[ŋg] / __V
w	r		j			

Note that nasal consonants are systematically orally released before oral vowels (through an intervening consonant, as we will see), i.e. they are realized as voiced post-ploded consonants: /m, n, ŋ/ → [mb, nd, ŋg] / __V[-nasal].

In Kpan, the labial-velar approximant /w/ is fully nasalized into [ŋ] only when immediately preceded by a labial consonant (m or n), AND immediately followed by a nasal vowel, as summarized and illustrated in (207) (Shimizu 1972; the author does not provide illustrations for this rule).

(207) $\mathrm{w} \rightarrow \text{ŋ} \,/\, \mathrm{C}_{[+\mathrm{nas}]}\_\mathrm{C}_{[+\mathrm{nas}]}$

At first sight, this alternation looks like self-additive teamwork: the nasal consonant and vowel each exert a weak nasal coarticulatory effect on the intervening [w], cumulatively leading to a categorical nasalization into the velar nasal [ŋ]. However, several aspects of this phonotactic pattern and of the phonology of the language seem to undermine an analysis in terms of teamwork.

Firstly, as I mentioned earlier, only two of the three nasal consonants co-trigger w-nasalization: /m/ and /n/. The velar nasal /ŋ/ does not: /ŋwṼ/ → [ŋwṼ]. This, however, could be seen as resulting from an OCP effect against banning the *ŋŋ sequence, unrelated to the teamwork effect.

More convincingly, a good understanding of the complex rules by which the different realizations of /CwV/ sequences are derived clearly shows that subphonemic teamwork is not the optimal analysis of this pattern. The only allowed syllable structures in Kpan are CV and C_1C_2V, where C_2 may only be a glide: CwV and CjV. The realization of this second-position glide depends on the nature of the preceding C and following V, as shown in (208) for /w/ in C_2 position.

(208) /Cw/ clusters:

–		/tw/	[tk]	/kw/	[kp]
/bw/	[bg]	/dw/	[dg]	/gw/	[gb]
/fw/	[fk]	/sw/	[sk]	/hw/	[hw]
/vw/	[vg]	–		–	
/mw/	[mŋ] / __Ṽ [mbg] / __V	/nw/	[nŋ] / __Ṽ [ndg] / __V	/ŋw/	[ŋw]

As seen, C_2 /w/ is only faithfully realized as [w] when it follows /h/ and /ŋ/. Elsewhere, it is realized as an obstruent –labial when C_1 is velar, velar elsewhere. This obstruent additionally assimilates in voicing and nasality with the immediately preceding C_1, or its second half, as in the case of the orally realized nasals mb and nd. Note that partial denasalization of nasal consonants followed by oral vowels needs to apply before nasal assimilation, otherwise /w/ would change to [ŋ] in both /mwV, nwV/ and /mwṼ, nwṼ/. The rules at work in the realization of underlying C_2 /w/ are summarized and illustrated in (209).

(209) /Cw/ clusters:

		/kw/	/bw/	/mwṼ/	/mwV/
a.	Partial denasalization: /m,n,ŋ/ → [mb,nd,ŋg] / _$V_{[—nas]}$	–	–	–	mbwV
	Glide obstruentization: /w/ → B / $C_{velar—}$ /w/ → G / elsewhere	kB	bG	mGṼ	mbGV
b.	Voicing & nasal assimilation: {B,G} → [αvoice, βnasal] / $C_{[voice,nasal]—}$	[kp]	[bg]	[mŋṼ]	[mbgV]

The /w/ → [ŋ] change in /mwṼ/ and /nwṼ/ is thus better analyzed as simple nasal assimilation with the preceding nasal consonant. The fact that the following vowel is systematically nasal as well is entirely fortuitous: the correct generalization is not that the following vowel ought to be nasal, but that it ought not to be oral. In other words, the impression of teamwork emerges from the bleeding relation between partial denasalization and nasal assimilation.

4.6 Dissimilatory subphonemic teamwork?

All the cases of subphonemic teamwork identified so far are assimilatory. I have found only one case of multiple trigger dissimilation that seems to involve cumulative subphonemic effects: a dissimilatory process targeting stem-final /a/ in Finnish, described by Anttila (2002). Whether this case of dissimilation qualifies as subphonemic teamwork is not clear, as I will show in this section.

In Finnish, a stem-final /a/, when immediately followed by suffixal /i/ (i.e. plural *-i* and past *-i*), either mutates to /o/, or deletes completely. Whether deletion or mutation applies depends on the immediately preceding vowel, as illustrated in (210) and (211) below (the data and analysis in this section are entirely borrowed from Anttila 2002).

(210) a → o / {i,a,e}._-$\text{i}_{\{\text{pl,past}\}}$

/kana̲-i-ssa/	→	kano̲-i-ssa	'hen-PL-INE'
/pala̲-i/	→	palo̲-i	'burn-PAST'

(211) a → ∅ / {u,o}._-$\text{i}_{\{\text{pl,past}\}}$

/muna̲-i-ssa/	→	mun-i-ssa	'egg-pl-PL-INE'
/otta̲-i/	→	ott-i	'take-PAST'

As seen, mutation takes place when the vowel of the preceding syllable is unrounded, whereas deletion occurs when the vowel of the preceding syllable is round. Anttila does not account for the a o mutation itself, but cites Itkonen (1942), who analyzes the change ai > oi∼i as a case of partial height assimilation of low /a/ to the following /i/. The reason why /a/ is changed to /o/ rather than /e/ is not mentioned in Anttila (2002), but is most likely due to the fact that /a/ and /o/ agree in backness, unlike /a/ and /e/. In Optimality theoretic terms, there are thus two repairs to the high-ranked markedness constraint **ai*: partial height assimilation (= mutation to /o/) when the preceding vowel is [–round], and deletion when the preceding vowel is [+round]. Anttila analyzes deletion as a case of dissimilation, motivated by an OCP constraint affecting the feature [round]: in the words in (175), mutation to /o/ would yield two round vowels in a row, violating OCP[round], hence deletion of the target vowel is preferred. Mutation (height assimilation) thus seems to be the default repair to **ai*, deletion applying as an alternate repair when mutation would violate OCP[round].

Interestingly, mutation and deletion apply categorically only in nonderived stems with an even number of syllables, as is the case of all the forms in (210) and (211), where no cumulativity is involved[57]. In odd-numbered or derived stems, on the other hand, both processes apply with much less regularity, and cumulative effects are involved, as we will see.

The divide between stems with an even vs. odd number of syllables can be explained in terms of prosodic structure. Finnish words are parsed into trochaic feet from left to right, with primary stress on the head of the leftmost foot, and secondary stress on all following metrical heads: (σ́ σ)(σ̀ σ)(…). The two repairs to **ai* are thus sensitive to both morphology and prosodic structure: they are systematic and categorical within feet in non-derived stems, but not across feet or in derived stems, where they apply with what, at first sight, appears to be complete irregularity, as shown in (212) for trisyllabic stems.[58]

(212)

a.	/tavara̲-i-ssa/	→	tavaro̲-i-ssa	'thing-PL-INE'
b.	/jumala̲-i-ssa/	→	jumal-i-ssa	'God-PL-INE'
c.	/itara̲-i-ssa/	→	itaro̲-i-ssa∼itar-i-ssa	'stingy-PL-INE'

The irregularity, however, is only apparent. While it is true that neither process can be described as categorical in this context, strong tendencies and regularities emerge when one takes

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[57] Anttila (2002: 14) notes that there are only very few exceptions to this regularity.

[58] For expository purposes, I will only concentrate on nonderived trisyllabic stems here.

into account the nature of the vowel and consonant immediately preceding the target vowel. The influence of the preceding vowel is illustrated in Table 4.38, where the numbers and rates correspond to the number of attestations in an electronic version of Sadeniemi's (1973) Dictionary of Modern Finnish (the cell with the highest rate in each line is highlighted in dark grey; lesser rates higher than 20% are highlighted in light gray).

	Mutation	Mut. ∼ Del.	Deletion	Total
i . __	306	2	–	308
	99.4%	*0.6%*	–	*100%*
u . __	186	49	10	245
	75.9%	*20%*	*4.1%*	*100%*
a . __	272	85	50	407
	66.8%	*20.9%*	*12.3%*	*100%*
e . __	58	183	41	282
	20.6%	*64.9%*	*14.5%*	*100%*
o . __	17	15	28	60
	28.3%	*25%*	*46.7%*	*100%*
Total	839	334	129	1,302

Table 4.38: Influence of the preceding vowel on the choice of **ai* repair (Anttila 2002: 6)

As seen, the highest mutation rate is found after /i/, and the highest deletion rate after /o/, a tendency which is particularly strong in recent loanwords, where deletion is systematically impossible after /i/, and typically preferred after /o/, as illustrated in (213).

(213) a. /angiina-i-ssa/ → angiino-i-ssa 'angina-pl-ine'
b. /triljoona-i-ssa/ → triljoon-i-ssa 'trillion-pl-ine'

The other three vowels /u, a, e/ all readily allow free variation between mutation and deletion, although /a/ and /u/ seem to have a strong preference for mutation, while /e/, the most neutral of all five vowels, shows a strong tendency towards free variation. The five vowels thus seem to stand in the hierarchy schematized in (214).

(214) Vowel hierarchy (Anttila 2002: 6):
Mutation preferred Deletion preferred
/i/ > /a, e, u/ > /o/

The preceding consonant also plays a role, as shown in Table 4.39. Labial consonants favor deletion, dorsal consonants favor mutation, and coronals tend to favor free variation, with a strong preference for mutation, as illustrated in (215).

(215) a. /pisama-i-ssa/ → (*pisamo-i-ssa) pisam-i-ssa 'freckle- pl-ine'
b. /omena-i-ssa/ → omeno-i-ssa ∼ omen-i-ssa 'apple-pl-ine'
c. /silakka-i-ssa/ → silakko-i-ssa (*silakk-i-ssa) 'Baltic herring'

Consonants, like vowels, thus also stand in a hierarchy with respect to the choice of **ai* repair:

	Mutation	Mut. ∼ Del.	Deletion	Total
Dorsal	422	3	1	426
	99.1%	*0.7%*	*0.2%*	*100%*
Coronal	402	297	12	711
	56.5%	*41.8%*	*1.7%*	*100%*
Labial	15	34	116	165
	9.1%	*20.6%*	*70.3%*	*100%*
Total	839	334	129	1,302

Table 4.39: Influence of the preceding consonant on the choice of **ai* repair (Anttila 2002: 6)

(216) Consonant hierarchy (Anttila 2002: 8):
Mutation preferred Deletion preferred
Dorsals > Coronals > Labials

Comparing the vowel and consonant hierarchies in (215) and (216), it appears that dorsal consonants and /i/ pattern together in favoring mutation, and so do labial consonants and the round vowel /o/, which favor deletion. Dorsal and labial consonants thus act as high and round segments respectively, on a par with the high vowel /i/ and the round vowel /o/.

It is worth noting that Tables 4.38 and 4.39 illustrate what appears to be an inherent bias toward mutation, in particular mutation is still more frequently attested after /o/ (28.3%) or a labial consonant (9.1%) than deletion after a high segment (unattested after /i/, only 0.2% after a velar consonant). It also appears that a preceding round consonant is a stronger predictor of deletion (70.3% deletion, 9.1% mutation) than a preceding round vowel (46.7% deletion, 28.3% mutation), whereas both the high vowel /i/ and high consonants are very strong predictors of mutation (over 99% mutation in both cases).

Anttila (2002: 15) notes that “the entire alternation system is grounded in two simple and general phonological principles: roundness and height dissimilation.” Indeed, additionally to the roundness dissimilation, which we saw earlier motivates deletion, it seems that the strong preference for mutation and the near impossibility of deletion after high segments in odd-numbered or derived stems is motivated by an OCP constraint affecting the feature [high]: if the target vowel in (213a) /angiina-i-ssa/ (→ *angiino̲-i-ssa*) and (215c) /silakka-i-ssa/ (→ *silakko̲-i-ssa*) were to delete, the high vowel /i/ of the suffix would be tier-adjacent to the stem final high vowel in (213a) (**angi̲i̲n-i̲-ssa*), and string-adjacent to the stem-final high consonant /k/ in (215c) (**silak̲k̲-i̲-ssa*). Note, however, that, contrary to deletion, mutation itself is not caused by a dissimilatory effect: it is in fact a case of height assimilation, as we saw earlier. Only the impossibility of deletion (hence the strong preference for mutation) after high segments in odd-numbered and/or derived stems is motivated by OCP[height].

Importantly, when two [round], or two [high] segments “team up”, as in the stems *glaukooma* ‘glaucoma’ (*oo* + *m*) and *mansikka* ‘strawberry’ (*i* + *kk*), the tendencies noted above are reinforced. Table 4.40 summarizes the cumulative effects of the preceding C and V, from the highest mutation rate (line 1) to the highest deletion rate (line 12).

As seen, when the vowel and consonant preceding the target vowel are both [high], deletion is never attested (line 1), whereas it virtually always applies when they are both [round] (line 12: 94%, the remaining 6% showing free variation between deletion and mutation). The highest rate

	V	C	Mutation	Mut. Del.	Deletion	Total	Example
1.	high (i)	high (vel)	100%	–	–	140	mansikka
2.	high & round (u)	high (vel)	100%	–	–	89	puolukka
3.	neutral (e, a)	high (vel)	100%	–	–	187	silakka
4.	high (i)	neutral (cor)	99%	1%	–	162	karsina
5.	high (i)	round (lab)	83%	17%	–	6	Fatima
6.	high & round (u)	neutral (cor)	68%	32%	–	143	ikkuna
7.	round (o)	high (vel)	60%	30%	10%	10	mahorkka
8.	neutral (e, a)	neutral (cor)	36%	64%	0%	373	omena
9.	round (o)	neutral (cor)	33%	33%	33%	33	gallona
10.	neutral (e, a)	round (lab)	8%	22%	70%	129	orava
11.	high & round (u)	round (lab)	–	23%	77%	13	hekuma
12.	round (o)	round (lab)	–	6%	94%	17	glaukooma
						1,302	

Table 4.40: The combined vowel-consonant effect (Anttila 2002: 10)

of free variation (64%) is found when both the consonant and vowel belong to a neutral category with respect to height and rounding (coronals, non-high and non-round vowels, line 8).

The effect of the preceding consonant in each vocalic context is clearly shown in Table 4.41. As can be seen, the highest mutation rates are systematically observed with high consonants, and the highest deletion rate with round consonants. As noted by Anttila, the consonant hierarchy (cf. (216) holds in all vocalic environments.

	V	C	Mutation	Mut. Del.	Deletion	Total	Example
a.	high (i)	high (vel)	100%	–	–	140	mansikka
	high (i)	neutral (cor)	99%	1%	–	162	karsina
	high (i)	round (lab)	83%	17%	–	6	Fatima
b.	high & round (u)	high (vel)	100%	–	–	89	puolukka
	high & round (u)	neutral (cor)	68%	32%	–	143	ikkuna
	high & round (u)	round (lab)	–	23%	77%	13	hekuma
c.	neutral (e, a)	high (vel)	100%	–	–	187	silakka
	neutral (e, a)	neutral (cor)	36%	64%	0%	373	omena
	neutral (e, a)	round (lab)	8%	22%	70%	129	orava
d.	round (o)	high (vel)	60%	30%	10%	10	mahorkka
	round (o)	neutral (cor)	33%	33%	33%	33	gallona
	round (o)	round (lab)	–	6%	94%	17	glaukooma
						1,302	

Table 4.41: Effect of preceding V (kept constant) and C (Anttila 2002: 11)

Table 4.42 below highlights the respective effects of every vowel in each consonantal context. Like the consonant hierarchy, the vowel hierarchy holds in all consonantal contexts: the highest mutation rates are with high vowels, and the highest deletion rates with round vowels.

Table 53 confirms the double asymmetry noted in Table 51 and Table 52: a preceding round

	V	C	Mutation	Mut. Del.	Deletion	Total	Example
a.	high (i)	high (vel)	100%	–	–	140	mansikka
	high & round (u)	high (vel)	100%	–	–	89	puolukka
	neutral (e, a)	high (vel)	100%	–	–	187	silakka
	round (o)	high (vel)	60%	30%	10%	10	mahorkka
b.	high (i)	neutral (cor)	99%	1%	–	162	karsina
	high & round (u)	neutral (cor)	68%	32%	–	143	ikkuna
	neutral (e, a)	neutral (cor)	36%	64%	0%	373	omena
	round (o)	neutral (cor)	33%	33%	33%	33	gallona
c	high (i)	round (lab)	83%	17%	–	6	Fatima
	neutral (e, a)	round (lab)	8%	22%	70%	129	orava
	high & round (u)	round (lab)	–	23%	77%	13	hekuma
	round (o)	round (lab)	–	6%	94%	17	glaukooma
						1,302	

Table 4.42: Effect of preceding V and C (C kept constant) (Anttila 2002: 12)

vowel has a stronger effect than a preceding round consonant (compare lines lines 9 and 10), while there is virtually no difference between the effect of a high vowel (cf. line 4) and that of a high consonant (cf. line 3). The asymmetry between round vowel and round consonant is most probably due to the closer proximity of the latter to the target vowel. The asymmetry between round and high segments, on the other hand, is directly related to the inherent bias toward mutation (favored by high segments) as the default repair. This is in particular visible in the behavior of the vowel /u/, which is both high and round, and clearly favors mutation over deletion, even if it tolerates deletion much more (4.1%, as well as 20% free variation) than high non-round /i/, which virtually accepts nothing but mutation.

To summarize, mutation of /a/ to /o/ (partial height assimilation) and deletion of /a/ are two possible repairs to the marked structure **ai*. Deletion is triggered by rounding dissimilation, while mutation is partially driven by height dissimilation when applying across feet and in derived stems. Within a foot, in non-derived stems, these two repairs are “strong and yield categorical outcomes”, while across feet and in derived stems, they are “weak and yield a range of surface results… [where] the influence of phonology is clearly felt” (Anttila 2002: 15).

One of the main factors at work in this last context is cumulativity. While neither mutation nor deletion are cumulative *per se*, a cumulative effect is however involved in the choice between these two repairs, which depends on the degree of violation of two OCP constraints: OCP[round], which favors deletion, and OCP[high], which prevents deletion and thus indirectly favors mutation. Thus, the more [high] segments immediately before the target vowel, the more likely mutation is; and conversely, the more [round] segments before the target vowel, the more likely deletion is. If all preceding segments (V and C) are neutral, then free variation is most likely. Finally, if the preceding segments belong to both categories (one high, one round), then some variation is attested, but the presence of one high segment is enough to reinforce the inherent bias toward mutation, which is the default repair to **ai*.

Whether this cumulative effect qualifies as subphonemic teamwork as defined in § 1.3 is not clear. On the one hand, it looks very similar to the cases of self-additive subphonemic teamwork involving team competition that we saw in § 4.3.2 and § 4.2.2.2. One more similarity is the role played by the relative strength between target and trigger. In an even-numbered stem, the stem-final vowel is not the head of a foot. It is thus phonetically and phonologically weaker than the final vowel of an odd-numbered stem, which is the head of a foot once the suffix *-i* is added, and as such receives secondary stress. The cumulative effect is not necessary for OCP[round] to force deletion to apply instead of mutation when the target is weak (even-numbered stem). But a strong target (odd-numbered stems) offers more resistance to both OCP[round] and OCP[high], and the cumulative effects of multiple triggers reinforces the likelihood of their application.[59]

However, the cumulative effect in question does not seem to target a segment directly, but rather to influence the conditions and rate of application of a phonological process: deletion of [o]. The fact that the teamwork-driven process is full deletion of the target segment also makes it difficult to analyze it as being subphonemically driven: categorical deletion cannot be said to be triggered by the addition of two or more partial deletion effects. This case of multiple trigger dissimilation thus does not seem to involve any subphonemic effects. This is likely due to the fact that the need to dissimlate is satisfied by segment deletion, rather than feature-modification (e.g. unrounding, or fronting). I thus conclude that the gradient effects at work in this case of dissimilation do not qualify as subphonemic teamwork, and dissimilation is likely never driven by subphonemic cumulative effects in the same way as assimilation.

4.7 Typological summary

I will now discuss the typological properties of the different examples of subphonemic teamwork seen above, focusing on the nature and position of targets and triggers (§ 4.7.1), the type of cumulative effect involved (§ 4.7.2), the phonetic/phonological properties and types of processes at work (§ 4.7.3), the role of strength and weakness in teamwork (§ 4.7.4), and the phonological domain of application of subphonemic teamwork (§ 4.7.5).

4.7.1 Target and triggers

4.7.1.1 Target

The triggers and targets in all 52 cases listed at the beginning of this chapter involve only segmental interactions. As we just saw, one of the main characteristics of subphonemic teamwork is a very strong tendency to target vowels and not consonants: only one of the 52 cases identified so far targets a consonant (that is also one out of 232 cases of double-sided consonant assimilation in P-base). Based on the present sample one can safely conclude that consonant-oriented subphonemic teamwork is not impossible, but is very rare.

This discrepancy is not surprising, given the respective articulatory and perceptual properties of consonants and vowels. Vowels are perceptually more salient, and easily identified from their

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[59] Anttila (2002: 16) does not resort to the phonetic and phonological strength difference between heads and non-heads to explain the cumulative effects observed, but to the structural difference incurred by the metrical structure to the domain of application of mutation and deletion: "vocalic dissimilation within a foot is stronger than vocalic dissimilation across feet, perhaps universally. This is consistent with Mohanan's (1993) proposal regarding assimilation: the smaller the domain [one foot in the case of even-numbered stems vs. the whole stem in the case of odd-numbered stems], the stronger the effect."

acoustic/perceptual properties (spectrum, formants etc.). On the other hand, the main perceptual cue to consonant place of articulation is in the formant transitions from/into adjacent vowels, i.e. in the coarticulatory effect of the consonant onto adjacent vowels, rather than in the consonant itself. Vowels thus carry a double burden, in that they are the locus of perceptual cues to both vowel and consonant identification.

4.7.1.2 Triggers

The number of co-triggers is limited to a maximum of three, with most cases (47 out of 52, i.e. 90%) having only two, as summarized in (217).

(217)	a.	2 triggers (47/52)	
		C + C (39)	Acehnese, Arabana (x2), Asmat (x2), Cantonese, Chakosi/Anufo, Unami Delaware, Iaai, Irish Gaelic (x2), Kalispel (x2), Kumeyaay, Louisiana Creole French, Madhi Madhi, Maléku Jaíka, Nisga'a, Northern Gbaya, Nyangumarta (x2), Quichua, Russian, Straits Salish (Samish), Tamil, Tauya, Thompson (x4), Turkana, Wambaya, Wangganguru (x2), Wangganguru (Eastern), Wemba Wemba, Wergaia (x2), Wirangu
		C + V (4)	Laal, Kɔnni (x2), Kaska
		C + {C,V} (1)	Khmuʔ
		V + V (3)	Woleaian (x2), Sonsorolese (Pulu-Annan)
	b.	2∼3 triggers (1/52)	
		C + (C) + V (1)	Taa
	c.	3 triggers (4/52)	
		C + C + V (2)	Fe'fe' Bamileke, Igbo
		C + V + V (1)	Capanahua
		C + V + {C,V} (1)	Kazakh

Not only do the vast majority of cases involve only two triggers, those two triggers are in most cases two consonants (39 out of 52, i.e. 75%). We will see below that all these cases involve double-sided triggers, i.e. C__C. Very few cases involve vowel triggers: in seven cases a consonant and a vowel team up, and in only three cases do two vowels adjacent to the target co-trigger a subphonemic teamwork effect (Woleaian raising and backing/rounding, and Sonsorolese raising). These are also the only three cases involving only vowels, i.e. 49 out of 52 cases involve at least one consonant. The discrepancy between vowels and consonants noticed for targets is thus reversed for triggers: targets are overwhelmingly vowels, triggers are most of the time consonants.

The set of triggers at work may subsume all the segments of the language carrying the relevant feature(s) and exerting a similar coarticulatory effect –as is the case for Wergaia (§ 4.3.1.1) for instance, where all the labial, velar, and retroflex consonants may co-trigger rounding–, or only a subset thereof. In Woleaian, for example, high vowels may trigger *a*-raising, but not the two glides [j] and [w], which presumably have a raising effect on an adjacent [a] of a magnitude at least equal to the high vowels [i] and [u] (§ 4.2.3, ex. (134)). The phonological nature of the triggers (V vs. C) is thus a crucial criterion, which is a clear indication that the cumulative effect is not enforced by superficial phonetic implementation, but is phonological in nature.

4.7.1.3 Position of triggers with respect to target

Since subphonemic teamwork is driven by coarticulatory effects, it is always a local effect, and it most of the time involves (near-)adjacency between the triggers and the target. The only case potentially involving a long distance effect is Kaska back harmony. However, as noted in § 4.4, there is as yet no evidence that the long distance anticipatory effect of the back vowel /a/ in back harmony is subphonemic. If it turns out not to be, then Kaska back harmony falls into the category of subphonemic enabling, i.e. teamwork between a subphonemic effect (/e/ → [æ] / _h) and a purely categorical, long-distance phonological process (back harmony).

The vast majority of the cases of subphonemic teamwork identified so far (listed in (4)-(6)) involve double-sided triggers (49 out of 52, i.e. 92%). As mentioned earlier, this skewing is in great part due to the fact that 37 of the 52 cases of teamwork were extracted from P-base using the two search keywords "bidirectional assimilation" and "progressive & regressive assimilation." Additionally, only 4 of the 17 cases I added did not involve double-sided triggers. Although double-sidedness is most probably overrepresented, and it is impossible to evaluate the actual typological frequency of a pattern based on a skewed database, it is not unreasonable to hypothesize that double-sided co-triggers might be the most frequent case. Indeed, double-siding is the configuration in which both triggers are likely to exert the strongest effect possible on the target. The uncontroversial attestation of cases that do not involve double-sidedness (or at least do not require it, as in the case of Laal) clearly shows, however, that it is by no means a necessary definitional criterion of subphonemic teamwork.

As mentioned earlier, all the cases where subphonemic teamwork is driven exclusively by consonants (39 out of 52, i.e. 73%) involve strict adjacency of both consonants, i.e. double-sided C__C. This makes C__C the most frequent environment conducive to teamwork. This can be explained by the fact that the coarticulatory effect of a consonant on an adjacent vowel consists mostly in the formant transitions from or into that vowel. C__C is thus expected to be the ideal case of consonantal teamwork targeting a vowel. The crucial role of formant transitions in CV VC coarticulation explains the absence of long-distance subphonemic effects (e.g. C...C__ ∼ __C...C), as well as that of single-sided configurations such as CC__ and __CC. Of course, the fact that the last type is not attested in the 52 cases listed here does not necessarily imply that they are impossible. However, they are expected to be at the very least much less frequent than C__C.

In the 17 examples described and analyzed in this chapter, there are a few cases where the position of the triggers does not seem to matter. In Laal, for instance, the coarticulation-inducing labial co-trigger can be before or after the target, as long as it is (near-)adjacent to it. The only position that does matter is that of the round vowel co-trigger, which is not surprising, since this is a typical characteristic of categorical, phonological alternations, which the rounding harmony is.

In cases involving double-sidedness (Woleaian, Cantonese, Wergaia, Tamil, etc.), the position of the two triggers on both sides of the target seems to be a strict positional restriction (X → Y / B_B). However, as we saw, double-sidedness is actually the only configuration where the two triggers are both adjacent to the target, i.e. where both triggers can exert the necessary coarticulatory effect on the target. This apparent positional restriction is thus only an emergent property resulting from the necessity for both triggers to be immediately adjacent to the target.

Another case where position seems to matter is Kɔnni trans-dorsal backing, where the two triggers bay be both on the left (UG__), or both on the right (UG__) of the trigger but never on both sides (UC__G, G__CU). As discussed in § 4.2.1.3.3, this restriction is also likely to be only apparent, and result from the coarticulatory properties of the segments involved, and of the configurations in which these coarticulatory effects manifest themselves in the most salient way. Positional restrictions on subphonemic trigger-target interactions are thus most of the time emergent, and arise from independent articulatory properties conditioning coarticulation.

The fundamental articulatory and perceptual distinction between vowels and consonants plays a crucial role in shaping the typology of subphonemic teamwork, which most of the time consists in consonants teaming up to assimilate the vowel that they surround. We have seen that this is likely rooted in the articulatory and perceptual properties of consonants vs. vowels. This asymmetry constitutes an argument in favor of a phonetically grounded, representational approach to teamwork, which builds the phonetically grounded distinction between the coarticulatory relations between segments directly into the theory. The theory of subfeatural representations proposed in chapter 3 is a first step toward such a theory.

4.7.2 Teamwork type

The number of attested cases of each type of teamwork is shown in Table 4.43.

	Articulatory property	Perceptual property
Self-additive (33)	same	same
Mutually enhancing (16)	different	same
coincidental (1)	different	different
Subphonemic enabling (2)	n/a	n/a

Table 4.43: Teamwork types

As seen, self-additive teamwork is the most frequent (33 cases), followed by mutual enhancement (16). Only one case of coincidental teamwork is attested: Kaska back harmony, although, as noted in § 4.4.2, it could well turn out to be a case of subphonemic enabling. Finally, antagonistic teamwork and subphonemic enabling are each attested twice.

All 16 cases of mutually enhancing teamwork are cases of vowel backing or rounding, i.e. They involve lowering of higher formant frequencies (F2, F3, that is the “horizontal axis” of the vowel system). This is expected given what we know of phonetic enhancement: two articulatory properties are said to stand in an enhancement relation if they share at least one acoustic/perceptual property (Stevens, Keyser, and Kawasaki 1986; Keyser and Stevens 2001). The number of articulatory properties that are known to stand in an enhancement relation is relatively limited, in particular regarding vowels. Only four cases involving vocalic properties are mentioned in Stevens, Keyser, and Kawasaki (1986), Stevens and Keyser (1989), Keyser and Stevens (2001: 280–281, 285–286), and Clements (2009: 50–52): 1) tongue raising and lip spreading enhance vowel frontness, by raising the center of gravity of higher frequency formants; 2) widening of the vocal tract (i.e. breathy voice) enhances tongue root advancement, by lowering F1; 3) spreading the glottis enhances nasalization, by further decreasing the prominence of F1; and 4) labial constriction enhances vowel backness and vice versa (both gestures lower the center of gravity of the higher formant frequencies of a vowel);[60] Finally, as mentioned earlier, labial constriction and tongue tip retroflexion are also known to be mutually enhancing, since they both lower all the vowel formants, notably F3 (cf. Fant 1968, Stevens and Blumstein 1975, and Dave 1977, Ladefoged and Maddieson 1996: 28; Stevens 1998: 525–542; see also Flemming 2002: 90–91). All the cases of mutually enhancing teamwork in the sample illustrate the last two (and most well-known) enhancement relations.

Enhancement of frontness by tongue raising could be said to be at work in the Taa data described in § 4.2.2.2, where raising and fronting work hand in hand. This is not a case of enhancing teamwork, however, since all the co-triggers involved contribute both properties: coronal consonants and the non-low front vowels [e, i] all involve both tongue raising and fronting.

The last two cases of known enhancement between vocalic properties involve tongue root advancement and nasality, and both involve glottis spreading, a gesture that never plays a role in any of the cases of subphonemic teamwork identified so far. Additionally, as we will see in § 4.7.3.1, tongue root advancement is either unlikely to give rise to subphonemic teamwork effects, or at the very least likely to do so only rarely, by virtue of being a morpheme- or word-level feature in most languages.

Another known enhancement relation is that between lip spreading and vowel fronting. However, this articulatory gesture is always associated with the articulation of non-low front vowels, and is never used independently in the same way that lip rounding can be, e.g. to distinguish rounded and unrounded back (as well as front) vowels. Consequently, it does not correlate with a dedicated phonological feature independent of the feature [round], in the same way as tongue fronting vs. tongue backing, which correlate with the two (semi-)independent features [front] and [back]. Indeed, there is no contrast between, say, front vowels with and front vowels without spread lips. Contrary to lip rounding, lip spreading is thus unlikely to ever play any crucial role in a subphonemic teamwork effect: if it is at all involved, it is as a purely phonetic enhancer of vowel fronting. This highlights an important property of subphonemic teamwork, namely that the phonetic properties involved in the cumulative effect need to be related to a potentially contrastive phonological feature (see chapter 3).

The only case of coincidental teamwork in my sample is Kaska back harmony, where the lowering effect of coda [h] and the backing effect of the back vowels [ɐ(ː), ʊ, oː] trigger lowering and backing of [ɛ] to [ɐ]. This is not a case of enhancing teamwork, because tongue backing and tongue lowering cannot be said to stand in an enhancement relation. It is however easy to see why lowering and backing should work hand in hand: the articulatory and perceptual space between front and back vowels decresases with vowel height. As a consequence, [ɛ], [æ], and [ɐ] are all relatively close to each other, both articulatorily and perceptually, and more easily confusable under coarticulation. Note that, as we saw in § 4.4.2, more instrumental measurements are needed in order to determine whether Kaska back harmony is really a case of coincidental teamwork, rather than a case of subphonemic enabling.

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[60] Note that height also enhances both backness and rounding, although this relation is unidirectional (Stevens, Keyser, and Kawasaki 1986; Terbeek 1977; Linker 1982; Stevens 1998.

4.7.3 Phonetic/phonological processes and properties involved

4.7.3.1 Phonetic/phonological properties giving rise to teamwork effects

All the main vowel articulatory features except tongue advancement/retraction are involved in the subphonemic teamwork cases identified so far, as shown in (50)-(52): fontness/backness, height, roundness. The acoustic feature of gravity (related to both front/back and lip rounding) is also at work in four cases, cf. (53).

There is no case of teamwork involving any of the phonation types (breathy voice, pharygealization, laryngealization, stridency). These are rarely phonologically contrastive, which could explain why I have not been able to find any case so far.

The absence of any subphonemic teamwork effect based on tongue root advancement or retraction might simply be due to an accidental gap. However, the phonological properties of tongue advancement/retraction may also be a good explanation. Indeed, tongue root advancement/retraction is most of the time a word- or morpheme-level property: languages with an ATR contrast with a clear phonetic realization (perceptually distinctive [+ATR] and [–ATR] vowels) also have [ATR] harmony. A case of teamwork involving ATR assimilation would require the possibility to have ATR disharmony within a word, e.g. $V_{[-ATR]} \rightarrow [+ATR] / V_{[+ATR]}C\_CV_{[+ATR]}$ implies that $V_{[ATR]}CV_{[+ATR]}$ and $V_{[+ATR]}CV_{[-ATR]}$ are both licit, and would only be possible in a language with a robust [ATR] contrast, but without ATR harmony is very least rare.[61]

In fact, subphonemic teamwork rarely, if ever, involves suprasegmental properties. The only potential case identified so far is Kpan double-sided nasal assimilation (§ 4.5.2). However, nasality is not systematically a suprasegmental property. It actually behaves like any other segmental feature in a vast number of languages. Since the description of the Kpan nasal assimilation is extremely limited, as we saw (not even one example is given in the source), it is impossible to determine the status of the nasal feature in this language. If it turned out that nasality does not have suprasegmental properties in Kpan, the preliminary typology of subphonemic teamwork presented in this chapter would not include any case of teamwork involving a suprasegmental property.

Another suprasegmental property is completely absent from the typology: tone. The exclusion of tonal phenomena can be explained by the fact that tone is an abstract category that has no invariant phonetic correlate: even its phonetic realization can be said to be “abstract” in a sense, since it is defined, not as a specific F0 target, but as a quantal F0 difference relative to the F0 of neighboring tone-bearing units. Tonal processes also very frequently operate over long distances, and rarely involve synchronic coarticulatory effects. However, tone could possibly be involved in subphonemic effects in the case of tonal depression (either synchronically or in tonogenesis), which involves the coarticulatory effect of depressor consonants on the F0 of neighboring vowels, i.e. an effect driven by segmental rather than suprasegmental properties. It is not impossible, for instance, to imagine a language where tonal depression is categorical –e.g. systematically changes a high tone into a low tone– only when the target tone-bearing vowel is wedged between two depressor consonants: $\acute{V} \rightarrow \grave{V} / C_{dep}\_C_{dep}$. I have not found such a case yet. The only two cases I know of that come close are Nupe and Ngizim (Hyman and Schuh 1974106–108, based

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[61] Mundang (Elders 2000) is such a language, but no teamwork effect involving the feature [ATR] is reported for this language.

on Smith 1969, George Madugu 1970, and Schuh 1971). However these do not qualify as tonal teamwork as I briefly show below.

In Nupe, a low tone spreads onto a following H-toned syllable only if the intervening consonant is voiced:

(218) a. [pá] ‘peel’ [èpá] ‘is peeling’
b. [bá] ‘be sour’ [èbǎ] ‘is sour’
c. [wá] ‘want’ [èwǎ] ‘wants’

As Hyman and Schuh show, two analyses of the Nupe facts are possible: L-spreading is either caused by voiced consonants, or it is a general rule of the language that is blocked by voiceless consonants. In the first hypothesis, one could analyze the subphonemic depressor effect of the voiced consonant on the pitch of the following vowel to be what allows the L tone to spread onto it, in which case Nupe L-spreading could be analyzed as a case of subphonemic teamwork —either self-additive, if the L-tone and the intervening voiced consonant both have a partial lowering effect on the target, or subphonemic enabling if only the consonant has such an effect, feeding an otherwise categorical tonal assimilation. Note that the fact that L also spreads through sonorants as well as voiced stops (218c) is not a solid argument against this analysis, since tonal depression caused by sonorants is attested, even if much less frequently than with voiced stops.

However, data from Ngizim (Schuh 1971) allows Hyman and Schuh to opt in favor of the blocking hypothesis. In Ngizim, L spreads through voiced stops in L-H-H > L-L-H, similarly to what we saw in Nupe:

(219) /mùgbá + bái/ → [mùgbà̱ bái] 1it’s not a monitor’

Unlike Nupe, H-spreading through voiceless consonants is also attested: H-L > H-$\overset{\frown}{\mathrm{HL}}$:

(220) /ná kàasúw/ → [ná ká̱àsúw] ‘I accept’

So far, a subphonemic teamwork analysis is also possible in both cases. This hypothesis is however proven wrong by the fact that both L- and H- spreading are attested with intervening sonorants, as shown below.

(221) a. L-spreading: /màarə́m + tə́n/ → [màarə̱̀m + tə́n] ‘big nose’
b. H-spreading: /á + rə̀pcí/ → [á rə̱̂pcí] ‘open!’

The logical conclusion is that both L- and H-tone spreading are general phonological rules in Ngizim, which are blocked in specific contexts. L-spreading is blocked by an intervening voiceless stop, while H-spreading is blocked by an intervening voiced stop. By extension, this analysis is also most likely applicable to Nupe. The coarticulatory properties of voiceless vs. voiced stops are most probably the historical origin of these tonal rules in both languages (it is no coincidence that voiced stops should block H- rather L-tone spreading, and *vice versa*), but there is no subphonemic teamwork (anymore) in synchrony.

4.7.3.2 Processes involved: the role of similarity

The 52 cases of subphonemic teamwork gathered so far are all cases of assimilation, most often of a vowel to neighboring consonants (39/52, 75%), as we saw in § 4.7.1.2 and (217). Assimilation to neighboring consonants and vowels is much less frequent (10/52, 19%), and assimilation to neighboring vowels only is rare (3/52, 6%). This discrepancy is partly due to the overrepresentation of double-sided assimilation in the sample, as explained earlier (§§ 4.1.1 and 4.7.1.3). The only case of multiple-trigger dissimilation was found not to qualify as subphonemic teamwork (cf. § 4.6).

These processes are grounded in articulatory and/or perceptual similarity or confusability. Phonetic and phonological similarity thus plays a crucial role in subphonemic teamwork. Cumulative coarticulation makes the target segment sound more and more like another segment, triggering assimilation when a certain threshold of similarity is reached. Similarity also sometimes blocks or trumps the teamwork effect. For example, Acehnese double-sided rounding (ɨ → u / B_B) is systematic and exceptionless, except when the immediately following vowel is /ɨ/ (ɨ → [ɨ∼u] / B_Bɨ), in which case it is optional. The similarity of the following vowel to the target seems to create an echo effect that makes the limited unaffected part of the target vowel salient enough to resist assimilation (cf. § 4.2.4.1). The role of similarity in subphonemic teamwork confirms Pierrehumbert's (2000) observation that "cumulative effects appear in aspects of phonology involving overall similarity and sequential probability" (p.7) , and "another area in which cumulative effects are to be expected involve[s] the perception of similarity" (p.14).

There is one intriguing gap among the assimilatory processes attested. While both fronting and backing, and both acute and grave assimilation are attested, teamwork-driven height assimilation seems to be asymmetric, all the cases in the database involve raising, no case of lowering is attested. All the cases where uvular consonants are involved in a teamwork effect are cases of vowel backing and/or rounding (including the cases of e → a alternation in Thompson, which are better described as backing than as lowering, given the general C-V interaction patterns of the language). I specifically looked for known vowel lowering environments in P-base, e.g. lowering of high vowels by uvular consonants, and found only single trigger cases: it seems like a uvular consonant is always strong enough to lower a neighboring vowel single-handedly.

Finally, I found one case described as unrounding of /o/ to [ɤ] between a subset of consonants:

(222) Unrounding in Asmat (Voorhoeve 1965: 12–14): /o/ → [ɤ] / $\begin{cases} \text{\{t,s\}\_\{t,s\}} \\ \text{j\_\{tʃ,ɾ\}} \end{cases}$

This is intriguing because unrounding is thought to be unattested: "a possible [hypothesis] is that [–round] does not exist: the feature is universally and permanently privative. The chief predictions of this approach are that [–round] will never give rise to assimilation or dissimilation... Those predictions are largely correct" (Steriade 1995: 148). However, it is unclear whether this is a genuine case of unrounding, or simply a case of fronting/centralization. Indeed, I have changed Voorhoeve's (1965) original "ë" to [ɤ] on the basis of his description of this vowel as back and unrounded (p.12). But the author does not give any instrumental or phonological evidence in favor of analyzing this vowel as back rather than central, and one may surmise that "ë" might in reality stand for a centralized version of [o], which is likely to be less rounded than [o] (and thus look and sound like an unrounded vowel) by virtue of being less back. This is in keeping with the fact that in the same language, [u] is fronted/centralized to [ʉ] in a similar double-sided context: /u/ → [ʉ] / D_D (D = alveolar), cf. (50b).

Language	Weak target	Weakness
Woleaian	yes	phonologically short /a/
Konni (fronting)	yes	phonologically short /a/
Acehnese	yes	phonologically and intrinsically short /ɨ/ + unstressed
Russian	yes	unstressed reduced vowel
Fe’fe’ Bamileke	yes	epenthetic underspecified high vowel
Konni (backing)	yes	epenthetic /I/ + phonologically and intrinsically short
Kazakh	yes	post-radical V, unspecified for backness and rounding
Cantonese	no	–
Northern Gbaya	no	–
Wergaia	no	–
Tamil	no	–
Iaai	no	–
Kaska	no	–
Taa	no	–
Laal	no	–
Capanahua	no	–
Maléku Jaíka	?	?

Table 4.44: Target weakness in subphonemic teamwork

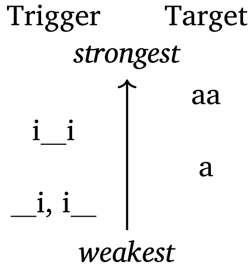
4.7.4 Strength and weakness

Teamwork is defined as the necessity to join forces in order to overcome a form of weakness. A good understanding of what is meant by weakness is thus important. In exactly half of the 17 cases described in this chapter, we noted that the target was weak, as summarized in Table 4.44.

However, target weakness is an insufficient criterion. Indeed, weakness and strength are not absolute, but relative properties. What counts is the “power relation” between target and trigger, i.e. their relative strength with respect to each other (cf. Pycha 2008: 7, 18, and references therein). Triggers and targets thus stand in a strength scale defined on the basis of the coarticulatory relation between them, i.e. the coarticulatory (palatalizing, rounding, fronting, etc.) power of the trigger compared with the sensitivity of the target to that coarticulation. The greater the strength differential between trigger and target, the less likely it is that teamwork will be necessary: a trigger with a strong coarticulatory power will need no help to affect a target with little resistance to that coarticulatory effect, while a strongly resistant target will likely not be affected by any combination of very weak triggers. Teamwork is typically observed when the strength differential is relatively small, more precisely when the target is minimally stronger than a single trigger. For instance, in the Russian dialects described in § 4.2.2.1, we saw that the difference in power between a palatalized consonant C^j and a fully reduced vowel was such that one C^j was enough to trigger vowel-palatalization ($ə \rightarrow i$). However, moderately reduced vowels, being longer and perceptually more salient, resist the palatalizing effect of a single C^j, and two C^j are required for palatalization to occur. Finally, stressed vowels are strong enough to resist palatalization from even two adjacent C^j. We saw another good illustration of this in Kazakh (§ 4.2.4.2), where teamwork is needed only when the strength difference between target and trigger is minimal.

The languages where the target has been described as weak are thus presumably languages where the triggers can be considered to be somewhat weak themselves, e.g. in Woleaian, high vowels are not strong enough to exert enough coarticulatory raising on a long adjacent /a/, even when they team up.

(223) Relative strength of triggers and target in Woleaian *a*-raising



It is thus important for any theoretical account of subphonemic teamwork to be able to model this power relation between triggers and target. In the theory of subfeatural representations, the coarticulatory relation between trigger and target, and its perceptual consequence on the target, are directly represented by coarticulatory coefficients and subfeatures (cf. chapter 3). I will show the advantages of this approach over other alternatives in chapter 5.

4.7.5 Domain

Most of the 17 cases of subphonemic teamwork described in this chapter are both static morpheme structure constraints and active alternations. Only in Fe'fe' and Capanahua is teamwork only an active alternation, while it is only observed as a static pattern in Northern Gbaya, Wergaia, Tamil and Iaai.

16 of the 17 cases of subphonemic teamwork described in this chapter are lexical processes, in Kiparsky (1982) and Kaisse and Shaw's (1985) sense: they do not apply across word boundaries, and do not appear to be sensitive to post-lexical, syntactic structure. In three cases, subphonemic teamwork is even morphologically conditioned, i.e. it applies only in specific morphological environments: between a root and a number marking suffix in Laal, in reduplicated forms in Fe'fe', and between a root and a following suffix in Capanahua. This clearly shows that subphonemic teamwork is not a postlexical phenomenon taking place in phonetic implementation, but a *bona fide* phonological process.

There is, however, one case where teamwork appears to be postlexical: Woleaian *a*-raising, which applies across word boundaries (possibly only within specific syntactic phrases, but it is unclear from Sohn's (1975) grammar. It thus appears that subphonemic teamwork may take place at any point in the phonological derivation.

More generally, subphonemic teamwork poses a potential problem for the distinction between lexical and post-lexical processes. Lexical processes are considered to be strictly structure-preserving (Kiparsky's (1985) Structure Preservation Constraint). However, subphonemic teamwork seems to involve strictly categorical lexical phonological processes of assimilation conditioned by non-structure preserving processes —notably phonetic coarticulatory allophony— which questions the strict ordering and separation of lexical and postlexical phonology, as well as that of phonology and phonetics, as we saw in chapter 3.

4.7.6 Conclusion

Subphonemic teamwork is a categorical phonological process of assimilation driven by a cumulative subphonemic coarticulatory effect. 52 cases have been found so far, 17 of which were analyzed in this and the preceding chapters. The existence and robustness of this type of phonological process confirm Flemming's (1997) claim that coarticulation is relevant to phonological processes, and seriously questions the relation and ordering of the phonological and phonetic modules, giving credence to phonetically grounded models of phonology. The theory of subfeatural representations proposed in chapter 3 to account for subphonemic teamwork consists in a representation of the partial, scalar, subphonemic effects at work in subphonemic teamwork. It gives phonetic knowledge, which plays a crucial role in phonetically based phonology, concrete representations that phonological computation can refer to. The characteristics of the typology of subphonemic teamwork presented here, in particular the asymmetry between vowels and consonants, and the types of properties and processes at work, are entirely compatible with the theory of subfeatural representations. The representations —subfeatures and coarticulatory coefficients— proposed mostly on the basis of a detailed case study (the Laal doubly triggered rounding harmony) have proven beneficial to the analysis of the other cases described here.

In the next and final chapter, I compare the theory of subfeatural representations to alternative theories, both substance-free and phonetically grounded, grammar-driven and representational, and show the advantages of subfeatures over these approaches.

Chapter 5

Alternative approaches

This final chapter reviews other possible accounts of teamwork that have been or could be proposed, and discusses the advantages of the theory of subfeatural representations over these alternatives.

The alternative proposals are presented from the most substance-free to the most phonetically grounded, and from most to least representationally conservative:

- Substance-free: Nevins' (2010) Search-and-Copy algorithm (§ 5.1, constraint cumulativity in either Local Constraint Conjunction or Harmonic Grammar (§ 5.2);
- Phonetically grounded, using only binary features (§ 5.3);
- Phonetically grounded, with reference to phonetic knowledge: Licensing-by-Cue approaches, specifically (Steriade's (2009) P-map (§ 5.4.1);
- Phonetically grounded, with dedicated auditory representations (Flemming 2002, 2002) (§ 5.4.2).

I will show that 1) substance-free accounts do not reach the descriptive and explanatory power of the theory of subfeatural representations, since they do not predict the partial effects attested in subphonemic teamwork; 2) binary features are not an adequate representation of those phonetic effects; and 3) The theory of subfeatural representations shares the same main insight as the Licensing-by-Cue / P-map approach, but by shifting the onus of explanation from faithfulness onto markedness and by giving phonetic knowledge discrete, quantized representations, it is both more in keeping with the basic tenets of phonetically based phonology, and gives a better account of the phonologization of coarticulation involved in cases of subphonemic teamwork such as Laal.

5.1 Nevins' Search-and-Copy

One of the most substance-free approaches to a case of subphonemic teamwork is to be found in Nevins's (2010: 39–45) analysis of Woleaian *a*-raising. In Nevins' theory, vowel harmony is defined as target- rather than trigger-driven: the vowel that undergoes the harmony (the target, or "recipient") needs a feature specification, and gets it from a neighboring vowel (the trigger, or "donor") through a Search-and-Copy procedure, formally defined in (224) below.

(224) Harmonic Search-and-Copy procedure, in two steps: (τ, δ, F):

a. Find: x = the closest τ to the recipient y in the direction τ

b. Copy: the value of F on x onto y, where x, y are segments, F is a feature, τ is a predicate over segments.

Vowel harmony is thus always initiated by the recipient vowel, not the donor, contrary to most views of harmony. This is illustrated in (225) below with the well-known case of Turkish back and round harmony (only roots with high vowels are shown, for the sake of concision). As seen, the accusative suffix agrees with the root vowel in both [±back] and [±round].

(225)	a.	/ip-I/	ip-i	‘rope-ACC.SG’
	b.	/kɨz-I/	kɨz-ɨ	‘girl-ACC.SG’
	c.	/yüz-I/	yüz-ü	‘face-ACC.SG’
	d.	/pul-I/	pul-u	‘stamp-ACC.SG’

The Search-and-Copy process driving the harmony is defined and illustrated in (226)-(229) below: the underspecified accusative suffix vowel searches for values of [±back] and [±round] leftward, and copies them to itself as soon as it finds them.

(226) Turkish accusative suffix must:
Back- and Round-Harmonize: δ = left, F = [±back, ±round]

(227) Accusative suffix begins Back-Harmonize in [ip-i]

$$\begin{array}{cccc} x_1 & x_2 & \leftarrow & x_3 \\ \begin{bmatrix} +\text{voc} \\ +\text{high} \\ -\text{back} \\ -\text{rd} \end{bmatrix} & \begin{bmatrix} -\text{voc} \\ \text{lab} \\ -\text{cont} \\ -\text{nas} \end{bmatrix} & & \begin{bmatrix} +\text{voc} \\ +\text{high} \\ \ldots \\ \ldots \end{bmatrix} \\ \text{i} & \text{p} & & \end{array}$$

(228) Accusative suffix finds [–back] on x_1 and finds [–round] on x_1

$$\begin{array}{cccc} x_1 & \leftarrow & x_2 & x_3 \\ \begin{bmatrix} +\text{voc} \\ +\text{high} \\ \boxed{\text{-back}} \\ \boxed{\text{-rd}} \end{bmatrix} & & \begin{bmatrix} -\text{voc} \\ \text{lab} \\ -\text{cont} \\ -\text{nas} \end{bmatrix} & \begin{bmatrix} +\text{voc} \\ +\text{high} \\ \ldots \\ \ldots \end{bmatrix} \\ \text{i} & & \text{p} & \end{array}$$

(229) Accusative suffix copies [–back] on x_1 and copies [–round] to itself

$$\begin{array}{ccc} x_1 & x_2 & x_3 \\ \begin{bmatrix} +\text{voc} \\ +\text{high} \\ \boxed{\text{-back}} \\ \boxed{\text{-rd}} \end{bmatrix} & \begin{bmatrix} -\text{voc} \\ \text{lab} \\ -\text{cont} \\ -\text{nas} \end{bmatrix} & \begin{bmatrix} +\text{voc} \\ +\text{high} \\ \boxed{\text{-back}} \\ \boxed{\text{-rd}} \end{bmatrix} \\ \text{i} & \text{p} & \underline{\text{i}} \end{array}$$

In this theory, Woleaian *a*-raising can simply be analyzed as a case of [low] harmony driven by a bidirectional Search-and-Copy procedure, formally defined in (230) below. The recipient vowel is viewed as underspecified for the feature [±low]. It initiates a search for a value of this feature in both directions simultaneously, and copies the [low] value of the next vowels on both sides, as illustrated in (231)-(233).

(230) Woleaian recipient vowel must:
Low-Harmonize: δ = left and right, F = [±low]

(231) Woleaian recipient vowel begins Low-Harmonize in /ʉlʉmami/ → [ʉlʉmemi̥]

$$\begin{array}{ccccccccc}
x_1 & & x_2 & \leftarrow & x_3 & \rightarrow & x_4 & & x_5 \\
\begin{bmatrix}\text{+voc}\\ \text{+rd}\\ \text{+high}\\ \text{–low}\\ \text{–back}\end{bmatrix} & & \begin{bmatrix}\text{–voc}\\ \text{lab}\\ \text{–cont}\\ \text{+nas}\end{bmatrix} & & \begin{bmatrix}\text{+voc}\\ \text{–rd}\\ \text{–high}\\ \ldots\end{bmatrix} & & \begin{bmatrix}\text{–voc}\\ \text{lab}\\ \text{–cont}\\ \text{+nas}\end{bmatrix} & & \begin{bmatrix}\text{+voc}\\ \text{–rd}\\ \text{+high}\\ \text{–low}\\ \text{–back}\end{bmatrix} \\
\text{ʉ} & & \text{m} & & & & \text{m} & & \text{i}
\end{array}$$

(232) Woleaian recipient vowel finds [–low] on x_1 and on x_5

$$\begin{array}{ccccccccc}
x_1 & \leftarrow & x_2 & & x_3 & & x_4 & \rightarrow & x_5 \\
\begin{bmatrix}\text{+voc}\\ \text{+rd}\\ \text{+high}\\ \boxed{\text{–low}}\\ \text{–back}\end{bmatrix} & & \begin{bmatrix}\text{–voc}\\ \text{lab}\\ \text{–cont}\\ \text{+nas}\end{bmatrix} & & \begin{bmatrix}\text{+voc}\\ \text{–rd}\\ \text{–high}\\ \ldots\end{bmatrix} & & \begin{bmatrix}\text{–voc}\\ \text{lab}\\ \text{–cont}\\ \text{+nas}\end{bmatrix} & & \begin{bmatrix}\text{+voc}\\ \text{–rd}\\ \text{+high}\\ \boxed{\text{–low}}\\ \text{–back}\end{bmatrix} \\
\text{ʉ} & & \text{m} & & & & \text{m} & & \text{i}
\end{array}$$

(233) Woleaian recipient vowel copies [–low] from x_1 and from x_5

$$\begin{array}{ccccc}
x_1 & x_2 & x_3 & x_4 & x_5 \\
\begin{bmatrix}\text{+voc}\\ \text{+rd}\\ \text{+high}\\ \boxed{\text{–low}}\\ \text{–back}\end{bmatrix} & \begin{bmatrix}\text{–voc}\\ \text{lab}\\ \text{–cont}\\ \text{+nas}\end{bmatrix} & \begin{bmatrix}\text{+voc}\\ \text{–rd}\\ \text{–high}\\ \boxed{\text{–low}}\end{bmatrix} & \begin{bmatrix}\text{–voc}\\ \text{lab}\\ \text{–cont}\\ \text{+nas}\end{bmatrix} & \begin{bmatrix}\text{+voc}\\ \text{–rd}\\ \text{+high}\\ \boxed{\text{–low}}\\ \text{–back}\end{bmatrix} \\
\text{ʉ} & \text{m} & \text{e̱} & \text{m} & \text{i}
\end{array}$$

Importantly, for copying to be successful, the closest vowels in both directions need to have the same value for [±low]. If their [low] values are different, copying cannot take place, as shown in (234)-(236) below.

(234) Woleaian recipient vowel begins Low-Harmonize in /mata-ji/ → [meta̱ji̥] (*mate̱ji̥)

$$\begin{array}{ccccccccc}
x_1 & & x_2 & \leftarrow & x_3 & \rightarrow & x_4 & & x_5 \\
\begin{bmatrix}\text{+voc}\\ \text{–rd}\\ \text{–high}\\ \text{+low}\end{bmatrix} & & \begin{bmatrix}\text{–voc}\\ \text{cor}\\ \text{–cont}\\ \text{–nas}\\ \text{–voi}\end{bmatrix} & & \begin{bmatrix}\text{+voc}\\ \text{–rd}\\ \text{–high}\\ \ldots\end{bmatrix} & & \begin{bmatrix}\text{–voc}\\ \text{cor}\\ \text{+del.rel}\\ \text{–nas}\\ \text{+voi}\end{bmatrix} & & \begin{bmatrix}\text{+voc}\\ \text{–rd}\\ \text{+high}\\ \text{–low}\\ \text{–back}\end{bmatrix} \\
\text{a} & & \text{t} & & & & \text{j} & & \text{i}
\end{array}$$

(235) Woleaian recipient vowel finds [+low] on x_1 and [–low] on x_5

$$\begin{array}{ccccccc}
x_1 & \leftarrow & x_2 & x_3 & x_4 & \rightarrow & x_5 \\
\begin{bmatrix} +\text{voc} \\ -\text{rd} \\ -\text{high} \\ \boxed{+\text{low}} \end{bmatrix} & & \begin{bmatrix} -\text{voc} \\ \text{cor} \\ -\text{cont} \\ -\text{nas} \\ -\text{voi} \end{bmatrix} & \begin{bmatrix} +\text{voc} \\ -\text{rd} \\ -\text{high} \\ \ldots \end{bmatrix} & \begin{bmatrix} -\text{voc} \\ \text{cor} \\ +\text{del.rel} \\ -\text{nas} \\ +\text{voi} \end{bmatrix} & & \begin{bmatrix} +\text{voc} \\ -\text{rd} \\ +\text{high} \\ \boxed{-\text{low}} \\ -\text{back} \end{bmatrix} \\
\text{a} & & \text{t} & & \text{j} & & \text{i}
\end{array}$$

(236) Woleaian recipient vowel fails to copy a value

$$\begin{array}{ccccccc}
x_1 & \leftarrow & x_2 & x_3 & x_4 & \rightarrow & x_5 \\
\begin{bmatrix} +\text{voc} \\ -\text{rd} \\ -\text{high} \\ \boxed{+\text{low}} \end{bmatrix} & & \begin{bmatrix} -\text{voc} \\ \text{cor} \\ -\text{cont} \\ -\text{nas} \\ -\text{voi} \end{bmatrix} & \begin{bmatrix} +\text{voc} \\ -\text{rd} \\ -\text{high} \\ \ldots \end{bmatrix} & \begin{bmatrix} -\text{voc} \\ \text{cor} \\ +\text{del.rel} \\ -\text{nas} \\ +\text{voi} \end{bmatrix} & & \begin{bmatrix} +\text{voc} \\ -\text{rd} \\ +\text{high} \\ \boxed{-\text{low}} \\ -\text{back} \end{bmatrix} \\
\text{a} & & \text{t} & & \text{j} & & \text{i}
\end{array}$$

In Nevins' account, in the absence of a copiable value, default [+low] is inserted as a last resort solution (→ *mata̱ji*).[1]

Nevins' theory does not offer a satisfying account of teamwork, for three main reasons: 1) it does not account for all the cases of teamwork described in chapter 4; 2) even in the cases that it does seem to account for, it is more stipulative, and therefore has less explanatory power than the subfeatural account; and 3) it is not even as descriptively adequate, since it does not predict the partial effects at work in subphonemic teamwork.

Firstly, Nevins' theory does not account for all the attested types of teamwork. Indeed, it predicts only single-trigger (unidirectional Search-and-Copy) and double-sided doubly-triggered harmony (bidirectional Search-and-Copy) to be possible. Cases like Laal, where both triggers can be on the same side (cf. ex. (7b-c) in § 2.2), or like Konni trans-dorsal backing, where both triggers have to be on the same side of the target (cf. ex. (78), and (91), § 4.2.1), cannot be accounted for. Additionally, the theory does not account for processes involving more than two triggers, e.g. Fe'fe' Bamileke vowel grave/acute assimilation (cf. § 4.3.2), Taa *a*-raising/fronting (cf. § 4.2.2.2). One could argue that Nevins' Search-and-copy theory is a theory of vowel harmony, not a general theory of assimilation. Since the cases that involve same-side co-triggers, or more than two triggers, all involve a consonant, they can be considered to fall outside the purview of the theory. Still, the theory of subfeatural representations offers the advantage of permitting a unified account of subphonemic teamwork.

Secondly, using Nevins' theory to account for teamwork has little explanatory power. What makes teamwork particularly interesting and challenging for phonological theory is its multiple-trigger requirement, i.e. the cumulative effect it illustrates. The advantage of Nevins' theory is that it does not view Woleaian *a*-raising and similar cases of double-sided teamwork as doubly-initiated processes, since the harmony has only one initiator: the recipient vowel. One thus no longer has to account for the necessity for the process to be initiated by two instances of the same feature, e.g. for the feature [–low] to spread from two sources at the same time. However,

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[1] After which *a*-dissimilation and word-final devoicing apply (→ *metaji̥*)

one still has to account for the fact that the recipient vowel is getting its feature specification from two sources, as opposed to only one in, e.g., Turkish (cf. (225) above). Nevins' solution, bi-directional Search-and-Copy, is stipulative: it builds bi-directionality into the definition of the grammatical process, rather than either deriving it from independent properties, or explaining it through phonetic grounding. The properties of the teamwork effect (the fact that one trigger is not sufficient, the restrictions on the number, type and position of the co-triggers, etc.) is thus not explained, only formalized.

Note, furthermore, that Nevins' analysis of the Woleaian data —essentially simplified for the illustrative purpose that it serves in the book— would need to be slightly elaborated in order to fully account for the Woleaian pattern. This elaboration would require further stipulations that are not necessary in a phonetically based account. One aspect of the harmony that is not addressed in Nevins' sketch, for example, is that the recipient vowel can only copy [–low] from a [+high] donor, i.e. [–high, –low] /e/ and /o/ cannot be donors, as can be seen in /le-lamwo/ [lenamwo̥] 'inside of the lagoon' (cf. ex. (133), § 4.2.3). This precondition on harmony has to be worked into the system, presumably through some sort of stipulative restriction. Such a restriction is naturally explained by the subfeatural approach where phonology has access to information about coarticulation (provided that the hypothesis that coarticulation is indeed at work in this case is correct).

Another characteristic of the Woleaian pattern that needs to be accounted for is the resistance of long /aa/ to the harmony. This could be done either by a stipulative restriction, or by a representational solution whereby long /aa/, unlike short /a/, is always fully specified, and thus does not need to initiate the Low-Harmony search. Once again, in the subfeatural account, such a restriction is naturally accounted for, rather than stipulated or explained away through ad hoc representational distinctions.

Finally, Nevin's theory fails to predict the partial effects that are at work in subphonemic teamwork, at least in the hypothesis adopted here, based on an extrapolation of the instrumental evidence available in Laal (cf. § 2.4). Nevins' theory is thus less descriptively adequate, and seems to be missing an important characteristic of subphonemic teamwork.

I would like to conclude this section by emphasizing that my point here is not that Nevins' theory of vowel harmony fails on all accounts. I simply argue that it fails to adequately account for subphonemic teamwork. This does not imply anything for its validity as a theory of canonical, coarticulation-independent, long-distance vowel harmony such as attested in Turkish or Finnish, which is outside the scope of the present work.

5.2 Cumulative constraint interaction

As briefly mentioned in § 1.4, one might analyze teamwork as resulting from the ganging up, not of weak phonetic effects, but of weak grammatical constraints, each militating in favor of a categorical change, but too weak to be active independently. This is what Farris-Trimble (2008: 9) calls a "cumulative markedness effect", which "occur[s] when the violation of a single markedness constraint is permitted, but the violation of multiple markedness constraints within a given domain is not" (also referred to as "worst-of-the-worst effects", cf. Prince and Smolensky 1993, Smolensky 1995).

Two implementations of this idea have been proposed: Local Constraint Conjunction (LCC; Smolensky 1993; 1995) in classic OT, or constraint ganging in weighted constraint models such as Harmonic Grammar (HG; Legendre et al. 1990; Smolensky and Legendre 2006). I will first summarize Suzuki's (1997) LCC-based analysis of Woleaian *a*-raising in § 5.2.1, and then propose in § 5.2.2 a Harmonic Grammar account of both the Woleaian and Laal alternations. Crucially, these accounts do not add to the traditional inventory of categorical phonological representations: the constraints refer to binary features only, and the cumulative effect is entirely driven by the grammar through constraint interaction. As mentioned in § 1.4, I show that these two very similar accounts of subhonemic teamwork are inferior to the subfeatural approach in that they do not predict the partial effects that have been documented in Laal and (plausibly) hypothesized in all other cases.

5.2.1 Local Constraint Conjunction in OT

Local Constraint Conjunction (LCC), couched in parallel Optimality Theory, allows two constraints C_1 and C_2, both ranked lower than C_3, to be conjoined into a separate local conjunction C_1 & C_2, ranked higher than C_3. As a result only a violation of both C_1 and C_2 (hence of their conjunction as well) will incur a penalty higher than one violation of C_3. The two conjoined constraints need to be violated in the same local domain in order for their conjunction to be violated as well.

(237) Local Constraint Conjunction (Smolensky 1995):
  a. The Local Conjunction of C_1 and C_2 in domain *D*, C_1 & C_2, is violated when there is some domain of type *D* in which both C_1 and C_2 are violated
  b. Universally, $C_1 \& C_2 \gg C_1, C_2$

Suzuki (1997) proposes an account of Woleaian *a*-raising (cf. §§ 1.3 and 4.2.3) using LCC. The double-sided effect is accounted for by two sequential grounding constraints (Smolensky 1993) banning high-low and low-high vowel sequences respectively, defined in (238) below.[2]

(238) a. *HI-LO: If a vowel is specified for [+high], it must not be followed by a vowel specified for [+low]
  b. *LO-HI: If a vowel is specified for [+high], it must not be preceded by a vowel specified for [+low]

Both constraints are ranked below IDENT[lo], and can therefore never trigger any repair strategy when violated (i.e. they are inactive). But their local conjunction, defined in (239) below, is ranked above IDENT[lo], explaining why the /a/ to [e] change occurs only when both constraints are violated, (i.e. when two triggers are present), as illustrated in (240)-(241) below (to simplify the presentation, final vowel devoicing and final *a*-raising are ignored in the following tableaux).

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[2] Sequential grounding (e.g. *Hi-Lo: no [+high] segment may be followed by a [+low] segment) is a syntagmatic extension of Archangeli and Pulleyblank's (1994) paradigmatic grounding (e.g.: Hi/Lo: if a segment is [+high], it cannot be [+low]).

(239) *Hi-Lo & *Lo-Hi:[3]

a. *Hi-Lo & *Lo-Hi is violated when both *Hi-Lo and *Lo-Hi are violated *locally* (i.e. by the same segment)

b. Universally, *Hi-Lo & *Lo-Hi ≫ *Hi-Lo, *Lo-Hi.

(240)

/ʉwa-li/	*Hi-Lo & *Lo-Hi	Ident[lo]	*Hi-Lo	*Lo-Hi
a. ʉwali	*!		*	*
☞ b. ʉwe̱li		*		

(241)

/ʉwa-le/	*Hi-Lo & *Lo-Hi	Ident[lo]	*Hi-Lo	*Lo-Hi
☞ a. ʉwale			*	
b. ʉwe̱le		*!		

Finally the resistance of long /aa/ to raising is ascribed to a general property of the language, since /aa/ is also immune to the other two raising rules of the language: word-final raising (/mel-a/ → [mele̱] 'tool', but /bel-aa/ → [bela̱] 'fish sp.', with word-final shortening), or *a*-dissimilation (/mata-i/ → [me̱tai] 'my eyes', but /faaragi/ → [fa̱a̱ragi] 'walk') (Suzuki 1997: 219–220; Sohn 1975). This general property of long /aa/ is implemented in the grammar with an undominated constraint requiring faithfulness to long low vowels (Ident[lo]$_{\mu\mu}$), as shown in the tableau in (242).

(242)

/i-taai/	Ident[lo]$_{\mu\mu}$	*Hi-Lo & *Lo-Hi	Ident[lo]	*Hi-Lo	*Lo-Hi
☞ a. itaai		*		*	*
b. ite̱e̱i	*!		**		
c. ite̱ai	*!		*		*
d. itae̱i	*!		*	*	

Strictly speaking, this constraint is also a conjoined constraint itself: Ident[lo] & Ident-V$_{\mu\mu}$, ranked higher than both its members (as shown in (242) for Ident[lo]), and violated only when a vowel is both low and long. This conjunction is actually unnecessary here: simple faithfulness to vowel length (i.e. Ident-V$_{\mu\mu}$ would have the same effect.

Suzuki argues that the two sequential grounding constraints *Hi-Lo and *Lo-Hi are justified on typological grounds by data showing their independent activity in other languages, notably Basque (where only *Hi-Lo is active, e.g. /mutil-bat/ → [mutli-be̱t] 'boy-indf') and Old High German (where only *Lo-Hi is active, e.g. /gast-i/ → [ge̱st-i] 'guest-pl'). The Basque and Old High German cases can be easily accounted for by simply reranking either *Hi-Lo or *Lo-Hi above Ident[hi]. He thus presents his account as being both typologically grounded and economic, since it only makes use of two well attested constraints, and of representations and machinery readily available in OT (on the condition that one accepts the principle of constraint conjunction, that is).

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[3] Note that additional constraints would need to account for the fact that a lo-hi-lo sequence is not unlawful, despite violating the conjoined constraint *Hi-Lo & *Lo-Hi as much as a hi-lo-hi sequence.

However, the LCC account of teamwork has two major limitations (in addition to the overprediction and lack of restrictiveness problem it has been shown to pose, cf. Pater et al. 2007). First, it stipulates, rather than explains, the same-target restriction that is crucial to the definition of teamwork. The tableau in (243) illustrates this important point: /laʉlijara/ → [laʉlijara] surfaces faithfully[4] in (243) because the two [+high] triggers target two different vowels. It is thus crucial for the analysis that simultaneous violation of both conjuncts does not incur a violation of the conjunction *HI-LO & *LO-HI in this case. In the LCC account, this is achieved by stipulating that a conjoined constraint can only be violated if the two conjuncts are violated *locally*, i.e. by the same segment (cf. (239a)). This same-segment requirement is thus not explained in LCC, contrary to the subfeatural account proposed in chapter 3 (or any other account making use of fine-grained phonetic representations), where the cumulative effect can only be obtained if the additive coarticulatory effects target the same segment.

(243)

/laʉli-yara/	*HI-LO & *LO-HI	IDENT[lo]	*HI-LO	*LO-HI
☞ a. laʉlijara			*	*
b. le̱ʉlijara		*!	*	
c. laʉlije̱ra		*!		*
d. le̱ʉlije̱ra		*!*		

The second limitation of the LCC account, briefly mentioned in § 1.4, is that it models a categorical effect rather than a cumulative one, i.e. it does not predict any partial effect on the target in the presence of only one trigger. Indeed, the two members of the conjunction *HI-LO & *LO-HI can only be fully active if they are both violated by the same segment. They are completely inactive otherwise, by virtue of being ranked lower than IDENT[lo], i.e. any violation of either *HI-LO or *LO-HI is inconsequential. Resorting to LCC to account for the Laal doubly triggered rounding harmony would (e.g. with a conjunction of the two constraints used in § 5.2.2.2) thus fail to predict and account for the partial effect revealed by the acoustic analysis in § 2.4.

5.2.2 Constraint ganging in Harmonic Grammar

Harmonic Grammar (HG; Legendre et al. 1990) makes use of weighted rather than strictly ranked constraints. This allows the model to account not only for everything that strict-ranking OT already accounts for, but also for gang-up effects such as the ones involved in multiple-trigger processes. The major advantage of HG over LCC is that it accounts for gang-up effects through constraint interaction alone, without the need for any additional machinery or stipulation. This is because both constraint ganging and the locality restriction on this ganging are emergent, in that they naturally derive from regular interaction between weighted constraints: it is impossible for two or more weak constraints to gang up in order to overcome a stronger constraint, unless the ganging constraints are "co-relevant" (i.e. share some feature(s), cf. Bakovic 2000: 34) and their violation is local (i.e. apply in the same small domain), as we will see below.

I will illustrate this here with an HG account of both Woleaian *a*-raising and Laal rounding harmony.

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[4] The actual surface realization is [laʉlijare̥] with word-final *a*-raising and devoicing.

5.2.2.1 Woleaian

Only one markedness constraint is needed to account for the Woleaian data: *SkipHeight, defined in (244) below. This constraint —which has the same effect as Suzuki's (1997) conjunction *Hi-Lo & *Lo-Hi— penalizes adjacent syllables whose nuclei are maximally distinct in height.[5]

(244) *SkipHeight:

Let X and Y be vowels. If X and Y are nuclei of adjacent syllables, X and Y may not differ in height by more than one height level. Assign one violation per pair of adjacent syllables whose nuclei are maximally distinct in height.

The faithfulness constraint violated by the raising of /a/ is Ident[lo], penalizing any change in the value of the feature [low]. The weights in all the tableaux below, calculated with OT-Help 2.0 (Staubs et al. 2010), are the minimum weights necessary to make the correct predictions, with weights restricted to positive real numbers and the minimal weight set to 1. Weight values are to be understood as relative to each other within the constraint system: an infinity of other weight combinations would predict the same results, as long as the relations between constraint weights are maintained. Crucially, the relative weights of the faithfulness (Ident[lo]) and markedness (*SkipHeight) constraints need to be such that the former is weaker than the latter, and two violations of *SkipHeight incur a penalty greater than one, but lesser than two violations of Ident[lo]. This is what Jäger and Rosenbach (2006) call "counting cumulativity", i.e. a ganging effect resulting from the addition of multiple violations of one weak constraint. It is illustrated in (245)-(247), where the raised vowels are underlined.[6]

(245)

/ʉwa-li/	Ident[lo] *3*	*SkipHeight *2*	
a. ʉwali		–2	*–4*
☞ b. ʉwe̲li	–1		*–3*

(246)

/ʉwa-le/	Ident[lo] *3*	*SkipHeight *2*	
☞ a. ʉwale		–1	*–2*
b. ʉwe̲le	–1		*–3*

---

[5] One might argue that this constraint is only a graphical shortcut for the conjunction of *Hi-Lo & *Lo-Hi. In reality, the rationale behind these two constraints is slightly different: *SkipHeight explicitly views the phonotactic problem posed by an *i-a* or *a-i* sequence as originating in the articulatory distance between the vowels, and is thus "more" phonetically grounded than *Lo-Hi or *Hi-Lo, whose formulation does not refer to any grounding of any sort. This is however orthogonal to the HG account, which would work just as well with the two weak markedness constraints *Hi-Lo and *Lo-Hi.

[6] In an account using the two weak markedness constraints *Hi-Lo and *Lo-Hi, Woleaian *a*-raising would be seen as an illustration not of counting, but of ganging cumulativity (cf. § 5.2.2.2).

(247)

/laʉli-yara/	Ident[lo]	*SkipHeight	
	3	*2*	
☞ a. laʉlijara		–2	*–4*
b. le̲ʉlijara	–1	–1	*–5*
c. laʉlije̲ra	–1	–1	*–5*
d. le̲ʉlije̲ra	–2		*–6*

As seen in (245)-(247), a candidate in which raising has applied as a repair to *SkipHeight may only be optimal if 1) it violates Ident[lo] only once, and 2) the faithful candidate violates *SkipHeight twice. In other words, both violations of *SkipHeight need to be incurred by the same segment, as in (245) /ʉwa-li/ → [ʉweli], but not in (246) /ʉwa-le/ → [ʉwale] (*ʉwele) where *SkipHeight is violated only once, or in (247) /laʉli-jara/ → laʉlijara (*leʉlijera) where the two violations of *SkipHeight in the faithful candidate are incurred by two different segments, thus violating Ident[lo] twice, i.e. one time two many.[7]

Two more faithfulness constraints are needed to explain why /a/ changes to mid front [e] rather than any other vowel. Ident[hi], penalizing changes to the feature [high], with a weight of 2, both prevents /a/ from raising to a high vowel (candidates f, g and i in (249)), and explains why lowering either or both of the two high trigger vowels is not the solution to the phonotactically ill-formed hi-lo-hi sequence (candidates c, d and e). Ident[back] (or Ident[round]) additionally accounts for the fact that /a/ is raised to front [e] rather than back/round [o] (candidate h).[8]

(248)

/ʉwa-li/	Ident[lo]	Ident[hi]	*SkipHeight	Ident[bk]	
	3	*2*	*2*	*1*	
a. ʉwali			–2		*–4*
☞ b. ʉwe̲li	–1				*–3*
c. ewali		–1	–1		*–4*
d. ʉwale		–1	–1		*–4*
e. ewale		–2			*–4*
f. ʉwili	–1	–1			*–5*
g. ʉwʉli	–1	–1			*–5*
h. ʉwoli	–1			–1	*–4*
i. ʉwuli	–1	–1		–1	*–6*

Finally, general faithfulness to vowel length (Ident-$V_{\mu\mu}$) is responsible for the resistance of long /aa/ to the assimilation.

(249)

/itaa-i/	Ident[lo]	*SkipHeight	Ident-$V_{\mu\mu}$	
	3	*2*	*1*	
☞ a. itaai		–2		*–4*
b. ite̲e̲i	–1		–2	*–5*

---

[7] The surface form of /laʉli-jara/ is actually [laʉlijare̥], the final /a/ being raised to [e] through reglar word-final *a*-raising, and devoiced (Sohn 1971, 1975). Since this type of *a*-raising is orthogonal to the issue at stake here, I have decided to ignore it for the sake of brevity and simplicity.

[8] The double-sided back/rounding assimilation /e/ → [o] / u_u also attested in Woleaian is ignored here, to simplify the demonstration. Including would not jeopardize the HG analysis, but only complicate it.

Note that it does not need to have a greater weight than *SKIPHEIGHT, contrary to Suzuki's (1997) LCC account above where IDENT$[\text{lo}]_{\mu\mu}$ needed to be ranked higher than *HI-LO & *LO-HI. In this simple tableau, a weight of 1 is sufficient to ensure that the ganging of IDENT[lo] and IDENTV-$_{\mu\mu}$) prevents *a*-raising. Incidentally, this gang up effect, which is what Suzuki's (disguised) constraint conjunction IDENT$[\text{lo}]_{\mu\mu}$ (= IDENT[lo] & IDENT-$V_{\mu\mu}$) stands for, is emergent in Harmonic Grammar.

5.2.2.2 Laal

An HG account of the Laal doubly triggered rounding harmony illustrates what Jäger and Rosenbach (2006) call "ganging cumulativity", i.e. a case of teamwork arising through the additive violations of two (or more) weak faithfulness constraints overcoming the protecting effect of a strong faithfulness constraint.

Using the same approach as in the illustrative analysis proposed in § 3.3, the Laal alternation can be analyzed as being driven by the two targeted markedness constraints defined below.

(250) *[–lab].[+lab]/[αH,βFR]:

Let X and Y be segments; X and Y may not disagree in the feature [labial] iff 1) X is [–lab] and precedes Y, and 2) X and Y are adjacent in the ordered set of output segments sharing the same height and [front] features. Assign one violation per pair of segments failing to comply.

(251) $^*C_{[\alpha\text{lab}]}V_{[-\alpha\text{lab,-fr,-lo}]}$/ADJACENT:

A non-low central vowel and a (near-)adjacent consonant (i.e. adjacent or separated from the vowel by only one consonant) may not disagree in the feature [labial]. Assign one violation per pair of adjacent C and V violating this requirement. [9]

The constraint in (250) militates in favor of unconditional, categorical, anticipatory rounding harmony from V_2 to V_1. The one in (251) militates in favor of labial assimilation between a labial consonant and a (near-) adjacent non-low central vowel, i.e. /ɨ/ or /ə/. The mechanism is the same as for Woleaian, except this time the two markedness constraints, each weaker than faithfulness to labiality (IDENT[lab]), "team up" to strike down any output candidate where they are both violated by the same segment. This is illustrated the tableaux in (252)-(254) below.

(252)

/ɓɨ̀r-ú/	IDENT[lab] *5*	*[–lab].[+lab] /[αH,βFR] *4*	$^*C_{[\alpha\text{lab}]}V_{[-\alpha\text{lab,-fr,-lo}]}$ /ADJACENT *2*	
a. ɓɨ̀rú		–1	–1	*–6*
☞ b. ɓùrú	–1			*–5*
c. ɓɨ̀rɨ́	–1		–1	*–7*

---

[9] Assuming that only potential bearers of the feature [labial] (i.e. vowels and labial consonants) may violate the constraint, and that similarity can be defined in terms of either featural identity or distance, as argued by Wayment (2009).

(253)

/ɓə̀r-ú/	IDENT[lab] *5*	*[–lab].[+lab] /[αH,βFR] *4*	*C$_{[\alpha\text{lab}]}$V$_{[-\alpha\text{lab,-fr,-lo}]}$ /ADJACENT *2*	
☞ a. ɓə̀rú			–1	*–2*
b. ɓòrú	–1			*–5*
c. ɓə̀r-ɨ́	–1		–1	*–7*

(254)

/gɨ́n-ù/	IDENT[lab] *5*	*[–lab].[+lab] /[αH,βFR] *4*	*C$_{[\alpha\text{lab}]}$V$_{[-\alpha\text{lab,-fr,-lo}]}$ /ADJACENT *2*	
☞ a. gɨ́nù		–1		*–4*
b. gúnù	–1			*–5*
c. gɨ́nɨ̀	–1			*–5*

Rounding of the target vowel is optimal in (252) /ɓɨ̀r-ú/ → [ɓùrú] because one violation of IDENT[lab] is preferable to one violation of each of the two markedness constraints. On the other hand, rounding is ruled out in favor of a faithful realization in (254) /gɨ́n-ù/ → [gɨ́nù] and (253) /ɓə̀r-ú/ → [ɓə̀rú], because the faithful candidate violates only one of two weak markedness constraint, and thus incurs a lesser penalty than that incurred by the violation of IDENT[lo].

Similarly, the input /mèn-ú/ → [mènú] in (255) surfaces faithfully because it violates only one of the two markedness constraints, since the sequence [me] does not violate *C$_{[\alpha\text{lab}]}$V$_{[-\alpha\text{lab,-fr,-lo}]}$ /ADJACENT).

(255)

/mèn-ú/	IDENT[lab] *5*	*[–lab].[+lab] /[αH,βFR] *4*	*C$_{[\alpha\text{lab}]}$V$_{[-\alpha\text{lab,-fr,-lo}]}$ /ADJACENT *2*	
☞ a. mènú		–1		*–4*
b. myònú	–1			*–5*
c. mènɨ́	–1			*–5*

The directionality of the assimilation falls from the combination of the directional markedness constraint *[–lab].[+lab]/[αH,βFR] —which penalizes [–lab].[+lab], but not [+lab].[–lab] sequences— and the strong weight of IDENT[lab].

(256)

/gōbə̄r/	IDENT[lab] *5*	*[–lab].[+lab] /[αH,βFR] *4*	*C$_{[\alpha\text{lab}]}$V$_{[-\alpha\text{lab,-fr,-lo}]}$ /ADJACENT *2*	
☞ a. gōbə̄r			–1	*–2*
b. gōbōr	–1			*–5*
c. gə̄bə̄r	–1		–2	*–9*

Perseverative rounding, as in candidate (256b) [gōbə̄r], is ruled out because it incurs a fatal violation of the strongest constraint of this small grammar: faithfulness to [low]. This is much too costly a repair for the minimal penalty incurred by the fully faithful candidate [gōbə̄r] (256a), which violates only the weakest constraint (*C$_{[\alpha\text{lab}]}$V$_{[-\alpha\text{lab,-fr,-lo}]}$/ADJACENT).

The blocking effect of intervening /w/ is accounted for by the markedness constraint *U(C)W introduced and defined in (35), § 3.3, as shown in (257) below.

(257)

/mə́w-ó/	IDENT[lab]	*[–lab].[+lab] /[αH,βFR]	$^*\mathrm{C}_{[\alpha\text{lab}]}\mathrm{V}_{[-\alpha\text{lab,-fr,-lo}]}$ /ADJACENT	*U(C)W	
	5	*4*	*2*	*2*	
☞ a. mə́wó		–1	–1		*–6*
b. mówó	–1			–1	*–7*
c. mə́wə́	–1		–1		*–7*

Finally, note that the weight difference between faithfulness and the markedness constraint $^*\mathrm{C}_{[\alpha\text{lab}]}\mathrm{V}_{[-\alpha\text{lab,-fr,-lo}]}$/ADJACENT needs to be sufficient to prevent any counting cumulativity effect. Although the faithful candidate in (258) /pɨ́rmɨ́n/ → [pɨ́rmɨ́n] violates it three times, it is still less costly than to violate IDENT[lab] even once.

(258)

/pɨ́rmɨ́n/	IDENT[lab]	*[–lab].[+lab] /[αH,βFR]	$^*\mathrm{C}_{[\alpha\text{lab}]}\mathrm{V}_{[-\alpha\text{lab,-fr,-lo}]}$ /ADJACENT	
	5	*4*	*2*	
☞ a. pɨ́rmɨ́n			–3	*–6*
b. púrmɨ́n	–1		–1	*–7*
c. pɨ́rmún	–1	–1	–2	*–13*
d. púrmún	–2			*–10*

The fact that the the two triggers driving the rounding harmony can only be a consonant and a vowel, and never two or more consonants (cf. ex. (9) in § 2.2), is thus accounted for by giving $^*\mathrm{C}_{[\alpha\text{lab}]}\mathrm{V}_{[-\alpha\text{lab,-fr,-lo}]}$/ADJACENT a significantly lower weight than both IDENT[lab] and *[–lab].[+lab]/[αH,βFR]. In other words, while V_1–V_2 labial agreement (i.e. anticipatory rounding harmony) is a strong requirement in Laal, CV labial agreement is a much weaker one. How this generalization is to be interpreted is unclear. On the one hand, it is in keeping with the fact that rounding harmony is a strong phonological pattern in Laal, while BV coarticulation is only a subphonemic effect. This is also in keeping with typological expectations; rounding harmony is more common than CV major feature assimilation. On the other hand, it is in stark contrast with the instrumental evidence, which shows that BV coarticulation is a strong and significant effect, while the coarticulatory effect of V_2 on V_1 is not.

5.2.2.3 Conclusion on LCC and HG

Harmonic Grammar offers a more elegant and economic account of teamwork than Local Constraint Conjunction, by doing away with LCC's unwanted stipulations and pathologies. Indeed, one of the definitional properties of teamwork —the fact that several triggers are needed to affect one target— is straightforwardly accounted for through the fine-tuning of constraint weights. Teamwork arises when two or more violations of weak markedness, incurred by one and the same segment, induce a penalty that is greater than one violation of the faithfulness constraint violated by the candidate in which teamwork has taken place, as schematized in Table 5.1. Furthermore, the two types of cumulative effects predicted to occur in a weighted constraint model —"counting" and “ganging” cumulativity, as shown by Jäger and Rosenbach (2006)— are attested in phonological teamwork: Woleaian *a*-raising illustrates the former, the doubly triggered rounding harmony of Laal the latter.

	Faithfulness		*Counting* Markedness		*Ganging* Markedness 1 + 2	
Violations:	$\boxed{1}$	>	1	,	1 + 0 (∼0 + 1)	
	1	<	$\boxed{2}$	,	$\boxed{1+1}$	= teamwork
	$\boxed{2}$	>	2	,	1 + 1	

Table 5.1: Cumulative markedness: counting and ganging

Another important aspect of teamwork —the strength relation between trigger and target (cf. § 4.7.4)— is indirectly suggested by he weight relations that drive gang-up effects in the HG account. Faithfulness to the input (e.g. Ident[low] in Woleaian, § 5.2.2.1) is indeed suggestive of the resistance of the target to coarticulation, while markedness of the coarticulated structure (e.g. *SkipHeight in Woleaian) seems to bear some relation with the (relatively weak) coarticulatory strength of each individual trigger. As for the relative weighting between these two constraints (3 vs. 2), it is reminiscent of the trigger/target strength differential, with Ident[low] (i.e. the target) being minimally stronger than SkipHeight (i.e. the trigger), in a way that allows two violations of SkipHeight, i.e. the cumulative coarticulatory effect of two triggers, to be stronger than a single target, and cause a → e raising. However, actual reference to coarticulation is absent from this substance-free and grammar-driven account. Contrary to the theory of subfeatural representations, which gives them dedicated representations, HG does not predict the partial effects or acknowledge the existence of the coarticulatorily grounded subphonemic categories that are attested in Laal (cf. § 2.4), and hypothesized in the other cases of subphonemic teamwork described in chapter 4. In other words, the HG account still analyzes teamwork as a categorical effect. More generally, HG can only model “*cumulative* markedness” effects (Farris-Trimble 2008: 9), but not the “*quantal* markedness” effects that drive subphonemic teamwork, which are straightforwardly accounted for by the subfeatural account proposed in chapter 3.

Subphonemic teamwork thus illustrates a case of cumulativity that cannot be used as an argument in favor of weighted constraint models over strict ranking. On the other hand it serves as a compelling argument in favor of an approach that includes phonetic representations: not only is phonology (partly) grounded in phonetic knowledge, this knowledge is reified into dedicated representations available to the phonological grammar.

5.3 Regular binary features

One could object that acknowledging the existence and relevance of the partial effects involved in subphonemic teamwork does not in and of itself warrant the introduction of gradient representations in phonology, if one can find a way to account for such effects using only traditional binary features.

In this section, I develop two alternative analyses of the crucial distinction between [ɨ, ə] and [ɨ^b, ə^b] in Laal (cf. chapter 2), using only traditional binary features. I show that, even though they are descriptively adequate in that they predict all the observed alternations, they do so at the expense of both grammatical simplicity and explanatory power. On this basis, I argue that they do not constitute an interesting alternative to the subfeatural account proposed in chapter 3.

5.3.1 Not ⟦.40 round⟧ but [+labial]

The first possibility is to analyze the coarticulatory effect of labial consonants on neighboring central vowels as the spreading of their [labial] feature: labialized [ɨ^{b}, ə^{b}] are both [–round] and [labial], and the doubly-triggered rounding harmony targets only [labial] vowels: V$_{[labial]}$ $\rightarrow$ [+round] / __C(C)V$_{[+round]}$. This supposes both that the C-place feature [labial] and V-place feature [round] are phonologically different (as in Vplace theory, cf. Ní Chiosáin and Padgett 1993, a.o.), and that [labial] may spread to a neighboring vowel, despite being a consonantal feature. In order to maintain the non-structure-preserving nature of this allophony (i.e. [ɨ, ə] and [ɨ^{b}, ə^{b}] do not constitute contrastive phonemes respectively), one would have to say that [labial], by nature a consonantal feature, is non-contrastive on vowels, and never part of any vowel's underlying representation; it may only spread to a vowel from a neighboring consonant. This account is descriptively adequate: the feature [labial] thus plays exactly the same role as the ⟦.40 round⟧ subfeature advocated for above, without adding any novel representations to the phonological machinery.

However, the distinction between [labial] and [round] vowels seems to be mostly based on convenience, rather than explanatory adequacy. The fact that labial consonants and round vowels pattern together in the doubly triggered rounding harmony is exactly the kind of arguments used elsewhere to argue in favor of considering labial consonants and round vowel as carrying the same contrastive [labial] feature (cf. Unified Feature Theory: Clements 1989, Clements and Hume 1995). What the acoustic measurements show in Laal is a partial level of F2 lowering, and using the feature [labial] and the mostly artificial distinction between [labial] and [round] vowels only dissembles the necessity to recognize and account for such partial effects. Additionally, such a convenient split between two similar features is not available for cases where the two triggers are identical or carry the same feature, e.g. Woleaian (cf. § 4.2.3), Cantonese (cf. § 4.2.1.1), or Acehnese (cf. § 4.2.4.1), which should be amenable to the same analysis as the Laal data presented here.

5.3.2 Not rounding but [+back] harmony

Another possibility is to consider that the doubly-triggered rounding harmony is actually better characterized as a [+back] harmony. Indeed, front vowels do not take part in the harmony – which we have seen involves only [–front] vowels– and rounding and backness are systematically correlated among [–front] vowels: the central vowels are always [–round], and the back ones always [+round]. There is thus a confound: the doubly-triggered harmony may be regarded equally as rounding harmony, or as [+back] harmony.

The advantage of choosing the latter option is that it leaves the feature [+round] available to account for the labial coarticulatory effect on [ɨ] and [ə]. If one analyses labial consonants as carrying a redundant [+round] feature (cf. Ní Chiosáin and Padgett 1993, this feature could be said to spread to neighboring [–front] vowels, making them [-back, +round]: ɨ, ə $\rightarrow$ ʉ, ɵ / B__, __(C)B. All that is left to do is restrict the possible targets of [+back] harmony to [-front, +round] vowels with the same height specification as the trigger vowel: ʉ, ɵ → u, o / __(CC)V[+back, αheight].

This analysis, which seems to render the use of subfeatures unnecessary, would be descriptively adequate if one focused only on the doubly triggered harmony. However, it encounters numerous problems when the simple rounding harmony described in section § 2.3 is considered, which seriously undermines its explanatory power. Firstly, it misses the very interesting similarity between what the subfeatural account treats as two rounding harmonies applying under different conditions in different morphological environments: the doubly triggered one targets ⟦≥.40 round⟧ of same height and backness specification, while the simple one targets [–round] vowels, with no further featural conditioning. But more importantly, by making the vowel inventory more complex, it mischaracterises the simple rounding harmony. As shown in Figure 5.1, the recognition of a featural distinction between [ʉ, ɵ] and [u, o] requires a third feature to account for the now five-way horizontal distinction: [±front] and [±round] are not sufficient anymore, [±back] is also necessary (compare with the inventory in table 2.1 in chapter 2).

+front		*—front*		
i	y	ɨ	[ʉ]	u
e	yo	ə	[ɵ]	o
ia	ya	a		ua
—rd	*+rd*	*—rd*	*+rd*	*+rd*
			—back	*+back*

Figure 5.1: Laal vowel featural specifications in the [+back] account

This vowel inventory and featural analysis make it impossible to characterize the simple rounding harmony as one single process, as shown in (259). Indeed, while the change from [+front] /i, e, a/ to [y, yo, ya] in (259a) can only be characterized as the result of rounding harmony, that from [–front] /ɨ, ə, a/ to [u, o, ua] in (259b) can only be viewed as a case of [+back] harmony, since rounding of these vowels would yield [-front, +round] vowels, i.e. [ʉ, ɵ, ?] (it is unclear what the low vowel in this series –i.e. the rounded version of /a/– would be, since this feature combination is unattested, or at least never realized in the language). Consequently, what appears to be a very simple case of rounding harmony has to be divided into two unrelated processes under the [+back] account (rounding harmony among [+front] vowels, [+back] harmony among [–front] vowels). However, there is no evidence that these are distinct processes, and treating them separately would go against both the economy principle and the human instinct for pattern recognition.

(259) Simple rounding harmony

a. [+front] target: [–round] → [+round]

i → y	/ndììl-ùn/	ndỳỳl-ùn	‘pinch her’
e → yo	/léér-òn/	lyóór-òn	‘wrap her’
ia → ya	/siár-uàn/	syár-àn	‘tear them (neut.) apart’ [10]

b. [–front] target: [–back] → [+back]

ɨ → u	/kɨ́r-ùn/	kúr-ùn	‘place her’
ə → o	/də̀g-òn/	dòg-òn	‘drag her’
a → ua	/dàg-uàn/	duàg-àn	‘drag them (neut.)’

To maintain a unified analysis of the simple rounding harmony within the [+back] account, one could say that vowel rounding has different triggers and targets in different morphological environments. In the environment conducive to the doubly triggered harmony, a vowel may only be rounded by a neighboring labial consonant, and only if it is [–front, –round]: ɨ, ə → ʉ, ɵ. With other affixes, unconditional rounding harmony applies: V_1 is rounded if V_2 is [+round]. In order to explain why this rounding harmony changes /ɨ, ə, a/ into [u, o, ua] and not [ʉ, ɵ, ?], one would have to further stipulate that the vowel inventory of Laal is different in the two morphological environments considered, i.e. that [ʉ] and [ɵ] only belong to the MSC and number marking affixes environment inventory only, and are unattested elsewhere, leaving [+back] [u, o, ua] as the only possible outcome of rounding of /ɨ, ə, a/ in other environments.

To avoid this very unsatisfactory ad hoc solution, one could develop a more abstract analysis, where 1) the simple rounding harmony does apply to all [–round] vowels, i.e. changes /i, e, ia, ɨ, ə, a/ to [y, yo, ya, ʉ, ɵ, ?], and 2) [+back] harmony applies in all morphological environments. Thus, [+back] harmony systematically takes care of changing [ʉ, ɵ, ?] to [u, o, a] in the case of the simple rounding harmony. Simple rounding harmony is thus simple only on the surface, and involves in reality the two different harmonies mentioned above –rounding and [+back]–, as well as an entirely abstract intermediate step in the derivation of back rounded vowels from central unrounded vowels: ɨ → ʉ → u (compare with the one-step i → y change with front vowels). Note that this intermediate step is so abstract that it involves a feature combination that is never attested: the [+round, –back] version of /a/, a necessary step on the way from /a/ to [ua] (a → ? → ua). Additionally, the abstract intermediate inputs to [+back] harmony, [ʉ] and [ɵ], may have two different sources depending on their environment: while the source of [ʉ] in /kɨ́r-ùn/ → kʉ́r-ùn → [kúr-ùn] 'place her' can only be rounding harmony, since there is no labial consonant in the word, in /pɨ́r-ù/ → pʉ́r-ù → [púr-ù] 'catch her', on the hand, it can be either rounding harmony (ɨ → ʉ / __Cu) or spreading of [+round] from the preceding labial consonant (through labial coarticulation: ɨ → ʉ / B__).[11] None of this complexity and abstractness is necessary in the subfeatural account, which offers a simple, intuitive, and straightforward account of both harmonies.

In conclusion, the [labial] and [+back] accounts seem to be uninsightful or unnecessarily complicated solutions whose unique advantage is to avoid adding new representations to phonological theory. However, they only achieve this representational economy at the expense of grammatical simplicity, and more importantly explanatory power. I contend that the new subfeatural representations proposed here offer a simpler and more explanatory account of the Laal data, a criterion I think should be ranked above representational economy in designing a theory. To quote Wright (2004: 34):

> While some would argue that permitting perceptually motivated constraints to play a role in phonological grammar introduces a prohibitive level of complexity into analyses, the (re)introduction of functionally motivated constraints permits the unification of previously disparate analyses, and... reduce[s] the number of ad hoc stipulations and exceptions necessary to capture the pattern.

---

[10] Note that the round vowel /ua/ of the suffix is realized [a], because of the ban against low peripheral vowels in V_2 position (cf. § 2.1).

[11] Cf. the realisation [pɨ́^{b}r] (i.e. [pʉr] in this analysis) of the uninflected verb root /pɨ́r/, as a result of labial coarticulation (see Appendices C and D).

I argue that Wright's reasoning should be extended to perceptually motivated representations as well.

5.4 Other phonetically grounded theories

The idea that coarticulation and its perceptual correlate is relevant for categorical phonology is not new. Two of the most recent theoretical proposals that formalize this insight are Steriade's (2001a-b, 2009) P-map hypothesis and Flemming's (2001, 2002, 2008) theory of auditory representations and unified model of phonetics and phonology. In this section, I compare the theory of subfeatural representations with these two alternative approaches, and show that the theory of subfeatural representations differs from these on three accounts: 1) the proposed architecture of the phonological grammar; 2) the representation of phonetic detail in phonology; 3) the choice of driving phonetically grounded phenomena through Markedness vs. Faithfulness (at least in the OT implementation of subfeatural theory proposed in §§ 3.3 and 3.5).

5.4.1 The P-map hypothesis

Steriade's (2001a-b, 2009) P-map hypothesis holds that some cross-linguistically invariant phonotactic patterns such as assimilation or neutralization depend on the speaker's knowledge of the relative perceptual distinctiveness of certain contrasts in various phonotactic environments. For example, the voicing neutralization that results from final devoicing in a pair like /tæp, tæb/ → [tæp] originates in the fact that the cues to the voicing contrast are much less perceptible word-finally than they are pre-vocalically (Δ(b-p)/__V > Δ(b-p)/__#, where Δ = perceptual distance). This explains why in many languages voiced consonants are prohibited word-finally, but allowed in all other contexts. Likewise, assimilation for a particular feature F is argued to "target positions where the F contrast, if realized, would be less salient." (Steriade 2001a: 222). This hypothesis is supported by a growing body of evidence (e.g. Steriade 2001a-b, 2009; Côté 2004; Fleischhacker 2005; Kawahara 2006; among others).

To implement this idea in OT, Steriade proposes that the phonological grammar be equipped with a "repository of speakers' knowledge, rooted in observation and inference, that certain contrasts are more discriminable than others, and that the same contrast is more salient in some positions than in others..." (Steriade 2001a: 236). This P(erceptual)-map is reflected in the grammar by the projection and ranking of correspondence constraints, whereby faithfulness to the more distinctive contrast is ranked higher, as illustrated in (260) below.

(260) P-map effects on the ranking of correspondence conditions (Steriade 2009: 153)

P-map comparisons	*More distinctive contrast* (e.g. [b]-[m] / V__#	vs.	*Less distinctive contrast* [b]-[p] / V__#)
Ranking of correspondence constraints	*Higher-ranked constraint* (e.g. Ident[±nasal]/V__#	≫	*Lower-ranked constraint* Ident[±voice]/V__#)

The reason why devoicing is almost universally chosen as a repair for word-final voiced consonants in those languages rather than, say, nasalization (e.g. /tæb/ → [tæm]), is that, among all the possible repairs, devoicing is the one that changes the input the least, i.e. that yields an output that is both compliant with the phonotactics, and as similar as possible to the input. Nasalization would be a less optimal repair because the nasality contrast [b]-[m] is much more salient word-finally than that the voicing contrast [b]-[p], since the cues for nasalization are mostly intact word-finally, contrary to the cues for voicing, i.e. Δ(b-m)/__# > Δ(b-p)/__#. Faithfulness to nasality in this context is thus ranked above faithfulness to voicing: Ident[±nasal]/__# ≫ Ident[±voice]/__#. To account for the strong cross-linguistic tendency to repair the phonotactic problem posed by word-final voiced consonants through devoicing, and not nasalization, the markedness constraint *[+voice]/__# simply needs to be ranked higher than Ident[±voice]/__#, but crucially not above Ident[±nasal], as illustrated in the tableau in (261).

(261)

/tæb/	Ident[±nasal]/__#	*[+voice]__#	Ident[±voice]/__#
a. tæb		*!	
☞ b. tæp			*
c. tæm	*!		

5.4.1.1 A P-map account of Woleaian

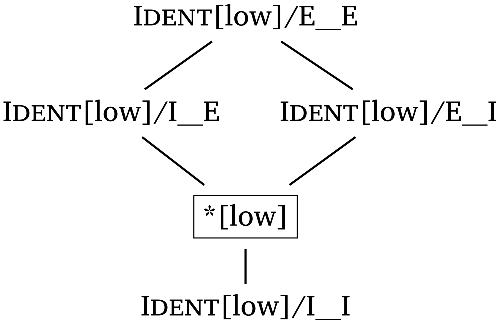
If subphonemic teamwork is indeed, as I argue here, driven by subphonemic effects mostly grounded in the perceptual correlate of coarticulation, a P-map account seems particularly suited. In Woleaian, the P-map contains information about the relative perceptibility of vowel contrasts in various contexts, specifically the perceptual distance between [a] and [e] in the vicinity of high vowels: the more high vowels in its immediate vicinity, the less perceptually distinct [a] is from [e]. This contextual perceptibility scale is represented in Table 5.2, along with the projected correspondence constraint hierarchy ("I" and "E" stand for $V_{[+hi]}$ and $V_{[-hi]}$ respectively).

	Perceptibility scale		Correspondence constraint ranking
	Δ(a-e)/E__E		Ident[low]/E__E
>	Δ(a-e)/I__E Δ(a-e)/E__I	≫	Ident[low]/I__E, Ident[low]/E__I
>	Δ(a-e)/I__I	≫	Ident[low]/I__I

Table 5.2: P-map and projected correspondence constraint ranking in Woleaian

The double-sided assimilation can then be accounted for by ranking the markedness constraint *[low], penalizing the low vowel [a], above Ident[low]/I__I, but below every other constraint in the hierarchy, as shown in (262), and illustrated in tableau (263) below.

(262)



(263)

		IDENT[low] /E_E	IDENT[low] /I_E	IDENT[low] /E_I	*[low]	IDENT[low] /I_I
a. /E-a-E/	☞i. E-a-E				*	
	ii. E-e-E	*!				
b. /I-a-E/	☞i. I-a-E				*	
	ii. I-e-E		*!			
c. /E-a-I/	☞i. E-a-I				*	
	ii. E-e-I			*!		
d. /I-a-I/	i. I-a-I				*!	
	☞ii. I-e-I					*

It is not difficult to see why the optimal change in (263d) is from /a/ to [e] rather than to any other vowel: [e] is perceptually the closest vowel to the partially raised $[{}^{i}a^{i}]$ that the grammar strives to avoid. Changing the vowel to a more perceptually distant vowel such as [i] or [o] would incur greater faithfulness violations, which are omitted in the tableau for convenience.

5.4.1.2 A P-map account of Laal

In the case of Laal, the P-map contains knowledge of the perceptual correlate of labial coarticulation, but also the perceptual similarity or distance between vowels. In essence, the contrast between [ɨ] and [u] (or [ə] and [o]) is more perceptible in $\mathrm{C}{\sim}\_\_\ldots\mathrm{V}_{[-\mathrm{rd}]}$ than in $\mathrm{C}{\sim}\_\_\ldots\mathrm{V}_{[+\mathrm{rd}]}$, where it is in turn more perceptible than in $\mathrm{B}{\sim}\_\_\ldots\mathrm{CV}_{[-\mathrm{rd}]}$, etc. (C = non-labial; B = labial; "B/C∼" = "(near-)adjacent to B or C"). A tentative version of this contextual perceptibility scale is represented in Table 5.3, along with the projected correspondence hierarchy.

With such a fine-grained level of contextual/phonetic detail in the definition of IDENT constraints, the markedness constraint responsible for rounding harmony need only be defined as *[–rd][+rd], without any reference to subphonemic or contextual information. Ranking this constraint above any of the lower constraints in the hierarchy yields various versions of conditional rounding harmony. To account for the Laal doubly triggered rounding harmony, *[–rd][+rd] needs to be ranked above the lowest constraint in the hierarchy, but below the next correspondence constraint up, as in (264).

	Perceptibility scale		Correspondence constraint ranking
	$\Delta(V_{[-rd]}\text{-}V_{[+rd]})/C{\sim}\_\_...V_{[-rd]}$		$\textsc{Ident}[+rd]/C{\sim}\_\_...V_{[-rd]}$
$>$	$\Delta(V_{[-rd]}\text{-}V_{[+rd]})/C{\sim}\_\_...V_{[+rd]}$	$\gg$	$\textsc{Ident}[+rd]/C{\sim}\_\_...V_{[+rd]}$
$>$	$\Delta(V_{[-rd]}\text{-}V_{[+rd]})/B{\sim}\_\_V_{[-rd]}$	$\gg$	$\textsc{Ident}[+rd]/B{\sim}\_\_...V_{[-rd]}$
$>$	$\Delta(V_{[-rd]}\text{-}V_{[+rd]})/B{\sim}\_\_...V_{[+rd,\ \neg\alpha h,\ \neg\beta fr]}$	$\gg$	$\textsc{Ident}[+rd]/B{\sim}\_\_...V_{[+rd,\ \neg\alpha h,\ \neg\beta fr]}$
$>\Big\{$	$\Delta(V_{[-rd]}\text{-}V_{[+rd]})/B{\sim}\_\_...V_{[+rd,\ \alpha h,\ \neg\beta fr]}$ $\Delta(V_{[-rd]}\text{-}V_{[+rd]})/B{\sim}\_\_...V_{[[+rd,\ \neg\alpha h,\ \beta fr]}$	$\gg$	$\textsc{Ident}[+rd]/B{\sim}\_\_...V_{[+rd,\ \alpha h,\ \neg\beta fr]}$, $\textsc{Ident}[+rd]/B{\sim}\_\_...V_{[+rd,\ \neg\alpha h,\ \beta fr]}$
$>$	$\Delta(V_{[-rd]}\text{-}V_{[+rd]})/B{\sim}\_\_...V_{[+rd,\ \alpha h,\ \beta fr]}$	$\gg$	$\textsc{Ident}[+rd]/B{\sim}\_\_...V_{[+rd,\ \alpha h,\ \beta fr]}$

Table 5.3: P-map and projected correspondence constraint ranking in Laal

(264)

$$\begin{tikzcd}
\textsc{Ident}[+rd]C\_\_...V_{[-rd]} \arrow[d, no head] \\
(\ldots) \arrow[d, no head] \\
\textsc{Ident}[+rd]/B{\sim}\_\_...V_{[+rd,\ \neg\alpha h,\ \beta fr]} \arrow[d, no head] \\
\boxed{*[-rd][+rd]} \arrow[d, no head] \\
\textsc{Ident}[+rd]/B{\sim}\_\_...V_{[+rd,\ \alpha h,\ \beta fr]}
\end{tikzcd}$$

The effect of this ranking is to make *[–rd][+rd] active only in the doubly-triggered environment, as illustrated in (265a) vs. (265b-e) below.

(265)

		IDENT[+rd] /C∼ __...$V_{[+\text{rd}]}$	IDENT[+rd] /B∼ __...$V_{[+\text{rd}, \neg\alpha\text{h}, \neg\beta\text{fr}]}$	IDENT[+rd] /B∼ __...$V_{[+\text{rd}, \alpha\text{h}, \neg\beta\text{fr}]}$	IDENT[+rd] /B∼ __...$V_{[+\text{rd}, \neg\alpha\text{h}, \beta\text{fr}]}$	$\boxed{\text{*[–rd][+rd]}}$	IDENT[+rd] /B∼ __...$V_{[+\text{rd}, \alpha\text{h}, \beta\text{fr}]}$
a. /ɓɨ̀rú/	i. ɓɨ̀rú					*!	
	☞ii. ɓùrú						*
b. /ɓə̀rú/	☞i. ɓə̀rú					*	
	ii. ɓòrú				*!		
c. /pílù/	☞i. pílù					*	
	ii. pýlù			*!			
d. /mèn-ú/	☞i. mènú					*	
	ii. myònú		*!				
e. /tílù/	☞i. tílù					*	
	ii. túlù	*!					

To account for the simple rounding harmony described in § 2.3, *[–rd][+rd] simply needs to be ranked higher than all the constraints in the correspondence hierarchy in Table 5.3, as shown in (266). This yields unconditional, systematic anticipatory rounding ($V_{[-\text{rd}]}V_{[+\text{rd}]} \rightarrow V_{[+\text{rd}]}V_{[+\text{rd}]}$), as illustrated in tableau (267).

(266)

$\boxed{\text{*[–rd][+rd]}}$
|
IDENT[+rd]C__...$V_{[-\text{rd}]}$
|
(...)
|
IDENT[+rd]/B∼__...$V_{[+\text{rd}, \alpha\text{h}, \beta\text{fr}]}$

(267)

			*[–rd][+rd]	IDENT[+rd] /C∼ _…$V_{[+rd]}$	IDENT[+rd] /B∼ _…$V_{[+rd, \neg\alpha h, \neg\beta fr]}$	IDENT[+rd] /B∼ _…$V_{[+rd, \alpha h, \neg\beta fr]}$	IDENT[+rd] /B∼ _…$V_{[+rd, \neg\alpha h, \beta fr]}$	IDENT[+rd] /B∼ _…$V_{[+rd, \alpha h, \beta fr]}$
a. /pɨ́r-ù/	i.	pɨ́rù	*!					
	☞ii.	púrù						*
b. /pə̀l-nǔ/	i.	pə̀lnǔ	*!					
	☞ii.	pòlnǔ					*	
c. /bìrw-ùn/	i.	bìrwún	*!					
	☞ii.	bỳrwún				*		
d. /pèr-nǔ/	i.	pèrnǔ	*!					
	☞ii.	pyòrnǔ			*			
e. /ndììl-ùn/	i.	ndììlùn	*!					
	☞ii.	ndỳỳlùn		*				

5.4.1.3 Advantages of the subfeatural approach

To sum up, the P-map hypothesis rests on the general idea that phonological markedness is grounded in detailed phonetic knowledge, here knowledge of contextual distinctiveness (cf. Hayes and Steriade 2004). In Steriade's (2009) model, this phonetic knowledge is referred to by faithfulness rather than markedness constraints: P-map perceptibility scales are projected onto very fine-grained faithfulness constraint hierarchies, which interact with very simple and general markedness constraints that do not refer to phonetic knowledge (at least not explicitly), e.g. cf. Steriade's (2009) *[+voice]_#, or *[low], and *[–rd][+rd] in the analyses proposed above.

The subfeature-based analysis of subphonemic teamwork I propose in chapter 3 aims to formalize the same intuition, but implements it in exactly the opposite way: detailed phonetic knowledge is mapped onto fine-grained, phonetically grounded MARKEDNESS constraints and hierarchies, which interact with very general faithfulness constraints that make no reference to phonetic information (e.g. IDENT[rd]). The markedness hierarchy proposed in chapter 3, repeated in (268) below, is in fact, *mutatis mutandis*, the inverse of the P-map correspondence constraint hierarchy in Table 5.3 above.

(268) Subfeatural markedness constraint hierarchy (subfeature-based account):

$$\begin{tikzcd}[column sep=tiny]
& {*\llbracket \geq .40\ \textsc{rd}\rrbracket\llbracket 1\textsc{rd}\rrbracket/[+\text{syll}, \alpha\text{height}, \beta\text{front}]} \arrow[d, dash] & \\
& \boxed{\textsc{Ident}[\text{rd}]} \arrow[dl, dash] \arrow[dr, dash] & \\
{*\llbracket \geq .40\ \textsc{rd}\rrbracket\llbracket 1\textsc{rd}\rrbracket/[+\text{syll}, \alpha\text{height}]} \arrow[dr, dash] & & {*\llbracket \geq .40\ \textsc{rd}\rrbracket\llbracket 1\textsc{rd}\rrbracket/[+\text{syll}, \beta\text{front}]} \arrow[dl, dash] \\
& {*\llbracket \geq .40\ \textsc{rd}\rrbracket\llbracket 1\textsc{rd}\rrbracket/[+\text{syll}]} &
\end{tikzcd}$$

As seen, the division of labor between markedness and faithfulness is reversed in the subfeature-based account, and, consequently, so is the ranking of the perceptually grounded constraints. In both cases, the structure in which the rounding contrast is the least perceptually distinct — [ɨ^{b}...u] or [ə^{b}...o]— is very unlikely to surface faithfully. But the rationale behind this low likelihood is different in both cases. In the P-map account, it is because this structure is only very weakly protected —i.e. protected only by the lowest faithfulness constraint in the hierarchy— that it is most likely to be penalized by a higher-ranked general markedness constraint (e.g. *[–rd][+rd] in Laal). In the subfeature-based account, this structure is analyzed as highly marked —it is penalized by the highest constraint in the markedness hierarchy—, and is thus very unlikely to be protected by a higher-ranked faithfulness constraint. In both cases, the "determining" constraint is ranked between the constraint referring to the least perceptually distinct structure and the rest of the hierarchy: in the P-map account, *[–rd][+rd] is ranked immediately above the lowest constraint in the faithfulness hierarchy in (266); in the subfeature-based account, Ident[rd] is ranked immediately below the highest constraint in the markedness hierarchy in (268).

One consequence of the choice of having phonetically grounded markedness rather than faithfulness constraints is an increase of the number of markedness constraints necessary to account for the two rounding harmonies of laal. In the P-map account, as we just saw, one markedness constraint (*[–rd][+rd]) is sufficient to account for both rounding harmonies. The difference between the two harmonies is simply accounted for by a different ranking of this markedness constraint with respect to the correspondence constraint hierarchy, as we saw in (266) and (267) above. In the subfeatural account, on the other hand, two separate markedness constraints are needed ($*\llbracket \geq .40\ \textsc{rd}\rrbracket\llbracket 1\textsc{rd}\rrbracket/[+\text{syll}, \alpha\text{height}, \beta\text{front}]$ and *[–rd][+rd]/[+syll]), which are part of a markedness constraint hierarchy.[12] Although this might make faithfulness-grounding seem more elegant and economical, it does not seem to be problematic to use two separate markedness constraints to refer to two separate marked structures. The /ɨ...u/ sequence in /ɓɨ̀r-ú/ (or rather its hypothetical realization [ɓɨ^{b}rú]) and the /i...u/ sequence in /ndììl-ún/ are indeed not marked for the same reasons: the former is perceptually marked, as we saw, while the markedness of the latter is presumably not phonetically grounded but results from the context-independent application of categorical anticipatory rounding harmony.

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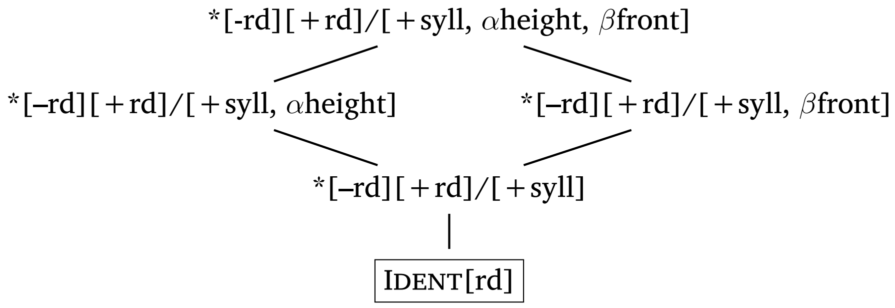
[12] As for the two markedness constraint hierarchies used in the subfeatural account, repeated in (268) above and (269) below, they can be considered to be sub-parts of one and the same markedness hierarchy referring to the rounding similarity scale in Laal.

(269) Featural markedness constraint hierarchy (subfeatural account):



Having markedness rather than faithfulness constraints refer to phonetic knowledge has three advantages. First, it is in keeping with the general foundational idea of phonetically based phonology that "the source of markedness constraints as components of grammar is [phonetic] knowledge" (Hayes and Steriade 2004: 1).

Second, it involves only a minor change in the architecture of the phonological grammar, namely the addition of a parallel set of phonetic knowledge representations that markedness constraints can refer to (cf. Figure 3.2 in § 3.4.3), without questioning the Richness of the Base principle (Prince and Smolensky 1993). Having faithfulness refer to phonetic knowledge, on the other hand, leads to a complexification of the architecture of phonology, and challenges Richness of the Base, as we will see in the next section.

Finally, the theory of subfeatural representations is similar to the P-map in so far as it is a theory of the architecture of phonology (cf. Figure 3.2 in § 3.4.3), but, unlike the P-map, it is also a theory of representations. In the P-map hypothesis, phonetic knowledge is not represented. It is only referred to by faithfulness constraints. Subfeatures, on the other hand, are a representation of phonetic knowledge. In that sense they constitute a reification of the P-map. We will see in the next section why this might be advantageous.

5.4.1.4 Representing phonetic knowledge: the Inferred/Realized Input

Flemming (2008) shows that one of the main issues in the formal implementation of the P-map hypothesis is the representation of language-specific phonetic detail. He argues that a theory of the implementation or representation of phonetic knowledge is necessary, because the ranking and evaluation of P-map constraints depend on it. For example, the degree to which the voicing contrast is less perceptible in word-final position, as in [tæb] vs. [tæp], depends on the language-specific realization of word-final consonants. In French, for example, prepausal stops are released, which is likely to make this contrast more robust than in languages like Korean, where word-final consonants are consistently unreleased before pause (Flemming 2008: 1, and references therein).[13]

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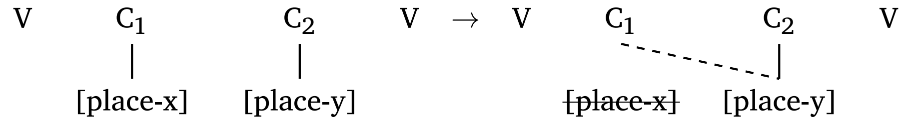
[13] Steriade (2009: 178) herself defines her hypothesis as a "first approximation" that needs to be further developed to account for non-universal aspects of perceptual similarity: "I have focused here on aspects of perceived similarity that correspond to broad crosslingustic generalizations, and for this reason it may appear that a claim of universality is made regarding the contents of the P-map. This is not the intention. If the perception of similarity is governed, in part, by 'the contents of the universe of discourse' (Tversky, cited in Frisch et al. 1997), the same pairs of sounds will rate differently for similarity, when embedded in different systems. The existence of such effect is not denied; the development of a first-approximation version of the P-map will hopefully make it possible to identify them."

Using consonant-place assimilation as a case in point, Jun (1995, 2002, 2004) shows that a P-map approach runs into the problem of language-specific phonetic detail, in this case the presence vs. absence of stop release. He observes that major place assimilation is cross-linguistically nearly always from C_1 to C_2, very rarely (and usually under strict morphological conditions) in the other direction, as schematized in (270) below.

(270) C-place assimilation



This typological observation is easily explained by the contextual differences in the phonetic realization of consonants. Perceptual cues to C-place are indeed universally stronger pre-vocalically, where consonants are always released and impose clear formant transitions on the following vowel, than pre-consonantally, where these perceptual cues are less audible or absent. In a P-map account, this asymmetry is naturally accounted for by a universal ranking of faithfulness constraints referring to the perceptibility of C-place auditory cues, as illustrated in (271):

(271) IDENT(place)/C__V ≫ IDENT(place)/V__C

Assimilation targeting pre-consonantal consonants and not pre-vocalic ones is then simply obtained by ranking the constraint responsible for consonant assimilation (e.g. AGREE(place), or $^*C_{[\text{place–x}]}C_{[\text{place–y}]}$) between these two faithfulness constraints.

Jun shows that this analysis of consonant assimilation asymmetries grounded in universal perceptual factors is insufficient. The cues that the constraints in (271) need to refer to are indeed not the same across languages: in some languages such as Arabic, Hindi, or Russian, C_1 is released before the constriction for C_2 is formed, while in other languages (e.g. Catalan, Korean, or English), it is not. As Jun shows, this difference is crucial, since only languages where C_1 is unreleased show C_1 assimilation, i.e. released consonants are immune to assimilation. The P-map faithfulness constraints in (271) must thus be able to refer to the presence vs. absence of stop release, i.e. language-specific phonetic information. This is highly problematic in OT, where the only level of representation that constraints may refer to is the input, which, by virtue of the Richness of the Base principle (Prince and Smolensky 1993), cannot be restricted to forms including language-specific phonetic information. Such information is only available in the output of the phonological grammar (EVAL, the entire set of constraints), i.e. too late for this information to be accessible to EVAL.

Consequently, once one accepts the core insight of the P-map hypothesis that phonological computation is sensitive to subphonemic effects belonging to language-specific phonetic knowledge, one needs to find a solution to the issue of both the representation of that phonetic knowledge, and the principles governing its interactions with the phonological grammar.

This can be done in several ways. Flemming (2008), building on Steriade (1997), Jun (2002), and Gallagher (2007), proposes to add an intermediate level of representation containing phonetically detailed information, which constitute the input to the phonotactic grammar. "There are three representations, the Input, the Realized input,[14] and the Ouptut, with three associated components of the phonology: the Inventory, Phonetic Realization, and the Phonotactics. All draw upon a single ranking of constraints, but only a subset of constraints are applicable in any given component." This architecture of phonology is schematized in the diagram on the left of Figure 5.2. The table on the right summarizes the division of constraint application between components, with ✔ marks indicating which constraints are applicable in which component.

	Markedness constraints					**Correspondence constraints**	
	Distinctiveness c.	Segment-internal markedness c.	Context-sensitive articulatory c.	Prosodic c.	Other Markedness c.	Cue realization c.	P-map c.
'Rich base'							
Inventory	✔	✔					
Input							
Phonetic Realization		✔	✔	✔		✔	
Realized Input							
Phonotactics	✔	✔	✔	✔	✔		✔
Output							

Figure 5.2: Structure of the phonology according to Flemming (2008)

The input to the phonotactic grammar —the Realized Input— is thus severely restricted in a two-step process. Constraints on distinctiveness (cf. Flemming 1995, 2001, 2002) and segment-internal markedness impose a first restriction on the infinitely rich base by allowing only input sequences drawn from the language-specific inventory. This inventory-compliant set of inputs is then fed to the Phonetic Realization component, which operates a second restriction, through Cue Realization constraints enforcing the expected realization of the contextual perceptual targets of the input segments (e.g. resulting from coarticulation). As a result, the inventory-compliant input is mapped onto a Realized Input, defined as "the expected phonetic realization of the input segment sequence" prior to the application of categorical phonotactic rules such as neutralization,

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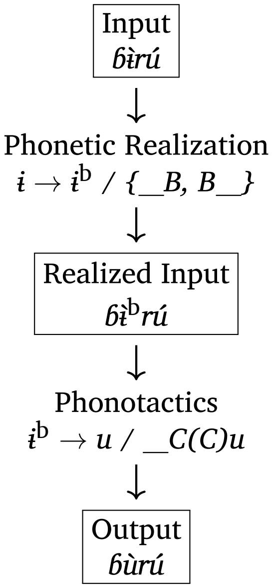
[14] The term "Realized Input" was first used by Gallagher (2007); the idea of a hypothesized realization of the input prior to the application of phonotactic constraints was first proposed by Steriade (1997) under the label "inferred input", which is also the term that Jun (2002) uses.

assimilation etc. It is this Realized Input that is then fed to the phonotactic grammar, which includes P-map correspondence constraints such as the ones in (271) above.

In a Realized-Input account of the Laal doubly triggered rounding harmony, labial coarticulation applies first (e.g. *ɓɨ̀rú* → *ɓɨ̀*$^{\text{b}}$*rú*), and only the fully coarticulated form of the input (the Realized Input *ɓɨ̀*$^{\text{b}}$*rú*) is then fed to the phonotactic component enforcing coarticulation-sensitive rounding harmony (*ɓɨ̀*$^{\text{b}}$*rú* → *ɓùrú*). This is summarized in (272) below, where the effects of each component are represented as rules.

(272)



The major difference with the theory of subfeatural representations and the architecture of phonology proposed in Figure 3.2 in § 3.4.3.1 is that only inputs are subject to this pre-phonological phonetic interpretation in Flemming's system. The necessity to include phonetic information in the input comes from the fact that, like in Steriade's original hypothesis, phonetically grounded processes are driven by faithfulness, i.e. by the degree of faithfulness of the output to this phonetic information. Indeed, faithfulness constraints have to refer to the input in order to evaluate how much the output differs form it. They can thus only refer to categories that are present in the input. In classic OT, this means phonological categories such as segments, binary features, etc. —but not phonetic information, which is by definition absent form the input. The Realized Input component that Flemming proposes to add to the phonological architecture is thus made necessary by the fact that phonetically grounded phenomena are analyzed as being faithfulness-driven. Markedness constraints, on the other hand, only refer to the output: they can therefore refer to any phonological representations that exist in the grammar, including subfeatural phonetic representations stored in phonetic knowledge. No restriction on the input is thus necessary in the OT-implementation of the theory of subfeatural representations I propose in § 3.3, which is crucially driven by markedness constraints. The input is pre-phonetic, and the predicted coarticulated phonetic realization is enforced by high-ranked markedness constraints belonging to language-specific phonetic knowledge. Richness of the Base is thus not a problem for this theory, which is closer to classic OT, with the addition of phonetic representations stored in phonetic knowledge that Markedness constraints can refer to. As a result, markedness —both typological and language-specific— is grounded in phonetic knowledge —in accordance with the main intuition of phonetically grounded phonology— and phonetically grounded processes such as subphonemic teamwork are entirely markedness driven.

5.4.2 Flemming's (1995, 2002) auditory representations

I have shown above, following Jun (1995, 2002, 2004) and Flemming (2008), that a representation of phonetic knowledge such as the subfeatures I propose here is advantageous. However, similar representations have already been proposed, notably by Flemming himself, in his 2002 dissertation, in which he develops a theory of Auditory Representations in a model that conflates phonetics and phonology (see also Flemming 2001). The two approaches are however not equivalent, as I show below.

In order to account for phonological phenomena that appear to be driven by auditory factors (including self-additive teamwork cases such as Woleaian, Cantonese and Acehnese), Flemming (2002) proposes to equip phonology with fine-grained, scalar representations that "include all auditory properties of sound relevant to phonological patterning" (p.17). Sounds are represented as "located in a multi-dimensional auditory space." A list of such dimensions is given in (273) below.

(273) Examples of scalar auditory dimensions (Flemming 2002: 17):

Formant Frequencies (F1, F2, F3):	Frequencies of formants
Noise Frequency:	Frequency of first peak in noise spectrum
Diffuseness:	Diffuseness of noise spectrum
Noise Loudness:	Loudness of noise in the spectrum
Loudness:	Overall loudness
VOT	Voice Onset Time

As seen, Flemming's auditory categories are defined in acoustic terms."Given the definitions offered here, most of these dimensions could be regarded as acoustic rather than auditory. The representations are labeled as auditory to emphasize the fact that it is distinctiveness to the human ear that is relevant to language" (Flemming 2002: 17). Consequently, between acoustic and auditory representations, only the values differ. For example, (actual, physical) acoustic vowel formant values are measured in Hz, while relative auditory formant values are determined along a *n*-point scale (*n* being language specific), as illustrated in (274) with arbitrary 5-point scales.

(274)

F1		F2		F3	
1	i	1	u	1	ɹ
2	ɪ	2	ɯ	2	
3	e	3	ɨ	3	u, y
4	ʌ	4	y	4	ɯ, a
5	a	5	i	5	i

Segments are thus not phonologically defined with traditional binary features, e.g. as in (275a), but only with scalar auditory features, e.g. as in (275b).

(275) a. $$[\text{i}] = \begin{bmatrix} +\text{high} \\ -\text{low} \\ +\text{front} \\ -\text{back} \\ -\text{round} \end{bmatrix}$$

b. $$[\text{i}] = \begin{bmatrix} \text{F1 } \mathit{1} \\ \text{F2 } \mathit{5} \\ \text{F3 } \mathit{5} \end{bmatrix}$$

Two major differences with subfeatural representations appear here: 1) subfeatures are more remote from acoustics, and in closer relation with phonological features, and, relatedly, 2) the theory of subfeatural representations does not abandon traditional binary features or the separation between phonology and phonetics.

Regarding the first point, subfeatures are meant, just like Flemming's auditory representations, to be a representation of perceptual information. However, no reference to acoustics is necessary: phonetic knowledge is represented *as it relates to* phonological information/knowledge, specifically information about contrast, i.e. phonological features. The acoustic correlate of subfeatures is not at issue here, and does not need to be represented. The acoustic correlate of a subfeature is defined as a bundle of perceptual properties, e.g. both [±round] and ⟦*x* round⟧ refer to relative F2 and F3 values. There is no need to represent both F2 and F3. It is the combination and co-variation of the two formants that is important here: they form one complex property, vowel rounding, which, in the subfeatural system, is represented by one and only one symbol: ⟦round⟧.

Phonetic knowledge, where subfeatures belong, is defined as phonologized knowledge of phonetic detail (not just a filtered selection of raw phonetic information), i.e. it consists of aspects of phonetic realization that are relevant to phonology. It is thus defined as a relation between phonological and phonetic properties and patterns. This relation is encoded in the subfeatural representations themselves. In that sense, subfeatures are both substantially related and subordinate to classic features, and they do a better job at showing their "relevan[ce] to phonological patterning" (Flemming 2002: 17). E.g. ⟦0.40 round⟧ is defined with respect to [±round], in so far as it is a representation of the unconscious knowledge the Laal speaker has that whenever the [–round] vowels /ɨ, ə/ are coarticulated with a labial consonant, they sound have a 40% of the perceptual and articulatory properties that characterize [+round] vowels, despite being phonologically [–round] (i.e. they are [–round] vowels that sound a little round).

Relatedly, the other main difference between Flemming's representations and mine originates in a different view of the architecture of phonology, the relation between phonetics and phonology, and the nature of phonological representations. Flemming proposes a unique model where phonetics and phonology are conflated (see in particular Flemming 2001). One of the consequences of Flemming's choice is that he completely does away with traditional binary (or privative) phonological features, arguing that they are unnecessary in a model that allows for detailed phonetic representations. The only representations are thus phonetic, and the role of the former phonological features —notably the representation of phonological contrast— is transferred onto phonological constraints that refer to these phonetic representations.[15] Phonological contrast is not accounted for by positing phonological features, but by drawing dividing lines across

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[15] "In dispersion theory, well-formed contrasts are selected from a wide range of representational possibilities by

the phonetic space through the evaluation of inviolable constraints on perceptual distinctiveness (MAXIMIZE-CONTRASTS and MINDIST) and articulatory effort. The number of contrasts in a language depends on the fine-tuning and ranking of these constraints, that is, on the accepted minimal distinction on a certain auditory dimension, given a certain accepted level of articulatory effort.

The theory of subfeatural representations I propose, on the other hand, keeps phonology and phonetics separate, simply allowing phonology to have access to phonetic information through abstract representations of phonetic knowledge. It does not abandon traditional phonological representations, but refines and improves them by subdividing features in order to represent subphonemic, "in-between" categories. The result, as we saw, is not just scalar phonological features (e.g. [0...0.40...1 round] in Laal, or [0...x_1...x_2...1...2 high] in Woleaian), but a two-tier featural system, with contrastive phonological categories defined by coarse-grained features (most of the time binary, e.g. [±round], sometimes ternary, e.g. [1...2...3 high]), and fine-grained, scalar subcategories within each of these featural categories, defined by subfeatures, subordinate to features (e.g. ⟦0...0.40...1 round⟧ or ⟦0...x_1...x_2...1...2 high⟧).

Flemming's (2002: 156) critique of representational approaches to contrast rests on three main points:

1. Its lack of explanatory power: restricting contrasts by stipulating how many features a language has and how many values those features may have (e.g. [nasal] can only binary) fails to explain why and how those restrictions arise (e.g. a three-way contrast in nasality would be both articulatorily difficult to produce and nearly impossible to perceive).

2. Its lack of economy: many restrictions on contrast that have to be posited in a featural model are actually unnecessary, since their goal is to exclude physically impossible or unlikely contrasts or feature combinations.

3. Its lack of descriptive power: a single set of features is insufficient to formulate all phonological generalizations or rules: non-featural properties like syllabification are also needed, as well as subphonemic (non-contrastive) segmental properties like presence vs. absence of audible release on stops.

However, what is at fault here is the stipulative character of the theory, not the representations it uses. One can have a fully explanatory, phonetically based theory of contrast, and still use phonological features as a handy representation of these contrasts, i.e. get rid of the stipulation, not of the representations. This is what a model like Archangeli and Pulleyblank's (1994) *Grounded Phonology* does.

The question of how contrast should be explained and accounted for in phonology falls outside the purview of this dissertation. I accordingly remain agnostic on that issue. The theory I propose keeps phonological features as a representation of phonemic contrast and other categorical phonological phenomena such as allophony, and adds fine-grained representations of non-contrastive, subphonemic distinctions, grounded in phonetic knowledge, that are relevant to phonological computation. The distinction between the two rounding harmonies of Laal —doubly triggered (cf. § 2.2) vs. simple (cf. § 2.3)— is a good illustration of how useful it is to allow phonology access to both types of representations.

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constraints on contrasts. Restrictions on contrast are thus accounted for in terms of the theory of constraints rather than the theory of representations." (Flemming 2002: 155)

5.5 Conclusion

In this chapter, I have shown that all grammar-driven accounts fail to predict the partial effects and "in-between", subphonemic categories at work in subphonemic teamwork. The strength of the theory of subfeatural representations theory is that it does predict such effects.

I have also shown that accounts of such partial effects using only classic, binary features have less explanatory power than the subfeatural account, mainly because of the amount of stipulation that they involve.

Steriade's (2009) P-map approach is closer to the mark, but fails to give phonetic knowledge the representations that it needs, and counterintuitively drives perceptually grounded phonological phenomena through faithfulness rather than markedness. Subfeatural theory both provides specific representations of phonetic knowledge (a reification of the P-map), and the OT implementation proposed in chapter 3 accounts for perceptually grounded phonemomena through markedness rather than faithfulness which 1) is more in keeping with the basic intuition of phonetically grounded phonology, and 2) is more easily implemented in an OT grammar, since it does not question Richness of the Base.

Finally, Flemming's auditory representations can only be considered advantageous if one abides by Flemming's conflation of phonetics and phonology into one single model, which I do not. The subfeatural representations that I propose are both closer and subordinate to classic phonological features, which is a good illustration of the nature of phonetic knowledge: abstract knowledge of the conditions of production and perception of the sounds of a particular language, in relation to the phonological system of that language.

Chapter 6

Conclusion

6.1 Summary

This dissertation, proposed a new theory of subfeatural representations to account for phonetically grounded subphonemic teamwork, on the basis of instrumental evidence provided by a detailed case study, and of a preliminary survey of 52 cases of subphonemic teamwork.

Chapter 2 described the Laal doubly triggered rounding harmony —a case of subphonemic enabling— and provided evidence that it is driven by a subphonemic, partial coarticulatory effect, i.e. it is phonetically grounded.

Chapter 3 proposed a representational approach to this phonetic grounding, by giving abstract phonetic knowledge dedicated scalar representations, SUBFEATURES, that can be referred to by phonological computation. The phonological feature system is thus refined into a two-tier system where contrastive featural categories can be subdivided into subfeatural categories representing non-contrastive, but perceptually distinct categories resulting from coarticulation. These subfeatural representations belong in phonetic knowledge, i.e. abstract knowledge about the (expected) contextual realization of the sounds of a given language. The role of this abstract knowledge is to mediate between phonetics and phonology, which are kept separate in a system that allows them to communicate. To quote Pierrehumbert (1990: 375):

> Both phonology and phonetics are necessary to understand language as a means of communication between people. If phonology is not related to phonetics, it models the mind of a solipsistic isolate. If phonetics is not related to phonology, it models noises and gestures to which no meaning or category structure can be assigned. A theory encompassing phonology, phonetics and their relation to each other is needed as a foundation for a theory of language processing and language acquisition. It is also needed for a model of historical sound changes, which typically originate in subphonological aspects of pronunciation and which are only of interest as they become shared in the speech community.

The theory of subfeatural representations and the architecture of the phonological grammar that it rests on, is a theory of the relation between phonology and phonetics: subfeatural representations of phonetic knowledge are one way in which phonetics may influence categorical phonology.

In chapter 4, I enlarge the empirical scope of the theory to 52 cases of subphonemic teamwork found in 42 typologically, geographically and genetically diverse languages. Two main types of teamwork are identified: ADDITIVE TEAMWORK, where two or more partial subphonemic coarticulatory effects team up to trigger a categorical assimilation, and SUBPHONEMIC ENABLING, where one subphonemic coarticulatory effect feeds an otherwise categorical phonological process. Additive teamwork can be further categorized into three subtypes: SELF-ADDITIVE, where the two (or more) coarticulatory effects at work are the same, i.e. involve the same articulatory and perceptual effects; MUTUALLY-ENHANCING, where the two or more subphonemic effects involved are articulatorily different, but perceptually similar; and COINCIDENTAL, where the two effects involved are articulatorily and perceptually different, but team up nonetheless to trigger a categorical effect. 16 cases out of the 52 listed in the typology are then described in detail, illustrating each of the four (sub)types of subphonemic teamwork, and each of the properties and processes attested in all 52 cases. They are shown to be compatible with the predictions and analytical power of the theory. One of the main conclusions that can be drawn from this typology is that subphonemic teamwork is typically triggered by consonants, and typically targets vowels. This asymmetry confirms the well-foundedness of a representational approach to inter-segmental interactions. Subphonemic teamwork is also shown to question both the strict separation between phonetics and phonology, and the distinction between lexical and postlexical phonology, since it seems to apply at both levels.

Finally, chapter 5 showed the advantages of the theory of subfeatural representations over alternative theories of various kinds. It showed that substance-free, grammar-driven theories such as Nevins's (2010) Search-and-Copy theory of vowel harmony, or cumulative constraint interaction modeled either through Local Constraint Conjunction or Harmonic Grammar, fail to account for the partial effects that drive subphonemic teamwork. Accounting for such effects using only classic binary features was then shown to be feasible, but at the expense of explanatory power and grammatical simplicity. Finally, other phonetically grounded approaches such as Steriade's (2009) P-map or Flemming's (2002) theory of auditory representations pose problems that are avoided in the theory of subfeatural representations, notably the failure to represent phonetic knowledge and the counterintuitive driving of perceptually grounded phonological phenomena through faithfulness constraints (P-map), and a radical remodeling of the architecture of phonology collapsing phonetics and phonology (Flemming), which is unnecessary in subfeatural theory, where phonetics and phonology are kept separate, with the possibility to communicate through phonetic knowledge.

6.2 Future directions

The research and theory presented in this dissertation are to a large extent at a preliminary stage. In the last few lines, I would like to hilghlight several directions to explore in future research.

6.2.1 The typology of subphonemic teamwork

One priority, on the empirical side, would be to enlarge the typology of subphonemic teamwork, by gathering more cases from more languages. This would doubtlessly lead to a refinement of the typological characterization of subphonemic teamwork, which in turn might have consequences for its theoretical analysis, and might lead to a refinement of the theory proposed here.

Another one is to test the predictions or assumptions made here, in particular the alleged presence and role of partial coarticulatory effects in languages for which no measurements were available for this dissertation.

6.2.2 The theory of subfeatural representations

As for the theory itself, two main priorities can be set forth for future research. Firstly, more work is needed on the exact implementation of subfeatural representations. This is related to the need for more precise instrumental data just mentioned. For example, a precise quantification of the subphonemic effects involved in such complex cases as Taa double-sided fronting and raising (§ 4.2.2.2) or Fe'fe' Bamileke multiple-trigger grave assimilation (§ 4.3.2) can only lead to an improved understanding of how to define and implement subfeatural distinctions.

Secondly, one must look into enlarging the scope of subfeatural representations. What else, beyond subphonemic teamwork, can subfeatures, or similar representations, be useful for? Because they represent non-fine-grained, non-contrastive properties, subfeatures show promise for tackling the issue of categories that seem to be "intermediate between contrast and allophony" (Hall 2013: 215), e.g. quasi-phonemic contrast (Scobbie and Stuart-Smith 2008; Kiparsky 2013; Kavitskaya 2014; a.o.), covert contrast (Macken and Barton 1980; Maxwell and Weismer 1982; a.o.), incomplete neutralisation (Dinnsen and Garcia-Zamor 1971; Port, Mitleb, et al. 1981; Port and O'Dell 1985; Slowiaczek and Dinnsen 1985; Charles-Luce and Dinnsen 1987; a.o.), near-mergers (Labov et al. 1991, Labov 1994, or phonetic analogy effects (Steriade 2000), which are still a problem for phonological theory.

6.2.3 The theory of the phonetics-phonology interface

As we saw, the theory of subfeatural representations is both a theory of representations and a theory of the structure of the phonological grammar. In particular, it is a theory of the phonetics-phonology interface: subfeatures are a representation of abstract phonetic knowledge, which mediates between abstract, categorical phonology and concrete, gradient phonetics. Phonetic knowledge has been considered one of the building blocks of phonetically grounded phonology for many years now (cf. Hayes and Steriade 2004). More research is needed, as pointed out by Flemming (2008), both on its detailed characterization (what's in it? what isn't?), and on its implementation. The theory proposed here is a preliminary step toward a more precise theory of the structure and role of phonetic knowledge in phonology.

6.2.4 Representational adequacy in phonology

Finally, I think that phonological theory would greatly benefit from reacquainting itself with the important question of representational adequacy. Since the advent of Optimality Theory more than twenty years ago, most phonologists have stopped working on phonological representations, taking classic representations such as segments or binary features for granted.

I hope to have shown in this dissertation that phonology has a lot to gain from refining the representations that it uses, instead of continuing to rely on coarse-grained, non-granular representations such as binary features and segments. The theory of subfeatural representations highlights the importance of representing phonemes and segments in their realizational context, thus questioning the very definition of what a phoneme or a segment is. In this sense, it is akin to recent proposals such as Q-theory (Shih and Inkelas 2014, Inkelas and Shih to appear), where each consonant and vowel is subdivided into three temporally ordered subsegments, which can be independently targeted by assimilation processes. Investigating possible ways of combining subfeatures and subsegments seems like a promising research avenue.

To quote Janet Pierrehumbert (1990: 392) once again: “we cannot arrive at a full understanding of language sound structure with the representations we have; it will be necessary to develop new ones all the time as we address different issues.” The theory of subfeatural representations proposed in this dissertation is meant to be an invitation to go further in this direction, and put the question of representational adequacy back at the heart of theoretical debate in phonology.

Appendix A

ə-words included in the Laal study (AK)

Condition				Wordlist		
ə(ə)	**20**	ə	12	gə̀gɨ́ny	2	‘disagree’
				gə̄rī	2	‘tree sp. (pl)’
				nə̀rə́l	2	‘my son’
				lə̀r	3	‘wait’
				tə̀grə̀	3	‘sieve (gerund)’
		əə	8	ə́ə́r	2	‘coals’
				ndə́ə́r	2	‘skull’
				ndə́ə́rə̀l	4	‘my skull’
B	**101**	Bə	50	mə̀g	1	‘lower back’
				pə́grí	1	‘think of me (associative)’
				pə̄nàr	1	‘his nose’
				bə̄rī	2	‘back’
				mə̀l	2	‘be straight’
				mə̀lí	2	‘tongues’
				pə́d	2	‘pass’
				pə̀gyə́l	2	‘quarrel’
				pə̄nà	2	‘your nose’
				bə̀g	3	‘mat sp.’
				ɓə̀glə̀l	3	‘my head’
				ɓə̀nə̀	3	‘glue (gerund)’
				mə̀lə̀l	3	‘my tongue’
				pə́grə́n	3	‘think of me’
				ɓə́l	4	‘not yet’
				ɓə̂n	4	‘glue, stick’
				pə̄nì	4	‘my nose’
				ɓə̀	5	‘head (genitive)’
		BəB	3	mə̀mlə̀l	3	‘my grand-child’
		Bəə	27	mə̀ə̀gə́	2	‘tamarind (pl.)’
				bə̀ə̀r	3	‘my father’

				mə̀ə̀rní	3	‘curse me (associative)’
				mə̄ə̄r	4	‘river’
				pə̄ə̄l	5	‘village’
				bə̄ə̄g	10	‘shoulders’
		BəəB	2	mə̀ə̀mə̀r	2	‘my grand-mother’
		əB	13	gə́m	1	‘fish sp.’
				gə̀m	2	‘fever’
				nə̀m	3	‘my brother’
				tə́bí	3	‘tell’
				kə́m	4	‘fish sp. (pl)’
		əəB	5	kə̀ə̀mə́	2	‘tree sp. (pl)’
				tə́ə́mə̀r	3	‘my cheek’
		əlm	1	ŋgə́lmə́	1	‘tombs’
U	**7**	ə-U	6	sə̀gó	1	‘tree sp. (pl)’
				də́nù	5	‘tree sp. (pl)’
		əə-U	1	ə́ə́rù	1	‘sauces’
BU	**9**	Bə-u	3	pə̄nùg	1	‘her nose’
				pə̄nùrú	2	‘our noses’
		Bəə-u	5	ɓə̀ə̀rú	1	‘orphans’
				bə́ə́gú	2	‘ostriches’
				mə̀ə̀gú	2	‘tamarind (pl.)’
		əBu	1	tə̀bú	1	‘fish sp. (pl)’
W	**23**	əəw	4	kə́ə́w	1	‘fingernails’
				kə́ə́wə̀r	1	‘my fingernails’
				gə̀ə́w	2	‘wings’
		əw	18	sə̀wí	1	‘horns’
				tə̀wlə̀l	1	‘my breast’
				də̌w	2	‘henhouse’
				gə̀w	2	‘monkey sp.’
				gə́wrə́l	2	‘snail’
				kə̀w	2	‘body’
				kə̀wə̀n	2	‘eat me’
				lə̄wə̄l	2	‘clay’
				sə̀wə́l	2	‘this year’
				tə̀wí	2	‘breasts’
		wə	1	wə̂l	1	‘oath’
BW	**12**	Bəəw	3	bə̀ə̀wə̀r	3	‘my grand-father’
		Bəw	9	mə̀wrì	1	‘rams’
				pə́wə̀r	1	‘my friend’
				bə́wə̀n	2	‘stroke me’
				mə̄wrə̄l	2	‘ram’
				bə́wní	3	‘stroke me (associative)’
BWU	**3**	Bəw-u	2	pə̂wrú	2	‘our friend’
		Bəwo	1	mə́wó	1	‘scorpions’

WU	**9**	əwo	7	sə́wò	1	‘warthogs’
				tə́wó	1	‘shields’
				gə́wò	2	‘hunters’
				sə̄wō	3	‘fish sp. (pl)’
		ərwo	2	sə́rwò	2	‘turtles’

Appendix B

ə-words included in the Laal study (KD)

Condition		Wordlist				
ə	**10**			dərə́l	5	‘fish sp.’
				lə̀r	2	‘traps sp.’
				də̀gə́n	2	‘drag me’
				gə̄rī	1	‘tree sp. (pl)’
B	**42**	Bə	12	ɓə̂n	6	‘pinch’
				mə̀gə̀n	2	‘my lower back’
				ɓə̀gyə̀r	2	‘fish sp.’
				pə̀gyə́l	2	‘quarrel’
		BəB	3	mə̀mlə̀l	3	‘my grandchild’
		Bəə	17	mə̄ə̄r	7	‘river’
				mə̀ə̀rní	1	‘curse me + ASS’
				mə̀ə̀rnı̌	1	‘curse them’
				mə̀ə̀rə́n	1	‘curse me’
				mə̀ə̀rnǎŋ	1	‘curse us (incl)’
				bə̄ə̄g	6	‘shoulders’
		əB	10	gə́m	6	‘fish sp.’
				gə̀m	1	‘fever’
				kə́m	3	‘fish sp. (pl)’
U	**12**	ə-U	9	sə̀gú	4	‘tree sp. (pl)’
				kə́rù	5	‘fish sp.’
		əə-U	4	ə́ə́rú	4	‘sauces’
BU	10	Bə-u	1	bə́núŋ	1	‘fish sp.’
		Bəə-u	5	jè ɓə̀ə̀rú	1	‘orphans’
				bə̀ə̀gú	2	‘ostriches’
				mə̀ə̀gú	2	‘tamarinds’
		əBu	4	tə̀bú	4	‘fish sp. (pl)’
W	**27**	əw	22	gə́wrə́l	3	‘snail sp.’
				kə́wə́r	1	‘be insufficient for me’
				sə̄w	8	‘fish sp. (pl)’
				lə̄wə̄l	5	‘clay’

				sə́wrə̌l	5	‘fish sp.’
		əəw	1	gə̀ə́w	1	‘wings’
		wə	4	wə́n	4	‘boule’
BW	**3**	Bəw	3	bə́wə́n	2	‘stroke me’
				bə́wní	1	‘stroke me +ASS’
BWU	**3**	Bəw-U	2	bə́wnó	1	‘stroke her +ASS’
				bə́wnùrú	1	‘stroke us (excl.) +ASS’
		BəwU	1	mə́wó	1	scorpions’
WU	**6**	əwo	6	tə́wó	1	‘shield’
				sə́wò	2	‘warthogs’
				gə́wò	2	‘hunter’
				kə́wò	1	‘be insufficient for her’

Appendix C

ɨ-words included in the Laal study (AK)

Condition				Wordlist		
ɨ	**41**	ɨ	41	dɨ̀g	3	‘be bad (pl)’
				dɨ̄gā	3	‘be bad’
				dɨ̄gɨ̄ny	2	‘fish sp. (pl)’
				dɨ̀gnyál	1	‘fish sp.’
				ɗɨ̄g	1	‘draw water’
				ɗɨ̀gɨ̀	1	‘draw water (ger)’
				ɗɨ̀lɨ̀	1	‘cut (pl,ger)’
				gɨ́g	1	‘doubt’
				gɨ́ná	1	‘net sp.’
				kɨ̀n	1	‘arrive (pl)’
				lɨ̀gɨ̀	2	‘braid (pl,ger)’
				lɨ̀r	1	‘wait’
				nɨ̀ŋɨ̀	1	‘throw (pl,ger)’
				sɨ̀g	3	‘how many/much’
				sɨ̄g	3	‘stand (pl)’
				sɨ̀gí	2	‘ears’
				sɨ̀glà	1	‘your ear’
				sɨ̀glàn	2	‘its ear’
				sɨ̀glə̀l	1	‘my ear’
				sɨ́ŋ	3	‘stamp (pl)’
				sɨ́r	2	‘drink’
				sɨ̀rɨ̀	2	‘drink (ger)’
				tɨ̄n	1	‘lie down’
				tɨ́rí	2	‘beams’
B	**99**	Bɨ	46	bɨ̀l	5	‘trash’
				bɨ̀n mɨ̄n	2	‘my forehead’
				bɨ́nàn	3	‘okra’
				ɓɨ̀dɨ́l	3	‘one’
				ɓɨ̀l	4	‘hole’
				ɓɨ̀lál	3	‘speech’

				ɓɨ̄lāy	1	‘holes’
				mɨ̄lā	1	‘eye’
				mɨ̀lɨ̀	4	‘stab (pl,ger)’
				mɨ́n nì	1	‘my eyes’
				mɨ́ná	3	‘thing’
				mɨ̄rā	7	‘cow’
				mɨ̄rgā	1	‘alcohol (pl)’
				mɨ́rííl	1	‘plant sp.’
				pɨ̄l	2	‘refuse (pl.)’
				pɨ́r	4	‘catch’
				pɨ̀rɨ̀	1	‘catch (ger)’
		Bɨɨ	3	mɨ̀ɨ̀ràn	1	‘curse (pl) it’
				mɨ̀ɨ̀rnǎŋ	1	‘curse (pl) us (incl)’
				mɨ̀ɨ̀rnìrí	1	‘curse (pl) them’
		BɨrB	1	pɨ́rmɨ́n	1	‘dust’
		ɨB	49	dɨ̄b	1	‘forge’
				dɨ̄m	5	‘Bagirmi people’
				dɨ̀mɨ́l	3	‘Bagirmi’
				ɗɨ́b	3	‘hit’
				ɗɨ́bàn	1	‘hit it’
				ɗɨ̀bɨ̀	5	‘hit (ger)’
				ɗɨ̄m	1	‘moor’
				ɗɨ̀mɨ̀	5	‘moor (ger)’
				lɨ̀mɨ̀	3	‘measure (ger)’
				nɨ̀bɨ̀	1	‘smoke fish (pl,ger)’
				nɨ̄mɨ̄n	6	‘salt’
				nɨ̀mɨ́r	1	‘my sister’
				sɨ̀mà	4	‘fishing net’
				tɨ́màn	1	‘its paw’
				tɨ́már	2	‘his hand’
				tɨ́mí	2	‘hands’
				tɨ́mɨ́r	5	‘my hand’
U	**1**			gɨ́nù	1	‘net sp. (pl)’
W	10	ɨw	6	kɨ̄w	1	‘eat (pl)’
				kɨ̀wàn	1	‘eat (pl) it’
				kɨ̀wɨ́n	1	‘eat (pl) me’
				kɨ̀wnǎŋ	2	‘eat (pl) us (incl.)’
				sɨ̀wɨ̀	1	‘cut (pl,ger)’
		ɨɨw	4	gɨ́ɨ́wàn	1	‘put it upside down’
				gɨɨ́wí	2	‘put upside down’
				gɨ́ɨ́wɨ́n	1	‘put me upside down’

Appendix D

ɨ-words included in the Laal study (KD)

Condition				Wordlist		
ɨ	**23**			dɨ̀gnyál	6	‘fish sp.’
				dɨ̄gɨ̄ny	6	‘fish sp. (pl)’
				sɨ́gál	1	‘ear’
				sɨ́gí	2	‘ears (pl)’
				ɗɨ̀gɨ̀n	2	‘be heavy (pl)’
				dɨ̄gā	1	‘bad’
				dɨ̀gà	2	‘pickaxe’
				ɗɨ̄lā	2	‘fish sp.’
				bɨ̀là	1	‘empty’
B	**74**	Bɨ	53	mɨ̄rā	2	‘cows’
				mɨ̄n-nǎŋ	1	‘our face’
				ɓɨ̀gál	1	‘tree sp.’
				bɨ̀gà	1	‘shell’
				bɨ̀gál	2	‘pubis’
				bɨ̀glɨ̀l	3	‘my pubis’
				bɨ̀gí nùrú	1	‘our pubis’
				bɨ̀glàl	1	‘his pubis’
				mɨ̄g	3	‘pass (pl)’
				bɨ̀l	1	‘trash’
				mɨ́ná	4	‘thing’
				bɨ́nàn	1	‘gombo, okra’
				ɓɨ̀rà	1	‘fish hook’
				mɨ̀dál	1	‘evening’
				mɨ̀lɨ̀l	1	‘my eye’
				mɨ̀làl	1	‘his eye’
				mɨ́n(í)	2	‘eyes’
				mɨ̄rgā	1	‘beers’
				mɨ́rííl	1	‘plant sp.’
				ɓɨ̀lál	4	‘speech’
				ɓɨ̀dɨ́l	1	‘one’

				pɨ́rɨ́l	5	‘catch me’
				pɨ́nán	2	‘millet shaft’
				pɨ́r	3	‘catch’
				pɨ̄lā	2	‘debt’
				pɨ̄l	2	‘refuse’
				ɓɨ̀l	1	‘hole’
				bɨ̄rgā	1	‘hurry’
				ɓɨ́lá	2	‘speak’
		Bɨɨ	4	mɨ̀ɨ̀rɨ̀	3	‘curse (pl,ger)’
				mɨ̀ɨ̀r-nìrí	1	‘curse them (pl)’
		BɨrB	4	bɨ̀rmɨ́n	3	‘savannah’
				pɨ́rmɨ́n	1	‘dust’
		ɨB	12	lɨ̀bár	4	‘plunge, immerse’
				nɨ̀mɨ́l	1	‘kin’
				nɨ̄mɨ̄n	1	‘salt’
				sɨ̀mà	2	‘fishing net’
				tɨ̀bà	2	‘tobacco’
				dɨ̀mɨ́l	2	‘Bagirmi’
		ɨCB	1	lɨ̀gmà	1	‘horses’
W	**4**	ɨw	4	gɨ́wí	3	‘put upside down’
				gɨ́wɨ́n	1	‘put me upside down’

Appendix E

Languages included in the typological database, and sources

Language (dialect) [ISO code]	Source
Acehnese [ace]	Durie (1985)
Anufo [cko]	Stanford and Stanford (1970)
Arabana [ard]	Hercus (1994)
Asmat (Flamingo Bay) [cns]	Voorhoeve (1965)
Cantonese [yue]	Flemming (2002), originally from Kao (1971), Cheng (1989, 1991)
Capanahua [kaq]	Loos (1967)
Delaware (Unami) [unm]	Goddard (1979)
Fe’fe’ Bamileke [fmp]	Hyman (1972)
Iaai [iai]	Ozanne-Rivierre (1976, 1984
Irish Gaelic [gle]	Ó Siadhail (1989)
Kalispel [fla]	Vogt (1940)
Kaska [kkz]	Hansson and Moore (2011)
Kazakh [kaz]	McCollum (2015)
Khmuʔ [kjg]	Smalley (1961)
Konni [lma]	Cahill (2000, 2007, 2009)
Kpan (Kente) [kpk]	Shimizu (1972, 1980)
Kumiái (Jamul Tiipay) [dih]	Gorbet (1976)
Laal [gdm]	(my own recordings and field notes)
Louisiana Creole French [lou]	Klingler (1992)
Madhi Madhi [dmd]	Hercus (1986)
Maléku Jaíka [gut]	Constenla (1981)
Nisga’a [ncg]	Tarpent (1987)
North-Gbaya [gya]	Moñino (1995) (also Monino and Roulon 1972, Noss 1981)
Nyangumarta [nna]	O’Grady (1964)
Quichua (Ecuador, Puyo Pongo) [qxl?]	Orr (1962)

Russian (South-Central) [rus]	Crosswhite (2000)
Sonsorolese (Pulo-Annan) [sov],	Oda (1977)
Straits Salish (Samish) [str]	Galloway (1990)
Taa (!Xóõ) [nmn]	Traill (1985, 1994)
Tamil [tam]	Schiffman (1999)
Tauya [tya]	MacDonald (1990)
Thompson Salish [thp]	Thompson and Thompson (1992)
Turkana [tuv]	Dimmendaal (1983)
Wambaya [wmb]	Nordlinger (1998)
Wanggangurru [wgg]	Hercus (1994)
Wemba Wemba [xmw]	Hercus (1986)
Wergaia (Djadjala) [weg]	Hercus (1986)
Wirangu [wgu]	Hercus (1998)
Woleaian [woe]	Sohn (1971, 1975); Sohn and Tawerilmang (1976)

Appendix F

Exceptions to Konni trans-dorsal backing

As we saw in § 4.2.1.3.2 (ex. 85), repeated in (278) below, perseverative trans-dorsal backing in Kɔnni applies to only seven out of the 17 nouns where the conditions for its application are met. Cahill (2007: 246, 248) reports finding only four exceptions in his data to perseverative trans-dorsal backing, all listed in (276) below. The nouns in (276a-b) are compounds, while the (276c-d) are reduplicated forms, i.e. forms that are often phonotactically irregular, and thus do not constitute true exceptions.

(276) Exceptions to perseverative backing: other nouns

a.	jèvʊ̀k-ɪ́-rí	‘snake-DEF.SG.1’	(< /jà + vʊ̀g-k-/ ‘small’ + ’wriggle-adj’)
b.	sʊ̀g-ɪ̀-tàá	‘sibling’	(< /sʊ̀g + tàá/ = ‘inside’ + ’sister’)
c.	mʊ́mʊ́gíl-í-ŋ	‘tree (sp.)-sg’	
d.	múgílíꜜmúgílí-ꜜŋ́	‘tree (sp.)-sg’	

(277) Exceptions to perseverative backing: all class 2 noun roots ending in /…Ug-/

	Plural *-tɪ́*			Indef. sg. *-ŋ́*	Def. sg. *-kʊ́*
a.	/yʊ́g-tɪ́/	yʊ́g-ɪ́-tí	‘nights’	yʊ́ŋ,	yʊ́k-kʊ́
	/ɲʊ̀g-tɪ́/	ɲʊ̀g-ɪ̀-tí	‘markets’	ɲʊ̌ŋ,	ɲʊ̀k-kʊ́
	/zàmpʊ́g-tɪ́/	zàmpʊ́g-ɪ́-tí	‘hedgehogs’	zàmpʊ́ŋ,	zàmpʊ́k-kʊ́
	/kàmbáꜜlʊ́ꜜg-tɪ́/	kàmbáꜜlʊ́ꜜg-ɪ́-tí	‘frogs (sp.)’	kàmbáꜜlʊ́ꜜŋ́,	kàmbáꜜlʊ́k-ꜜkʊ́
	/sʊ́nꜜsʊ́g-tɪ́/	sʊ́nꜜsʊ́g-ɪ́-tí	‘middles ’	sʊ́nꜜsʊ́ŋ,	sʊ́nꜜsʊ́k-kʊ́
b.	/zùzùg-tɪ́/	zùzùg-ɪ̀-tí	‘lungs’	zùzùg-ú-ŋ,	zùzùk-kú

(278) Perseverative (UG__) in nouns (repeated from (19))

a.	Class 1 nouns			Indef. sg. *-ŋ́*
	/kúg-rÍ/	kúg-ú-rí	‘cooking place-DEF.SG.1’	kúg-í-ŋ
	/bàɲʊ̀ʊ̀g-rÍ/	bàɲʊ̀ʊ̀g-ʊ̀-rí	‘soup leaf-DEF.SG.1’	bàɲʊ̀ʊ̀g-í-ŋ
	/dààgbúg-rÍ/	dààgbúg-ú-rí	‘stump-DEF.SG.1’	dààgbúg-í-ŋ
	/mʊ́g-rÍ/	mʊ́g-ʊ́-rí	‘river-DEF.SG.1’	mʊ́g-ʊ́-ŋ
	/tʊ́g-rÍ/	tʊ́g-ʊ́-rí	‘termite hill-DEF.SG.1’	tʊ́g-ʊ́-ŋ
b.	Class 4 noun			
	/ɲʊ̀ʊ̀g-bÚ/	ɲʊ̀ʊ̀g-ʊ̀-bʊ́	‘smell-DEF.SG.4’	ɲʊ̀ʊ̀g-í-ŋ
c.	Class 2 noun			
	/kʊ̂g-tÍ/	kʊ́g-ʊ́-ꜜtí	‘ghost-PL.2’	kʊ́g-ʊ́-ꜜŋ́

The six nouns in (277) represent all the nouns of class 2 whose root ends in /…Ug-/, with one exception: *kʊ́g-* ‘ghost’, in which trans-dorsal backing applies (278c).[1] As can be seen, non-application of the trans-dorsal backing is not the only exceptional property of these nouns. Indeed, they do not always allow the expected I-epenthesis when combining with consonant-initial suffixes. While epenthesis is systematic with the plural suffix -tÍ, it fails to occur with the indefinite singular -ŋ́, with which the root-final /g/ fuses, e.g. /yʊ́g-ŋ́/ → *yʊ́ŋ* (**yʊ́g-í-ŋ*) ‘night-IND.SG’ (except in (277b) /zùzùg-/). It also fails to apply with the definite singular suffix -kʊ́, whose initial /k/ assimilates the root-final /g/, e.g. /yʊ́g-kʊ́/ → *yʊ́k-kʊ́* (**yʊ́g-ʊ́-kʊ́*) ‘night-DEF.SG.3’. Compare with the class 1 and class 4 noun roots ending in /…Ug-/ in (278), where regular I-epenthesis and trans-dorsal backing apply whenever the conditions are met.[2]

Cahill (2007: 138-139) shows that the distinction between these two sets of nouns originates in a historical merger between /g/ and /k/ intervocalically. The root final /g/ in class 2 nouns used to be voiceless *k in Proto-Buli-Kɔnni, as shown in (34) with three of the class 2 noun roots in (277) above, which end in /k/ in Buli. The final /g/ in nouns of class 1 in (278), on the other hand, is the regular reflex of Proto-Buli-Kɔnni *g, as shown in (35), where both class 1 Kɔnni noun roots and their Buli cognate forms end in /g/.

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[1] The noun ‘ghost’ seems to have two forms, one with a final /g/ and one with a final /k/, in both Kɔnni (definite sg. *kʊ́g-ʊ́-kʊ́∼kʊ̆k-kʊ́*; cf. Cahill 2007: 445, fn. 2) and closely related Buli (root *kɔ́ɔ́-*, probably from *kɔ́gɔ́-*, in the Kanjaga dialect, *kɔ́k-* elsewhere; cf. Kröger 1992: 180). This could explain the fact that it does not pattern exactly like the other class 2 nouns ending in /…Ug-/.

[2] In the last three nouns in (90a), trans-dorsal backing applies to the final vowel, contrary to expectation. I will come back to this later (cf. (92).

(279) g∼k correspondence in Kɔnni and Buli

			Kɔnni (Cahill 2007)	Buli (Kröger 1992)
a.	‘night’	Root:	/yʊ́g-/	/yɔ́k-/[3]
		Indefinite sg.:	yʊ́ŋ	yɔ́k
		Definite sg.:	yʊ́k-kʊ́	yɔ́k-u (<…-ku)
		Plural:	yʊ́g-í̱-tí	yɔ́k-ta
b.	‘frog (sp.)’	Root:	/kàmbáꜜlʊ́gꜜ-/	/kānbɔ̄glɔ́k-/
		Indefinite sg.:	kàmbáꜜlʊ́ꜜŋ́	kānbɔ̄glɔ́k
		Definite sg.:	kàmbáꜜlʊ́k-ꜜkʊ́	kānnɔ̄glɔ̄k-ú (<…-ku)
		Plural:	kàmbáꜜlʊ́ꜜg-í̱-tí	kānbōglɔ́k-tā∼-sā
c.	‘lung’	Root:	/zùzùg-/	/zùzùk-/ (?)
		Indf. sg.:	zùzùg-ú̱-ŋ	zùzùk
		Def. sg.:	zùzùk-kú	zùzùk-u (<…-ku)
		Plural:	zùzùg-ì̱-tí	zùzùg-ta

(280) g∼g correspondence in Kɔnni and Buli

			Kɔnni (Cahill 2007)	Buli (Kröger 1992)
a.	‘river’	Root:	/mʊ́g-/	/mɔ́g-/ ‘large river, reservoir’
		Indf. sg.:	mʊ́g-ʊ̱́-ŋ	mɔ́g-í
		Def. sg.:	mʊ́g-ʊ̱́-rí	mɔ́g-ni
		Plural:	mʊ́g-à	mɔ́g-a
b.	‘termite-hill’	Root:	/tʊ́g-/	/tɔ́g-/
		Indf. sg.:	tʊ́g-ʊ̱́-ŋ	tɔ́g-í
		Def. sg.:	tʊ́g-ʊ̱́-rí	tɔ́g-ni
		Plural:	tʊ́g-â	tɔ́g-a
c.	‘ghost’	Root:	/kʊ́g-/	/kɔ̀g-/? (cf. fn. 1)
		Indf. sg.:	kʊ́g-ʊ̱́-ꜜŋ́	kɔ̀k∼kɔ̀ɔ̀-k (Kanjaga dial.; < kɔ̀g̱ɔ̀-k?)[4]
		Def. sg.:	kʊ́g-ʊ̱́-ꜜkʊ́∼kʊ̆k-ꜜkʊ́	kɔ̀k-kū
		Plural:	kʊ́g-ʊ̱́-ꜜtí	kɔ̀k-ta∼kɔ̀ɔ̀-ta (Kanjaga dial.; <kɔ̀g̱ɔ̀-ta?)

What can be concluded from this is that there seems to be a tendency for sequences reconstructible as *Uk-I- to resist perseverative trans-dorsal backing. The difference between the application of trans-dorsal backing in *mʊ́g-ʊ́-rí* ‘river-DEF.SG.1’ and its non-application in *yʊ́g-í-tí* ‘night-PL.2’ could be seen as a case of diachronic opacity, i.e. evidence that perseverative trans-dorsal backing is fossilized and irregular in the noun system (remember that it suffers no exception in verbs). Alternatively, one could analyze the final /g/ in class 2 nouns as an underlying /k/ (i.e. /mʊ́g-/ ‘river’ vs. /yʊ́k-/ ‘night’), in which case the opacity effect would be purely synchronic, i.e. belonging entirely in the synchronic phonological grammar of the language. One would simply have to say that trans-dorsal backing is limited to cases where the intervening dorsal is not

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[3] [ɔ] and [o] are allophones of /o/ in complementary distribution in Buli (Kröger 1992: 3; Schwartz 2005: 10-12). The [ɔ] allophone seems to be conditioned in particular by the presence of an adjacent velar consonant.

[4] Kröger (1992: 4) notes that “[ɔː] has nearly always been the result of a lengthened [ɔ] after omission of a velar fricative [ɣ],” (which is the most frequent realization of intervocalic /g/), i.e. *ɔɣɔ → ɔː.

/k/, and applies before intervocalic lenition of /k/ to [g], analyzed as an active process in the language (*contra* Cahill's diachronic analysis), as illustrated in (281) below. I will leave this discussion open for now, and come back to some potential consequences of this opacity for the theory of subphonemic teamwork in chapter 3.

(281)

		/mʊ́g-rÍ/	/yʊ́k-tÍ/
a.	I-epenthesis	mʊ́g-í-rí	yʊ́k-í-tí
b.	Trans-dorsal backing	mʊ́g-ʊ̱́-rí	n/a
c.	k → g / V__V	n/a	yʊ́g-í-tí

Regarding anticipatory trans-dorsal backing, we saw in § 4.2.1.3.2 (ex. 86) that it applies to only 26 of the 33 nouns where the conditions are met. The eight exceptions that I found in Cahill (2007: 439-456) data are listed in (282).

(282) Exceptions to anticipatory trans-dorsal backing:

a. Epenthetic [ɪ] preceded by [ɪ$C_{\text{coronal/palatal}}$ __]

/nàkpàchìy-/	nàkpàchìy-í̱-ꜜkʊ́	'centipede'	
/yís-/	yís-í̱-kʊ́	'sheep'	
/kpììl-/	kpììl-ì̱-kʊ́	'thigh'	

b. Epenthetic [ɪ] preceded by a [aC_{coronal} __]

/wár-/	wár-í̱-kʊ́	'block'	
/bàl-/	bàl-ì̱-kʊ́	'speech'	
/kpààl-/	kpààl-ì̱-kʊ́	'handle'	
/sàŋkpàr-/	sàŋkpàr-ì̱-kʊ́	'navel'	

c. Epenthetic [ɪ] preceded by a [ɪC_{labial} __]

/náꜜyíb-/	náꜜyíb-í̱-kʊ́	'toenail'	(ná- 'leg' + yíb- 'scratching')

It is not clear whether these are actual exceptions or simply cases in which the trans-dorsal backing was accidentaly not taken into account in the transcription. If they are actual exceptions, they do not seem to be entirely random. It is interesting to note, first, that all involve only [-ATR] vowels: the epenthetic vowel is thus always [ɪ]. Additionally, in all of them, the consonant and vowel immediately preceding the target that fails to undergo trans-dorsal backing are both non-dorsal: the consonant is front in seven cases out of eight (coronal in six cases, palatal in one) (282a-b), and labial in only one case (282c), and the vowel is always either /ɪ(ɪ)/ (282a,d) or /a(a)/ (282b). This is not a systematic criterion, since many nouns in (86), in which trans-dorsal bacing applies regularly, also have the same characteristics: compare in particular ***yíb-ʊ́-kʊ́*** 'crocodile' and ***nʊ́ꜜyíb-ʊ́-kʊ́*** 'fingernail' (***nʊ́***- 'hand' + ***yíb***- 'scratching') to ***náꜜyíb-í-kʊ́*** 'toenail' (***ná***- 'leg'), the last two being clearly related. However, the nouns in (86) do not seem to be characterized by any restrictions on the consonant or vowel preceding the target: all vowels are attested (except short /e, ɛ/, probably an accidental gap given the rarity of these two vowels in the language; cf. Cahill 2007: 176, as well as consonants of all places (although only one is dorsal,[5] and coronals are by far the most frequent, with 21 out of 26 cases). The "non-dorsal" coarticulation exerted

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[5] kʊ́g-ʊ́-ꜜkʊ́ 'ghost', which has two variants in the definite singular form: kʊ́g-ʊ́-ꜜkʊ́ and kʊ̌k-ꜜkʊ́ (Cahill 2007: 445, fn.2).

by the preceding VC sequence may have prevented trans-dorsal backing in these cases. These exceptional forms can thus be partly explained on a phonetic basis.

Finally, I mentioned earlier five exceptions to the immunity of word-final /I/ to trans-dorsal backing (cf. § 4.2.1.3.2, ex. (90c) and (92)). These exceptions, all nouns, are listed in (283).[6] Compare with the g-final noun roots in (93), repeated in (284) below, where epenthetic /I/ resists trans-dorsal backing in the word-final syllable (in the case of *-ŋ́* suffixation), but not elsewhere (in the case -CV́ suffixation).

(283)			Indefinite sg. *-ŋ́*
	/mʊ́g-/	‘river’	mʊ́g-ʊ̱́-ŋ
	/tʊ́g-/	‘termite hill’	tʊ́g-ʊ̱́-ŋ
	/kʊ̂g-/	‘ghost’	kʊ́g-ʊ̱́-ꜜŋ́
	/sʊ́g-/	‘fish trap’	sʊ́g-ʊ̱́-ŋ
	/zùzùg-/	‘lung’	zùzùg-ú̱-ŋ

(284)			Indefinite sg. *-ŋ́*
	/kúg-/	‘cooking place’	kúg-ɪ̱́-ŋ
	/bàɲʊ̀ʊ̀g-/	‘soup leaf’	bàɲʊ̀ʊ̀g-ɪ̱́-ŋ
	/dààgbúg-/	‘stump’	dààgbúg-ɪ̱́-ŋ
	/ɲʊ̀ʊ̀g-/	‘smell’	ɲʊ̀ʊ̀g-ɪ̱́-ŋ

There does not seem to be any clear criterion accounting for the exceptions in (283). The *g vs. *k difference mentioned earlier is not what is at work here, since all the noun roots in both (283) and (284) are likely to derive from *g-final roots in Proto-Buli-Kɔnni. It is however interesting to note that in all the exceptional cases, the target vowel is followed by the velar nasal (UG__ŋ), which, as we saw earlier (cf. (97), has a strong retracting effect on a previous /I/. The retracted realization [ɨ, ɪ] of the target vowel in the nouns in (283) is very likely to make it more sensitive to the backing effect of the two preceding dorsal target segments thus trumping the word-finality condition. Once again, these exceptions can thus be partly explained on a phonetic basis.

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[6] A sixth potential exception is the plural form of noun /kʊ́g-/ ‘tree (sp.)’, for which two forms can be found in Cahill (2007): *kʊ́g-ʊ́-sí* with trans-dorsal backing (Appendix B, p. 450), and *kʊ́g-í-sí* (p. 137) without. It is not clear whether this difference is due to a typo, or if both forms are attested. Cahill reconstructs this noun root with a final /k/ in Proto-Buli-Kɔnni, which is evidenced by the behavior of the final velar consonant in the indefinite sg. form /kʊ́g-ŋ́/ → *kʊ́ŋ* (not *kʊ́g-í-ŋ*), and the definite sg. form /kʊ́g-ká/ → *kʊ́k-ká* (never *kʊ́g-ʊ́-ká*, cf. Cahill 2007: 137, fn. 23).

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