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Low Vowel Raising in Sinitic Languages: Assimilation, Reduction, or Both?*

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Many Sinitic languages respect low vowel raising (LVR) whereby the low vowel /a/ is raised to /e/ only when flanked by a palatal glide and a coronal coda. In this article, I show that LVR in Sinitic languages is a genuine process of grammar because low-level phonetic coarticulatory effects alone cannot account for cross-linguistic/dialectal variation. Specifically, my survey reveals that vowel duration, onset consonants and/or the presence of retroflexes may have a direct bearing on LVR, thus calling for a phonological analysis. I argue that the phenomenon in question is better treated as additive effects of (i) target undershoot in the wake of impoverished vowel duration (i.e. vowel reduction) and (ii) contextual influences (i.e. backness assimilation). Phonological vowel quality change (LVR here) is motivated only when the benefit of contextual neutralization exceeds that of the sum of the "cost" of implementing the above coarticulatory patterns. Analytically, Flemming's (2003) feature co-occurrence constraints, together with phonetically driven constraints, provide a straightforward account of the relationship between coronal place and vowel backness attested in LVR. Finally, implications for Mandarin segmental phonology are also discussed.

Key words: vowel raising, vowel reduction, assimilation, segmental phonology, Sinitic languages

1. Introduction

In this paper, I consider a fairly common but understudied process of vowel quality change in a handful of Sinitic languages: The low vowel /a/ is raised to [e] when

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sandwiched between a palatal glide and a coronal coda in the domain of the syllable, as informally stated in (1) below.[1]

(1) a → e / (C)j __ n/t

I shall refer to this phenomenon as "low vowel raising" (henceforth LVR) — for the process in question involves vowel quality change in one fell swoop, along the height and backness dimensions of the target. LVR is characterized by both common types of vowel quality change, i.e. vowel reduction and vowel fronting. As Flemming (2005) puts it, "vowel reduction primarily eliminates height contrasts", while vowel fronting and retraction are conditioned by (one of) flanking segments (i.e. neutralization of vowel backness). A survey of previous studies, however, shows that analyses of the phenomenon in (1) include a wide range of treatments. Lin (1989:67), for example, proposes an assimilation rule for LVR in Mandarin Chinese (or, Standard Chinese) and this particular assimilation rule is translated into a constraint-based OT framework (e.g. Lin 2011, Ma 2003:147-150). Conversely, Li (1999) proposes a diachronically motivated account, according to which intensive language contact in North China facilitates the emergence of LVR. By contrast, Wang (1993) and Wu (1994), among others, attribute (1) to the results of some low-level phonetic effects (i.e. coarticulation). Therefore, under this view, no analysis is needed. Finally, the process in question is dismissed in Duanmu's (2007) analysis of Standard Chinese segmental phonology. The brief review above shows that the field has reached no consensus about the nature of LVR, nor has it even agreed that it exists at all.

The goal of this paper is thus two-fold. First, to regard old problems from a new perspective, this work examines the LVR data from other Sinitic languages, and it appears that this effort helps clarify the nature of LVR, namely whether the issue in question is "phonetic" or "phonological". This paper also helps fill a gap since no attempt has been made to explain LVR from cross-linguistic/dialectal perspectives. Second, as we shall see later, LVR cannot be easily accommodated within mainstream feature theories (e.g. Sagey's 1986 Articulator model or Clements' & Hume's 1995 Constriction model), especially in a derivational theory of phonology (e.g. Chomsky & Halle 1968). I shall provide a unified account of the full array of the LVR data within a framework under the rubric of phonetically based phonology (Hayes et al. 2004). Therefore, employing cross-linguistic/dialectal data and novel analytical methods, this paper contributes to a better understanding of why LVR is motivated and how it should be analyzed.

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1 The raised low vowel has been customarily transcribed as [ɛ] and the palatal glide [i], [^{j}] or [^{i}] in the literature. My analysis is not affected by these transcription differences, however.

The rest of this paper is organized as follows. In §2, I shall argue that LVR is not merely a result of low-level phonetic effects. Rather, it must be treated as a genuine process of grammar as evidenced in a survey of the LVR phenomena in Sinitic languages. Subsequently, a statement of the problem is given in §3. Since LVR has both the characteristics of vowel reduction and vowel fronting, I shall particularly focus on how significant analytical difficulty presents itself. In §4, I shall argue that LVR is, contrary to previous studies, better analyzed as backness assimilation in the wake of target undershoot, by integrating the insight of Flemming's (2003) approach to the relationship between coronal place and vowel backness (cf. Hume 1994, among others). Finally, §5 concludes this paper.

2. Why low vowel raising is a genuine process of Sinitic grammars

In this section, I shall argue that LVR cannot be treated as low-level coarticulatory effects (contra Wang 1993, Wu 1994, among others). Rather, the process in question is grammatically conditioned. Given the SPE model (Chomsky & Halle 1968), coarticulation, together with timing, articulation and the like, is placed in a low-level, extra-grammatical component, whereby discrete segments are translated into continuous physical parameters by means of a set of phonetic conventions. The translation is assumed to be automatic. In other words, these phonetic conventions are *universal* rules: phonetics converts fully specified, phonetically interpretable phonological representations into a physical utterance in an automatic fashion. Under this view, a phonological entity is supposed to be phonetically implemented in a consistent fashion across all languages.

From the above discussion, it is important to emphasize that low-level phonetic effects such as coarticulation are assumed to be universal. Given that, at first blush, it is fairly reasonable to say that LVR is coarticulatory in nature, implemented in low-level phonetics. This is because the phenomenon in question is attested only when the low central vowel /a/ is flanked by coronals in a broad sense. Therefore, front-back movement of the tongue is expected since the vowel /a/ retracts the tongue, while coronals are articulated with the tongue tip, most often inducing tongue fronting. Meanwhile, vowel duration is substantially reduced in closed/checked syllables in most Sinitic languages (see also (41)). Taken together, fast, abrupt front-back movement of the tongue may be extremely difficult to achieve in a short time span, thus resulting in a compromise (or, more pedantically, target undershoot). So the raised low vowel in (1) can be treated as being the outcome of compromise among the articulators. To this end, LVR, as a consequence of effort minimization, may well be implemented in the above-mentioned low-level, extra-grammatical component. That being the case, LVR should be invariably attested in appropriate environments across all languages.

A quick cross-linguistic survey, however, rejects the hypothesis that LVR is attributed to automatic consequences of speech physiology. According to SPE's universal phonetic framework just outlined above, LVR would not be blocked in Korean, for example. More precisely, it would be puzzling why the Korean word /jantɕəŋ/ 'social relationship' is not realized as [jentɕəŋ], given that LVR were exclusively motivated by *universal*, low-level coarticulatory effects (i.e. LVR is not attested in Korean). As a matter of fact, it has long been noted that coarticulatory patterns are language-specific and therefore must be specified in the grammar of each language (Keating 1985, cf. Manuel 1990). Furthermore, cross-language differences in the alleged low-level phonetic patterns include, but are not limited to: consonant-to-vowel coarticulation (Lubker & Gay 1982, Oh 2002, Öhman 1966, Recasens et al. 1995, *i.a.*), nasalization (Clumeck 1976, Huffman 1988, Keating & Cohn 1988, *i.a.*), tonal coarticulation (Chang & Hsieh 2012, and reference cited therein), and vowel-to-vowel coarticulation (Beddor et al. 2002, Manuel 1990, Manuel & Krakow 1984, *i.a.*). Returning to the Sinitic languages, consider now (2), in which the data are primarily based on Yuan et al. (1983), together with available phonetic studies (to be discussed in §3.1). It is safe to compare the process in question among Sinitic languages since language/dialect-specific phonotactics and phoneme inventories do not substantially differ in this regard. Specifically, Sinitic languages normally have a palatal glide, one (phonemic) low central and one (phonemic) nonlow front vowel and a coronal coda.

(2) Low vowel raising across Sinitic languages: An overview

Language group	Language/dialect	Low vowel raising
Cantonese	Guangzhou, Hong Kong	No
Gan	Nanchang	No
Hakka	Meixian, Meinong	Complicated
Mandarin	Beijing	Yes or No
Min	Xiamen, Taiwanese	Complicated
Wu	Shanghai	N/A (no [n] coda)
Xiang	Changsha	No

It is obvious by now that LVR is not uniformly attested in this survey, suggesting again that the process in question must be specified in the grammars of Sinitic languages, or, at least, is phonetically implemented distinctly. In fact, more complications are found even within a single language/dialect. For example, it has been noted in Lin (1989:67) that the labio-palatal glide fails to trigger LVR in some varieties of Mandarin Chinese (mostly spoken in China, or, Variety A in (3)), whereas it is not the case in Taiwanese Mandarin (i.e. Variety B in (3)). Yet we see that LVR is blocked in the presence of the labio-palatal glide in Variety A. In addition, Lee & Zee's (2003) phonetic study also confirms that both front glides trigger LVR in contemporary Beijing Mandarin. Notably, the labio-palatal glide [ɥ] and the palatal glide [j] do not substantially differ in backness, to my knowledge. Therefore, this disparity, again, rejects the claim that LVR is nothing more than a low-level, phonetic phenomenon.

(3) Mandarin Chinese: The labio-palatal glide may not condition LVR

Variety A	Variety B	Gloss
jen˧˥	jen˧˥	salt
ɥan˧˥	ɥen˧˥	garden

More significantly, different onset consonants may play a role, too. In Meixian Hakka (Yuan et al. 1983), LVR is "blocked" when the velars and glottals appear in onset position or the palatal glide alone serves as the onset. Remarkably, the same patterns are also reported in the variety of Taiwanese Hakka spoken by old speakers in Meinong, Kaohsiung (Chung 1997, cited in Chung 2004:98-99), suggesting that (4) cannot be an accidental, isolated case.[2]

(4) Variegated LVR in Meixian Hakka (Yuan et al. 1983:150, 161, slightly modified; tones are omitted)
   a. Low vowel raising is blocked in the context of
      ian 'tobacco', kian 'cunning', hian 'room with high eaves', ŋian 'speech, word', iat 'to call on a superior', kiat 'knot', hiat 'to take rest'
   b. Low vowel raising is attested elsewhere
      piɛn 'side', t^hiɛn 'field', tsiɛn 'arrow', p^hiɛt 'other', t^hiɛt 'iron', tɕiɛt 'node'

Third, vowel length may condition LVR as well. The evidence comes from a variety of Xiamen Chinese documented in Luo & Zhou's fieldwork in 1930, whose results were published in Luo & Zhou (1975). They report that LVR is only attested in checked syllables, suggesting that LVR may be dependent on vowel duration. That is because vowels are phonetically longer/bimoraic in open syllables and short/monomoraic in closed syllables, while vowels in checked syllables have the shortest duration among the three syllable types, as far as Sinitic languages are concerned (perhaps with the exception of certain Wu Chinese languages (e.g. Duanmu 1994); see also §4.2 for more discussion). The pattern in (5) below not only highlights the underestimated role of vowel duration in previous work on LVR, but also turns out to be a crucial "missing

[2] Note that the variegated LVR found in Meixian Hakka seems now obsolete because it is not documented in Lee & Zee's (2009) phonetic study, which is based on young speakers only.

link" in the diachronic development of LVR, to which I shall return shortly in (7).

(5) Xiamen Chinese (Luo & Zhou 1975:11-12)

a.	[iaː]	No low vowel raising in open syllables
b.	[ian]	No low vowel raising in nasal-ending syllables
c.	[iɛt]	Low vowel raising is attested in checked syllables

Fourth, a relatively recent sound change has been found in Taiwanese (Southern Min), namely that the palatal glide [j] has been lost in LVR contexts, especially among younger speakers (i.e. Variety B in (6) below). When the palatal glide drops out, there is no apparent reason as to why the raised low vowel is not restored, surfacing as the intact, underlying [a]. Again, if LVR were due solely to the automatic consequences of speech physiology, the LVR-ed vowel [e] could not survive simply because the environments with greater articulatory difficulty would have disappeared.

(6) The loss of the palatal glide in Taiwanese Southern Min (cf. (5))

Variety A	Variety B		Gloss
[ɕjen˥]	[sen˥]	*[san]	'celestial beings'
[tjen˧˩]	[ten˧˩]	*[tan]	'electricity'
[jen˥]	[en˥]	*[an]	'smoke'

LVR does not occur in Doty's (1853) dictionary of the Amoy dialect (i.e. Xiamen Chinese) because no rimes such as *ien* or *iet* are found. It is well known that Church Romanization (Pe̍h-ōe-jī, or "vernacular writing") is *not* strictly phonemic so that rimes like *ien*/*iet*, if they existed at all, would not be transcribed/phonemicized as *ian*/*iat*. Given that, a possible history of LVR can be accordingly constructed in (7), together with our discussion of (5) and (6) as these languages/dialects are closely related to one another. It is very likely that LVR started in checked syllables, then spread gradually to other syllable types by way of lexical diffusion.[3] The key motivation, as discussed earlier, is vowel duration, although other factors such as the onset should be taken into consideration as well (e.g. the variegated LVR in Meixian Hakka in (4)).

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[3] Regarding the diachronic development of LVR in Mandarin, Korean material (Kwanjo Kim 1991:258, cited in Li 1999:148) indicates that "the merger of Grade III [-^{i}an] and [-^{y}an] with Grade IV [-^{i}ɛn] and [-^{y}ɛn]…reached completion between 1455 and 1517." Xinkui Li (1984: 482, cited in Li 1999: fn.25, 148) noted that the [jan] vs. [jen] distinction "was maintained up until the *Zhongyuan Yinyun* (Rhymes of the Central Regions) (1506)". Evidence of LVR (i.e. the merger of [jan] and [jen]) was subsequently found in some pronunciation guides for Western missionaries in the late 1600s.

(7) Diachronic development of LVR in Southern Min (proper)

Stage 1	jan/jat	Doty (1853), dictionary of Amoy dialect
Stage 2	jan/jet	Luo & Zhou's fieldwork in 1930 (L&Z 1975)
Stage 3	jen/jet	Taiwanese and some Southern Min dialects
Stage 4	en/et	New forms among young Taiwanese speakers

Finally, Duanmu (2007:58) dismisses the existence of LVR, arguing "since [an], [uan], [yan] and [iɛn] rhyme, they ought to have the same surface vowel. It is not necessary to distinguish the low vowels" in the above four rimes (see Chen 1984:169 for a similar argument along this line). While it is true that the four rimes belong to the same rhyming group in traditional Chinese rime books, it is not appropriate to use rhyming as the *sole* evidence against this particular process. It is well-established that rhyming reflects speakers' knowledge of similarity (e.g. English imperfect puns (Fleischhacker 2005), Japanese rap rhymes (Kawahara 2007), Middle English alliteration (Minkova 2003) and Romanian half-rhymes (Steriade 2003)), but it is not uncontroversial as to whether rhyming is learned or acquired, especially with regard to rhyming groups in Chinese (historical) phonology. More importantly, Lee & Zee's (2003:110) acoustic study confirms that LVR does exist in contemporary Beijing Mandarin and the results of unpublished acoustic data of mine also show that the LVR-ed vowel is [e] in Taiwanese (both Stages 3 and 4 in (7)). In fact, later in his discussion of optional surface variations, Duanmu (2007:68) does remark: "short [a] may be raised between a high front vowel and the coda [n]" (i.e. his (37d)). Therefore, LVR *is* attested in at least some varieties of Mandarin Chinese (as well as other Sinitic languages). Also, note that the analysis developed here will not be undermined if LVR is not found in a certain variety of Mandarin Chinese or other Sinitic languages, simply because it is possible that a certain process is suppressed by the grammar (see §3.1 for more discussion).

In conclusion, it is evident from the above discussion that LVR cannot be attributed to universal low-level phonetics. Otherwise, language/dialect-specific variation would not be anticipated. As we have witnessed, in language after language, ample evidence has shown that the overall picture of LVR is much more complicated than one might expect: vowel duration, onset consonants, prenuclear glides and so on may all trigger or block LVR across Sinitic languages (see also (24) for a case study in which LVR may be "undone" in r-suffixation). All in all, our discussion strongly suggests that it is inappropriate to exclude LVR from any analysis of Sinitic segmental phonology.

3. Statement of the problem

3.1 Background

The main target of this work is Mandarin Chinese (or, Standard Chinese), unless otherwise noted. Nevertheless, the proposed analysis can be extended to LVR found in other Sinitic languages without any obvious problem. No crucial cross-linguistic/dialectal difference is found with respect to phonotactics, phoneme inventories and so forth for this particular process. For ease of discussion, some essential background knowledge and assumptions are given as follows. First, in most Sinitic languages, the maximal syllable has four underlying elements CGVX (e.g. Duanmu 2007), where "X" can be a glide (G), a nasal (N), a stop (S) or none of them. The linear compositions of segments in a syllable are given in (8) below. In this paper, I assume a flat structure of syllables in Sinitic languages (e.g. Yip 2003) because differences from extant proposals are analytically inconsequential.

(8) Syllable structures
(C)Vː, (C)GVː, (C)VG, (C)GVG, (C)VN, (C)VS, (C)GVN, (C)GVS

Second, I follow the SPE tradition in which low central and back vowels are specified as [+bk] (i.e. [a̟], [a], [a̠], [ɑ]), while front vowels are [–bk] (i.e. [e], [ɛ], [æ]). See also §3.4 for more discussion on featural specifications in terms of Clements & Hume's (1995) Constriction model.

(9) Low and non-low mid vowels and variations thereof

Front	Central	Back	
e			Mid
ɛ			
æ			
	a̟ a a̠	ɑ	Low

Finally, the conventional view is that Mandarin Chinese has only one low vowel phoneme /a/, featuring the following allophonic variations (e.g. Duanmu 2007, Li 1999, Lin 2007 and reference cited therein):

(10) Mandarin: The low vowel phoneme /a/ and its surface variants
a. [a̟] before [n]
b. [a̠] or [ɑ] before [w] or [ŋ]
c. [e], [ɛ], or [æ] in the LVR environment: after [j] and before [n]
d. [a] elsewhere

The variations in (10a-b) are less controversial, while there is some disagreement on the surface values of the LVR-ed vowel in (10c). On the one hand, Wu's (1986) acoustic study of two Standard Chinese speakers suggests that the vowel in question is a low front vowel [æ] (see also Xu 1980) or a slightly fronted low vowel [a̟]. By contrast, the LVR-ed vowel is [e] according to Lee & Zee's (2003) phonetic study and is transcribed as [ɛ] by many others in the literature (see Duanmu 2007, Li 1999, Lin 1989, among others). As we have discussed in §2, these differences simply reflect the assumption that potentially possible surface forms are generated by an individual grammar. For example, in Grammar *A*, the mapping from [jan] to [jæn] (i.e. vowel fronting) indicates that only vowel backness alternations, rather than vowel height changes, are tolerated, while LVR is completely banned in Grammar *B*, and so on. With these in mind, thus, our principal task will be to account for the varieties exhibiting the most analytically challenging phenomenon, namely that the low vowel is raised to [e] only when after [j] and before [n].

3.2 Low vowel raising as an additive effect

LVR is highly constrained in terms of its environments: this process targets only the low vowel flanked by a palatal prenuclear glide and a coronal coda. The strict restriction can be further confirmed as follows: First, anterior coronals alone do not trigger LVR (and vowel fronting), progressively, regressively, or, in both directions. The Mandarin Chinese data in (11) illustrate.

(11) Mandarin: Anterior coronals do not trigger LVR and vowel fronting

a. No progressive assimilation

taː˥	*teː, *tæː	'to build'

b. No regressive assimilation

pan˥	*pen, *pæn	'class'
kan˥	*ken, *kæn	'dry'

c. No assimilation in both directions

tan˥	*ten, *tæn	'to carry (on shoulders)'
nan˧˥	*nen, *næn	'difficult'

Second, it is evident in (12) that palatal glides alone do not trigger LVR, either. As in (12a), no LVR is attested in open syllables, or in syllables closed by a non-coronal coda (12b). More importantly, the postnuclear palatal glide [j] is not able to induce LVR, even though a coronal segment appears in onset position (12c).

(12) Mandarin: The palatal glide alone does not condition LVR, either

a. No progressive assimilation

[jaː˥]	*jeː	'duck'

b. No progressive assimilation in absence of a coronal coda

[jaŋ˥]	*jeŋ	'central'
[jam˥]	*jem	'to castrate' (Taiwanese/Xiamen Chinese)

c. No regressive assimilation even in presence of a coronal onset

[naj˥˩]	*nej	'resistance'
[taj˥]	*tej	'idiotic'

To a first approximation, LVR must be analyzed as the simultaneous application of progressive assimilation from the palatal glide plus regressive assimilation from the coronal coda. Put differently, the observation amounts to an unanalyzable, highly idiosyncratic chunk, namely that no low vowel /a/ is licensed between a palatal glide and a coronal coda and the linear orderings must be strictly observed. Flemming (2001, 2003) points out that restrictions of this sort can be better understood as a consequence of "additive effects", or the simple sum of two (or more) effects of the elements acting independently. From the Cantonese data in (13), we see that anterior coronals do not condition vowel fronting in either direction, namely that no backness neutralization of vowels is attested before or after an anterior coronal (13a). By contrast, backness contrasts are obligatorily eliminated if and only if the back vowels appear between anterior coronals (13b). In other words, as we can see in the Cantonese data below that vowel fronting in Cantonese is a *combined* result of progressive and regressive backness assimilation, while it is evident that the individual effects such as progressive assimilation have no bearing on vowel fronting.

(13) Vowel fronting in Cantonese (based on Cheng 1991, Flemming 2001, 2003)[4]

a. Neither regressive nor progressive backness assimilation is attested

[kyt˺]	'to decide'		[kʊt˺]	'bracket'
[tœː]	'classifier for flowers'		[toː]	'many, much, plenty'

b. Additive effects: only flanking coronals induce vowel fronting

[tyt˺]	'to take off'	*tut	[tʊk˺]	'bald head'
[tœn]	'shield'	*ton	[tɔk˺]	'to carry (on shoulders)'

[4] The only exception to this generalization is this: "to account for the fact that low vowels are not target, Cheng proposes that /a/ and /a:/ in Cantonese are [+ATR], a feature specification which is otherwise unmotivated" (Hume 1994:22-23). It remains to be seen why the Cantonese low vowels are not subject to vowel fronting when flanked by anterior coronals.

Similarly, LVR in Mandarin Chinese results from a *combined* effect of a prenuclear palatal glide and a coronal coda, while neither a palatal glide nor an anterior coronal can condition LVR on an individual basis (e.g. (11) and (12)). The only difference lies in the fact that LVR is further complicated by the neutralization of height contrasts. Therefore, it is anticipated that more fruitful results will be obtained if analyses along the line of additive effects are adopted (e.g. Flemming 2003).

3.3 Analytical problems

3.3.1 Rule-based analysis

Extant approaches to LVR in rule-based phonology and Optimality Theory (Prince & Smolensky 2004) are very different from one another. In rule-based phonology, a rewrite rule (and its counterpart in autosegmental representation) like the one in (14) has been proposed (e.g. Lin's 1989 closed syllable fronting rule for Mandarin Chinese; Ang's 1996 and Chung's 1996 vowel raising rule for Taiwanese, among others).

(14) An SPE-style rule for Low vowel raising

$$\begin{bmatrix} -consonantal \\ +vocalic \\ +back \\ +low \end{bmatrix} \rightarrow \begin{bmatrix} -back \\ -low \end{bmatrix} / \begin{bmatrix} -consonantal \\ -vocalic \\ -back \\ -low \end{bmatrix} \_\_ \begin{bmatrix} +consonantal \\ -vocalic \\ \alpha sonorant \\ \alpha nasal \\ -back \end{bmatrix}$$

The structure description of the rewrite rule (14) is merely a description, rather than a well-motivated phonological generalization. So it is conceivable that LVR might be due to the simultaneous application of a leftward [–back]-spread rule and a rightward [–back, –low]-spread rule. However, analyses in this vein would allow the arbitrary conjunction of two independent rules. For example, it is highly unlikely that a language would progressively spread [+labial] and regressively spread [–distributed] onto a target segment. In sum, chimerical combinations of this sort simply over-generate the typology of possible assimilation patterns.

Alternatively, a (configurational) constraint against *[–bk][+bk][–bk] sequences may be invoked at some point of derivation (15c). Phonotactic constraints of this sort, however, are not without problems. In particular, the key question is: why does [+bk] not survive *only* when flanked by [–bk] segments? In other words, given that either [+bk][–bk] or [–bk][+bk] sequences are perfectly fine (as is schematized in (15a-b); see also (11), (12)), it is quite puzzling why a combination of the environments of (15a-b) may result in the ungrammatical forms in (15c). Moreover, it is also not clear why syllables like [naj], a swapping of the onset and coda of [jan], are not ruled out by the constraint in (15c).

(15) a. [–bk][+bk] [jaː]
b. [+bk][–bk] [an]
c. *[–bk][+bk][–bk] *[jan] (compare: [naj])

In wider perspective, we may further ask why vowel retraction/lowering, the flip side of vowel raising, has never been attested in similar contexts. For instance, /kiŋ/ would be wrongly predicted to map to [kəŋ] in order to satisfy *[+bk][–bk][+bk]. What is worse, if phonotactic constraints can be freely generated, for example, *[+bk][–bk][+bk], *[–bk][–bk][+bk], *[+bk][+bk][–bk] and so on, the effects of these configurational constraints should be observed at least in some languages of the world. But none of the above constraints has ever been attested, to my knowledge. In sum, I conclude that LVR cannot be adequately captured by rewrite rules or (configurational) constraints in rule-based phonology.

3.3.2 The standard analysis in OT

With the advent of OT, phonological generalizations are stated as surface-oriented constraints. So the foregoing analytical problems can be translated into markedness constraints that militate against sequences that do not agree in features. The following AGREE-type constraints have been proposed in Duanmu (2007) (à la Baković 2000) and it is fair to say that approaches along this line are now the de facto standard treatment of segmental phonology of the Sinitic languages (cf. Lin 2003, 2007, Ma 2003, Wu 1994, to name only a few).

(16) Duanmu's (2007) assimilation constraints for Mandarin Chinese
a. Nucleus-coda harmony (NC-HARMONY, also known as RIME HARMONY)
'The nucleus and the coda must agree in frontness/rounding.'
b. Glide-nucleus harmony (GN-HARMONY, also known as GV-HARMONY)
'The prenuclear glide and the nucleus must agree in frontness/rounding.'

The ranking argument for the two assimilation constraints above is best exemplified in tableau (17), if we follow the de facto standard view that there is only one underlying mid vowel /ə/ in Mandarin Chinese (see also fn.19). As we can see, GN-HARMONY must be dominated so that candidate (17b) will not be mistakenly chosen as the winner. Remarkably, tableau (17) reiterates a well-established generalization that regressive assimilation rules/constraints (or, NC HARMONY) precede/outrank progressive assimilation rules/constraints (or, GN-HARMONY) (e.g. Cheng 1973, Lin 1989, Lin 2007:157, Ma 2003:142-144, Wu 1994:72-73).

(17) Basic constraint ranking in Mandarin Chinese

jəw	*[–bk, –hi, –lo, +rd]	NC-HARMONY	IDENT-(F)	GN-HARMONY
a. jəw		*!		*
b. jew		*!	*	
☞ c. jow			*	*
d. jøw	*!		**	

Likewise, LVR is predicted according to the current ranking of constraints. Consider now the tableau in (18) below. For present purposes, I assume that the creation of the low front vowel [æ] is independently eliminated by a top-ranked markedness constraint, *[–bk, –hi, +lo, –rd] (see (9)).

(18) LVR is guaranteed

tjan	*[–bk, –hi, +lo, –rd]	NC-HARMONY	IDENT-(F)	GN-HARMONY
a. tjan		*!		*
☞ b. tjen			**	
c. tjæn	*!		*	

IDENT-(F) must dominate GN- HARMONY here because prenuclear glides normally do not trigger vowel quality change in the nucleus: for example, /jaː/ does not map to *[jeː].[5] The current constraint hierarchy is further confirmed since it successfully explains why LVR is not possible when the coda is non-coronal, as tableau (19) illustrates. This is, again, because segments preferentially agree in place across the Nucleus-Coda boundary.

[5] That is an oversimplification. I shall show in §4.2 that bimoraic vowels are not subject to assimilation (i.e. long vowel faithfulness). More seriously, the partial ranking here, IDENT-(F) ≫ GN-HARMONY, predicts that forms like /jəː/ do not map to /jeː/, contradicting the de facto standard analysis (e.g. Duanmu 2007, Lin 1989, 2003, 2007, 2011, *i.a.*). See also fn.20 for more discussion.

(19) LVR is blocked

tjaŋ	*[–bk, –hi, +lo, –rd]	NC-HARMONY	IDENT-(F)	GN-HARMONY
☞ a. tjaŋ				*
b. tjeŋ		*!	**	

What is often overlooked in analyses along this line is that the active NC-HARMONY constraint derives certain unattested patterns, of which we consider two. First, LVR would be over-predicted if the low vowel /a/ is flanked by anterior coronals. So employing a monolithic markedness constraint like NC-HARMONY wrongly downplays the significance of the palatal glide.[6]

(20) Unexpected LVR: the low vowel between anterior coronals

nan	NC-HARMONY	IDENT-(F)	GN-HARMONY
!☞ a. nen		*	
b. nan	*!		

Second, and more importantly, given the current constraint hierarchy, vowel fronting (not LVR) would be wrongly motivated. That is, central and back vowels (conventionally specified as [+bk]) would undergo fronting between anterior coronals. As tableau (21) shows, NC-HARMONY penalizes a rime that does not agree in backness, i.e. the expected winner (21b).

(21) Unexpected vowel fronting #1: central vowel between anterior coronals

nən	NC-HARMONY	IDENT-(F)	GN-HARMONY
!☞ a. nen		*	
b. nən	*![7]		

Ma (2003:84-89) proposes that closed syllable vowel reduction, i.e. reduction of [e] to [ə] in closed syllables, rules out (21a). But this is rejected by the fact that [e] is attested

[6] Notably, it is not possible to decompose IDENT-(F) into IDENT -([hi]) and IDENT -([bk]) and then rank IDENT -([hi]) over NC-HARMONY. If so, candidate (17a) would be chosen as the winner.

[7] I follow Lee & Zee (2003:111) that [ə] is "a plain mid-central schwa in syllables closed by a nasal". In addition, the present case also casts doubt on underspecification approaches to Mandarin segmental phonology: suppose that central vowels lack a [back] specification, as proposed by Clements (1991). Then, there is no obvious reason why, in *surface* representation, schwa [ə] fails to obtain a [back] specification from its adjacent segments in exactly the same way as the conventional analysis outlined in (17). See §4.4 for more discussion.

in closed syllables such as [tjen˥] 'sky'. Furthermore, left unexplained is why only the vowel [e] undergoes reduction in closed syllables, whereas other vowels such as [u] or [i] are resistant to vowel reduction in the same environments.

Similarly, tableau (22) shows that anterior coronals do not condition fronting, again indicating that the top-ranked NC-HARMONY constraint derives yet another undesirable result. Crucially, there is no denying that both [ny] and [yn] are well-formed surface sequences in Mandarin.[8]

(22) Unexpected vowel fronting #2: back vowel between anterior coronals

nún	NC-HARMONY	IDENT-(F)	GN-HARMONY
!☞ a. ný́n		*	
b. nún	*!		

It appears that an analytical dilemma emerges here. NC-HARMONY must outrank GN-HARMONY to ensure that /jəw/ does not map to *[jew] (17), at the expense of over-predicting unattested instances of rime harmony (e.g. the unexpected LVR in (20) and vowel fronting in (21) and (22)). To answer this, an anonymous reviewer suggested that the rime harmony constraints (NC-HARMONY) be relevant only for diphthongs (e.g. ALIGN-RIME 'align the V-PL features of a high glide within the rime' in Lin 2003:307) so the problems discussed in tableaux (20)-(22) would disappear. While I believe there is merit to this approach, it must be pointed out that the rime harmony effect on [an] constitutes an essential part of LVR. Otherwise, /jan/ and /jaŋ/ would both undergo LVR, if velar nasal codas, too, were not subject to rime harmony effects (see (19)). Therefore, I again conclude that previous approaches couched in OT fail to account for these empirical facts.

3.4 In search of the "raising" feature

The aim of this section is to show that it is difficult to locate a "raising" feature in terms of the mainstream feature theories in (23) below.

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[8] That is a rare word, meaning 'fragrant'. According to Duanmu (2007:325), the SR for 'fragrant' is [n^{w}ə́n] (see also Lee & Zee 2003). So the present case study may be valid for Taiwanese Mandarin only. Also, no vowel fronting is attested in syllables such as [lun], [sun], [tun], etc., suggesting that (22) cannot merely be an isolated case (again, at least in Taiwanese Mandarin).

(23) LVR: defying mainstream feature theories?

	Articulator model	Constriction model
Palatal	[–bk, –ant, +hi]	[+cor, –ant]
Coronal	[–bk, +ant, –hi]	[+cor, +ant]
Low vowel	[+bk, +lo, –hi]	[–cor, –dor, +radical]
Front vowel	[–bk, –lo]	[+cor, –ant]

Some discussion is in order. In the Halle-Sagey (articulator-based) model, the widely accepted view is that [–bk] is the feature responsible for LVR (e.g. Duanmu 2007, Lin 1989, 2003, 2007, among many others). As we have seen in §3.3.2, however, this stance wrongly predicts that flanking anterior coronals trigger LVR as well, e.g. /nan/ → *[nen] (20) vs. /jan/ → [jen], since palatals and coronals are both [–bk]. Alternatively, we might stipulate that only [–ant] palatals are allowed to spread [–bk] onto the target vowel, but, as we have discussed earlier, the idiosyncratic grouping of [–ant, –bk] ultimately leads to over-generation of the typology of place assimilation. If a rule or an OT constraint could make references to two *unrelated* subfeatures, impossible patterns would be generated: for instance, spreading of [+rd] would be dependent on the presence of [+ant].

The Constriction model does not fare better in this regard, either. As noted in Lin (1989:67, fn.24), for example, the low vowel /a/ may not be raised in r-suffixation (or, *Erhua*) in Mandarin Chinese. Consider now (24).[9]

(24) LVR may be "undone" in r-suffixation (Lin 1989, Wang & He 1985, among others)
/jan/ → [jen˥] 'tobacco'
/jan+ɚ/ → [jaɚ˥] 'r-suffixed form for tobacco'

While (24) lends firm support to the assumption that the underlying vowel in the LVR contexts *is* the low vowel /a/,[10] more importantly, the blocking of LVR in r-suffixation strongly argues against the Constriction model for the case at hand. The r-suffix, a rhotic sound, is represented as [+cor, –ant, –distr]. So we expect that palatals

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[9] I, following Lee & Zee (2003:111), treat the r-suffixation as "suffixation of a rhotacized subsyllabic [ɚ] to a rhyme, or to rhotacization of a vowel or a sequence of two vowels in a rhyme."

[10] In their ABX discrimination test, Wang & He (1985:30) report that the confusion rate between [jaɚ] (from [jaː]) and [jaɚ] (from surface [jen] or underlying /jan/) was on average 96.2% (data from 50 native speakers of Beijing Chinese), suggesting that LVR is actually blocked in r-suffixation.

and retroflexes pattern alike with respect to LVR, as (25) would predict: these segments are not distinguishable in terms of the [coronal] specification. However, we have learned in (24) above that that flanking [+cor] segments trigger LVR in some forms (when in non-derived forms) and, without any obvious reason, block the same process in some other forms (i.e. r-suffixation).[11]

(25) Is [+coronal] *the* raising feature?

a.	Palatals	[+cor, –ant]
b.	Anterior coronals	[+cor, +ant]
c.	R-suffix	[+cor, –ant]
d.	Front vowels	[+cor, –ant]

It remains a moot point as to whether any LVR feature could be pinpointed (notably, a much more famous case being the perennial pursuit of the "palatalization" feature); if we stick to the well-established convention that if sound types interact in phonological processes, they must inherently share a feature.

3.5 Interim summary

I have reviewed various attempts to analyze LVR in this section,[12] arriving at the conclusion that neither of them satisfactorily accounts for the phenomena in question. On the one hand, the structural description of the assimilation rules in (14) is simply too ad hoc. Furthermore, breaking the rewrite rule (14) into two separate assimilation rules simply leads to quandaries of over-generation of the assimilation processes. On the other hand, standard OT markedness-based approaches cannot derive the desired effects of which LVR is only possible when following the palatal glide and preceding a coronal coda, and, at the same time, potential ill-formed cases of vowel fronting/raising are

[11] Yet another possibility is that LVR is subject to derived environment blocking (DEB) effects (e.g. Hall 2006). I opt for a phonetically based account in this paper (see (37)).

[12] For the sake of completeness, Li (1999:148-149) proposes that LVR might have arisen from language contact. His proposal is as follows: "because Turkic syllable structure generally does not allow the syllable medial G typically in the Mandarin $C^{G}VE$ syllable, a speaker of Turkic encountering the Mandarin $C^{G}VE$ syllable would most likely analyze the Mandarin structure as two Turkic syllables, i.e., CV_1 + GV_2E, treating the monosyllabic Mandarin word as a disyllabic word, to which vowel harmony would apply … For example, Chinese [m^{i}an] might be analyzed as Turkic disyllabic *miyan*, becoming *miyän* through application of vowel harmony, prompting the shift to Chinese [m^{i}en]". It is fair to say that this scenario is highly unlikely because neither Mongolian nor Tungustic languages had any impact on non-Mandarin Sinitic languages, to the best of my knowledge.

eliminated, too. I have also shown that feature systems play a limited role here, because it seems unrealistic to locate a single feature that is responsible for *all and only* the attested patterns of the process in question. In conclusion, previous analyses as well as feature theories do not suffice to explain LVR and related phenomena.

4. Low vowel raising as backness assimilation in the wake of target undershoot

To set the stage, the phenomenon in question is broken down into two steps. We first assume that vowel centralization occurs in closed syllables and backness assimilation is in turn "triggered", as shown below. Notice that the derivation in (26) is for expository reasons only. LVR, as we shall see below, is better regarded as a derivation in one fell swoop (e.g. Walker 2010).

(26) Approximation: Step-by-step derivation of Low Vowel Raising

UR	/tjan/
Vowel centralization	tjən or tjän
Backness assimilation	tjen
SR	[tjen]

It is important to note that the "intermediate steps" above are by no means arbitrarily stipulated. First, it has long been noted that vowel space contracts as duration reduces, particularly along the F1 dimension (Lindblom 1963). So vowel centralization may not be unexpected since vowel length is substantially reduced in closed/checked syllables (see §4.2 for more discussion). Second, contextual coarticulatory effects involve assimilation in F2 and are particularly robust with respect to segments with comparatively short duration, presumably due to effort minimization (Flemming 2004, 2005). Taken together, it follows that LVR is a kind of special backness assimilation, in that this process is only licensed by target undershoot resulting from impoverished vowel duration. This is because, in language after language, neutralization is overwhelmingly attested in non-prominent positions, while non-prominence is most often, if not always, cued by phonetic length (and perhaps intensity as well). So, metaphorically speaking, target undershoot causes a "vulnerable" centralized low vowel, which subsequently facilitates backness assimilation when appropriate. Therefore, the bulk of the present analysis centers on the above two main factors and argues that LVR is better explained when simultaneous optimization of both factors is achieved.

4.1 Motivating backness assimilation

In this article, I adopt Flemming's (2003) approach to the relationship between coronal place and vowel backness. Departing from the standard assumption, according to which sound types must share a feature just because they interact in phonological processes, he proposes that coronal place and vowel backness are distinctly specified as in (27) below.

(27) "Independence" of coronal place and vowel backness (Flemming 2003; irrelevant sound types are not included)

a. Coronal consonants
   - i. Coronals: [+ant]
   - ii. Palatal-alveolars: [–ant, laminal]
   - iii. Retroflexes: [–ant, apical]
   - iv. Palatals: [front, tense] (see (32) for more detail)

b. Vowel backness
   - i. Front vowels: [front]
   - ii. Central vowels: [central]
   - iii. Back vowels: [back]

By examining a wide range of cross-linguistically attested patterns, Flemming's (2003) insight is that interactions between coronals and vowels are mediated by the three basic constraints in (28), deriving fronting by anterior coronals and palato-alveolars and retraction by retroflexes. For example, ANT → FR requires that [+anterior] coronals have a front tongue body (i.e. [front]). So a [+anterior] coronal articulated with a [central] or [back] tongue-body position incurs a violation of ANT → FR. Likewise, the constraints in (28b-c) require a specific interaction between the relevant sound types. For concreteness, some types of interactions between coronal place and vowel backness are provided in (28d). It is remarkable that the interactions are established via the fact that coronals and front vowels are both produced with the tongue body. In other words, the tongue body position is redundantly specified in the phonological representation.

(28) The relationship between coronal place and vowel backness: The basic assimilation constraints (Flemming 2003:340)

a. ANTERIOR → FRONT (ANT → FR) (where → means 'co-occur')
   [+anterior] → [front]

b. PALATAL-ALVEOLAR → FRONT (PA → FR)
   [–anterior, laminal] → [front]

c. RETROFLEX → BACK (RETRO → BACK)
[–anterior, apical] → [back]

d. Some predicted typology (when the target is a *vowel*. See fn.13 and Flemming 2003:344-345 for a full list of the attested typology)

Vowel fronting:	ANT → FR	/tu/ → [ty]
	PA → FR	/ʃu/ → [ʃy]
Vowel retraction:	RETRO → BACK	/iʈ/ → [ɯʈ]

Directionality effects are regulated by the sub-constraints in (29). Simply put, a consonant is assumed to have (at least) two phases: closure and release, where a closure precedes a release; or schematically, $V^{CLO}C^{REL}V$. Given that, then if assimilation occurs in the release phase, it should be progressive assimilation in $C^{REL}V$ transitions (29a). Likewise, regressive assimilation should occur in $V^{CLO}C$ transitions (29b).

(29) Directionality effects (Flemming 2003:346)

a. ANTERIORRELEASE → FRONT (ANTREL → FR)
'A [+ant] coronal is produced with a [front] tongue body in its release phase', potentially causing *progressive* assimilation: $C^{REL}V$.

b. ANTERIORCLOSURE → FRONT (ANTCLO → FR)
'A [+ant] coronal is produced with a [front] tongue body in its closure phase', potentially causing *regressive* assimilation: $V^{CLO}C$.

The markedness constraint in (30) penalizes tongue-body movement in the transitions into a vowel. Notably, the present formulation may also favor consonant-to-vowel coarticulation encroaching into the vocalic portion.

(30) AGREE[backness] (Flemming 2003:346)
'A consonant closure or release must have the same feature value of backness as the vowel adjacent to that phase of the consonant.'

A sample illustration of Flemming's approach is given in (31). As shown, candidate (31a) means that there is a front tongue position in CV transition, although the following vowel is not [front]. This output form is penalized by the assimilation constraint AGREE[backness] because the consonant release does not have the same feature value of backness as the following vowel. By contrast, candidate (31b) exhibits a "mutual independence" case of CV coarticulation in which a central tongue position follows a [+anterior] onset consonant, thus incurring a violation of ANTREL → FR. Also, it is not impossible that vowel quality may be altered under the influence of adjacent consonants.

This possibility can be either candidate (31c) (i.e. vowel raising) or (31d) (i.e. vowel fronting).[13]

(31) Deriving vowel fronting and raising

ta	AGREE [backness]	ANTREL → FR	IDENT-[backness]$_V$	IDENT [height]$_V$
a. t^{i}a	*			
b. t^{ɨ}a		*		
c. t^{i}e			*	*
d. t^{i}æ			*	

(Where a superscript [^{i}] means a front tongue-body position, and a superscript [^{ɨ}] a central tongue-body position)

Palatal glides are subject to another set of markedness constraints. Recall that palatals are inherently [front] (27a, iv). To account for LVR, we need an additional markedness constraint, requiring that a palatal cannot be articulated with a central tongue-body position in its release phase.

(32) *CENTRALPALATALRELEASE (*CNTPALREL)

a. 'A palatal is not produced with a [central] tongue-body in its release phase.'

b. E.g. *[j^{ɨ}a] is penalized vs. [j^{i}a] is satisfied.

We now turn to the task of showing that a unified account of LVR crucially hinges on the constraints formulated above. First of all, following Flemming (2003), additive effects (§3.2) can be modeled as a self-conjoined constraint of AGREE[backness], in the domain of the syllable (Smolensky 1995).[14] Informally, this constraint is violated if and only if both the preceding and following consonants do not agree in backness with the vowel in the domain of a syllable.

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13 For present purposes, I ignore cases in which vowel backness is assimilated to adjacent consonants. See Flemming (2003) and references therein.

14 An alternative is to employ Flemming's (2001) weighted constraints or Harmonic Grammar (e.g. Pater 2009). In this paper, I use the classic OT framework since additive effects are successfully replicated with the help of self-conjoined constraints as far as LVR is concerned.

(33) AGREE[backness]$_2$
‘Assign a violation mark only if a double violation of AGREE[backness] occurs in the domain of a syllable.’ Or, ‘assign a violation mark only if *both* consonant closure and release do not have the same feature value of backness as the vowel adjacent to that phase of the consonant.’

An analysis of LVR is given in (34) below. To begin, let us consider the case of “mutual independence” coarticulation. That is, candidate (34c) is a fully faithful realization of backness both in the vocalic and transitional portions of the syllable, as is represented with superscript [^{ɨ}]. This faithful rendition is made at the cost of violations of *CNTPALREL (in CV transition) and ANTCLO → FR (in VC transition; regressive assimilation), respectively. By contrast, candidate (34b) satisfies both *CNTPALREL and ANTCLO → FR (motivating regressive backness assimilation), since the consonants are produced with a front tongue body in the CV/VC transitions. But tongue-body movement should be obligatory in this case, because the low vowel /a/ is specified as [central] ((9) and (27)), flanked by flanking [front] tongue body gestures (i.e. superscript [^{i}]’s in [tj^{i}a^{i}n]). Consequently, (34b) incurs a double violation of AGREE[backness] or a single violation of AGREE[backness]$_2$. As we see, the current ranking predicts that faithful realization of a low vowel is strongly disfavored in this context; the only viable solution is to have recourse to LVR, that is, candidate (34a).

(34) Why /jan/ is realized as [jen][15]

	tjan	AGREE [bk]$_2$	*CNTPA LREL	ANTCLO → FR	AGREE [bk]	IDENT [ht]	IDENT [bk]
☞	a. tj^{i}e^{i}n					*	*
	b. tj^{i}a^{i}n	*!			**		
	c. tj^{ɨ}a^{ɨ}n		*!	*			
	d. tj^{ɨ}a^{i}n		*!		*		
	e. tj^{i}a^{ɨ}n			*!	*		

(Where AGREE[bk] = AGREE[backness]; IDENT[ht] = IDENT[height]; IDENT[bk] = IDENT[backness]; I assume that height contrasts are conventionally represented with [±low] and [±high] specifications.)

To derive the fact that flanking coronals does not trigger LVR, as in tableau (35), AGREE[backness] must be ranked below IDENT[height]. Note that this re-ranking will

[15] I assume that other serious candidates such as [jæn] are independently ruled out by some other markedness constraints, e.g. *[–bk, +lo, –hi, –rd] in (18).

not undermine the above analysis because it is obvious in tableau (34) above that no crucial ranking locates AGREE[backness] above IDENT[height], or vice versa.

(35) Why flanking coronals fails to condition LVR

	tan	AGREE [bk]$_2$	*CNTPAL REL	ANTCLO → FR	IDENT [ht]	AGREE [bk]	IDENT [bk]	ANTREL → FR
	a. $\mathrm{t^{i}e^{i}n}$				*!		*	
	b. $\mathrm{t^{i}a^{ɨ}n}$			*!		*		
☞	c. $\mathrm{t^{ɨ}a^{i}n}$					*		*
	d. $\mathrm{t^{i}a^{i}n}$	*!				**		

Some discussion is in order. First, the new ranking has a welcome result: it captures the fact that the presence or absence of the palatal glide has a strong bearing on LVR and, at the same time, coronals alone are incapable of motivating the process in question. This is because *CNTPALREL is vacuously satisfied in (35). Alternatively, we may say that the violation of IDENT[height] is tolerated only if higher ranked assimilation constraints are not active in determining a winning candidate. Second, and more importantly, candidates (35a) and (35c) are tied up with respect to the top-ranked constraints, AGREE[backness]$_2$ and *CNTPALREL. Moreover, it is evident that ANTCLO → FR (requiring regressive backness assimilation) alone does not suffice to trigger vowel raising given that AGREE[backness] is dominated by IDENT-[ht]. So LVR is not expected in (35). The current analysis successfully explains the major puzzle in §3.3.2, namely that there are no rime harmony effects in Vowel-Nasal rimes (for example, no vowel fronting/raising in [tan]), whereas the coronal nasal coda serves as an indispensible factor for LVR (recall that /jan/ → [jen] vs. /jaŋ/ → [jɑŋ]).

A careful reader may wonder how these candidates are phonetically realized. The original assumption is that these superscript forms, [^{i}] or [^{ɨ}], stand for a specific tongue-body position in CV/VC transitions, while AGREE[backness], the assimilation constraint, demands that consonantal backness assimilates to an adjacent vowel. Under these assumptions, the winning candidate (35c) is interpreted like this: no substantial backness assimilation occurs in CV, whereas the coda consonant is produced with a front tongue body in VC. In fact, this conforms to the well-known observation that in the context of codas the low vowel /a/ takes a relatively front allophone before the coronal nasal/stop in a handful of Sinitic languages. The magnitude of the F2 differences between [an] and [ɑŋ] in Mandarin Chinese can be as large as 400~500 Hz (e.g. Mou 2006, among many others). By contrast, no such variation has been reported for [ta] vs. [ka], as far as I know. Taken together, this asymmetry in coarticulatory effects is motivated by the ranking: ANTCLO → FR ≫ ANTREL → FR. See §4.4 for more discussion.

Likewise, the tableau below shows that LVR is not possible when a non-coronal appears in coda position. Our explanation again hinges on the fact that the winning candidate incurs no violation of the feature co-occurrence constraints.

(36) Why the palatal glide alone does not trigger LVR

jaŋ	AGREE [bk]$_2$	*CNTPALREL	ANTCOL → FR	IDENT [ht]	AGREE [bk]	IDENT [bk]
a. j^{i}e^{i}ŋ				*!		*
☞ b. j^{i}a^{i}ŋ					*	

Finally, the analysis developed so far can be extended to the r-suffixation data without any problem. We have learned in (24) that the low vowel /a/ may be faithfully realized in r-suffixation in some varieties of Mandarin Chinese. I argue that this phenomenon is purely assimilatory in nature. More precisely, retroflexes are preferentially licensed in VC transition because i) a lowered F3 is perceptually more salient in postvocalic position (Steriade 2001) and ii) kinematically speaking, retroflexes are fully retroflexed only at the onset of constriction, thus requiring a back tongue-body position in the closure phase/onset of constriction (Flemming 2003; see also Boersma & Hamann 2005). This preference has been formalized in (28c), while a more specific incarnation is used here: RETROCLO → BACK 'A retroflex is articulated with a [back] tongue-body position in its closure phase' (i.e. requiring regressive backness assimilation). We see in tableau (37) that LVR is blocked in r-suffixation, if RETROCLO → BACK dominates the self-conjoined constraint AGREE[backness]$_2$.[16]

(37) Why Low Vowel Raising is blocked in r-suffixation

jan+ɚ	RETROCLO → BACK	AGREE [backness]$_2$	IDENT [height]	AGREE [backness]
☞ a. j^{i}a^{ɯ}ɚ		*		**
b. j^{i}e^{i}ɚ	*!		*	

(Where a superscript [^{ɯ}] means a back tongue-body position.)

So the present case study is yet another example lending support to the generalization that not all coronals condition vowel fronting and/or retraction (Flemming 2003). It is obvious by now why [coronal] alone cannot account for the full array of the LVR

[16] The current analysis wrongly predicts that the r-suffix cannot follow any central or front vowels. While more analytical details need to be fleshed out, I leave it for future research because the main concern here is the affinity of retroflexes and the back tongue body and its consequences for LVR.

data in Sinitic languages (see also (25)). To this end, I have shown that backness assimilation (i.e. the second "step" in (26)) is straightforwardly explained in a wide range of phenomena related to LVR.

4.2 The role of target undershoot

What is left unanswered in the foregoing analysis is the neutralization of height contrasts in LVR (i.e. the rule of vowel centralization in (26)). It has been proposed that vowel centralization is phonetically grounded, especially for the low vowel. In his seminal work, Lindblom (1963) proposes that longer duration is needed to achieve the open upper vocal tract required to produce a higher F1, especially when a low vowel is being produced between consonants, which is reflected in the well-established generalization that low vowels tend to be longer than high vowels (Lehiste 1970). Thus, it has been proposed that the direct effect of vowel shortening is to increase the difficulty of producing low vowels, thus triggering the raising of low vowels (Flemming 2004, 2005 *i.a.*). That is instrumentally confirmed in Mandarin Chinese, too. For example, Lee & Zee (2003) report that "in syllables closed by a nasal, … [a]=[a̝]", indicating that the low vowel is reduced to a raised allophone in closed syllables. By contrast, contextual coarticulatory effects primarily involve assimilation in tongue body (and lip position), "because the positions of the relevant articulators in the vowel are generally anticipated during a preceding consonant and continue to influence the articulation of a following consonant" (Flemming 2005).

Recall that the raised low vowel changes to the nonlow front vowel [e] only when preceded by the palatal glide and followed by a coronal nasal. To account for this particular restriction, therefore, I propose that the raised low vowel in closed syllables has a strong bearing on the operation of LVR, although LVR is primarily conditioned by contextual influence. More precisely, the raised low vowel helps reduce the greater opening and closing movements of the vocal tract involved in producing a low vowel between consonants, thus facilitating front-back tongue movement to a substantial extent. In other words, backness assimilation is driven by effort minimization only when neutralization of height contrasts occurs.

The correlation between duration and raising of low vowels is further confirmed by the fact that LVR is "blocked" when the target is a (phonetically) long vowel. I offer a faithfulness-based account here.[17] From a cross-linguistic survey, Beckman (1998) argues

[17] A markedness-based account may run as follows. Contrasts tend to be neutralized under extreme pressure from markedness, namely that it is not easy/hard to overcome articulatory difficulty in achieving appropriate targets in impoverished durations. Under this view, "bad" vowels would be eliminated across the board (cf. Flemming 2004:246 under *SHORT LOW V, a

that "faithfulness constraints may be more protective of long vowels than their short counterparts" (see also Barnes 2006). In OT terms, this asymmetry may be attributed to long vowel faithfulness, which is presumably motivated by Hayes' (1989) geminate inalterability. In view of functionalism, faithfulness, too, may be prioritized over long vowels because more contrasts are licensed among them so that unfaithful realization is accordingly disfavored, the main reason being that confusability increases as contrasts are not fully faithfully realized. That being the case, this preference can be translated into a fixed ranking of the two indexed faithfulness constraints: IDENT[height]$_{\text{LONG V}}$ ≫ IDENT[height]$_{\text{SHORT V}}$.

The two tableaux below illustrate the effects of long vowel faithfulness in LVR. Note that there may be different violation profiles for candidates (38b-c), if the faithfulness constraints are gradiently assessed. For present purposes, it is not necessary to distinguish between them — for the main concern here is that (phonetically) long vowels must be faithfully realized regardless of markedness pressure.

(38) Phonetically long vowels

	jaː	IDENT[height]$_{\text{LONG V}}$	AGREE[bk]$_2$	IDENT[height]$_{\text{SHORT V}}$
☞	a. jⁱaː			
	b. jⁱeː	*!		
	c. jⁱæ͡a	*!		

(39) Phonetically short vowels

	jan	IDENT[height]$_{\text{LONG V}}$	AGREE[bk]$_2$	IDENT[height]$_{\text{SHORT V}}$
	a. jⁱaˑⁱn		*!	
☞	b. jⁱeˑⁱn			*

Good evidence that the different degrees of shortening can result in different patterns of LVR is provided by the variety of Xiamen Chinese documented in Luo & Zhou (1975). Their finding in (5) is repeated below. The significance of the Xiamen Chinese data is that checked syllables do not pattern with nasal-ending syllables, as far as LVR is concerned. That is to say, vowel duration plays a decisive role for the case at hand. In fact, three (non-contrasting) duration types have been documented in two separate phonetic studies (Taiwanese: based on unpublished data of mine from 10 young male speakers and Hong Kong Cantonese: based on Zee's 2003 data from 50 male

markedness constraint eliminating low vowels in durationally impoverished syllables (i.e. absolute neutralization of low and nonlow vowels in short syllables). That is apparently not the case in Sinitic languages. As we have seen, low vowels are only *contextually* neutralized with mid front vowels when they follow the palatal glide and precede a coronal coda.

speakers and 50 female speakers). Both sets of results exhibit a significant correlation of vowel duration and syllable types.

(40) Xiamen Chinese (Luo & Zhou 1975:11-12)

a. [iaː] No low vowel raising in open syllables

b. [iaˑn] No low vowel raising in nasal-ending syllables

c. [iɛt] Low vowel raising is attested in checked syllables

(41) Mean vowel duration across different syllable types

		Taiwanese	Cantonese (Zee 2003)
Long vowel	CVː	210 ms	approx. 350 ms
Half-long vowel	CVˑN	133 ms	approx. 200 ms (CVˑN/S)
Short vowel	CVS	92 ms	approx. 120 ms

Therefore, the correlation in question can be further formalized in terms of three faithfulness constraints indexed to a specific duration type (cf. tableaux (38) and (39)). For the same reason, it is plausible that faithfulness constraints on vowel backness are formulated in a similar fashion.

(42) IDENT[height]$_{Vː}$ ≫ IDENT[height]$_{Vˑ}$ ≫ IDENT[height]$_{V}$

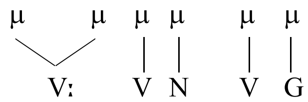
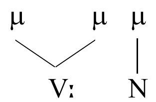
Regarding factorial typology, the proposed faithful and assimilation constraints are sufficient to derive all of the predicted patterns of interaction between vowel duration and LVR. (43a) predicts (contemporary) Mandarin Chinese, Taiwanese (Stage 3 in (7)), and some varieties of Hakka (e.g. Lee & Zee 2009). (43b) is exemplified by the variety of Xiamen Chinese in Luo & Zhou (1975) (Stage 2 in (7)). The ranking in (43c) allows no LVR, which is found in Cantonese, Gan (Nanchang Chinese), Min (Xiamen Chinese, Stage 1 in (7)), Xiang (Changsha Chinese), and some dialects of Mandarin/old Mandarin (see fn.3). The only unattested typology is the one predicted by (43d), requiring obligatory backness assimilation between consonants and vowels, but this occurs probably because (43d) may be ruled out by independent reasons; for example, no language would strictly enforce “CV harmony”, disallowing surface forms such as *[ki], *[tu], *[ja] and so on. Presumably, this is not a possible language since too many indistinct contrasts would be created.

(43) A factorial typology

Rankings	Attested?
a. IDENT[ht]$_{V:}$ ≫ AGREE ≫ IDENT[height]$_{V\cdot}$ ≫ IDENT[ht]$_{V}$	Yes
b. IDENT[ht]$_{V:}$ ≫ IDENT[ht]$_{V\cdot}$ ≫ AGREE ≫ IDENT[ht]$_{V}$	Yes
c. IDENT[ht]$_{V:}$ ≫ IDENT[ht]$_{V\cdot}$ ≫ IDENT[ht]$_{V}$ ≫AGREE	Yes
d. AGREE ≫ IDENT[ht]$_{V:}$ ≫ IDENT[ht]$_{V\cdot}$ ≫ IDENT[ht]$_{V}$	No (see text)

Last but not least, it must be pointed out that the correlation in question does not easily accommodate abstract timing units such as mora. By way of example, Taiwanese has a (non-lexical) three-way weight distinction (44). Here I assume that Taiwanese is a good approximation of Xiamen Chinese, since they are closely related (sub-)dialects. As we can see, it is not the case that monomoraic vowels are uniformly subject to LVR, as evidenced in Luo & Zhou's (1975) data ((5) and (40)).

(44) Weight reflection in Taiwanese Southern Min/Xiamen Chinese

			Weight reflection
a.	light	Checked syllable Neutral tone 	Only level tones are licensed
b.	heavy		Only level and contour tones are licensed
c.	superheavy	Initial syllable in double reduplication 	Level, contour and convex tones are licensed

Similarly, bimoraic/phonetically longer vowels are not always resistant to LVR, as this process remains intact in double reduplication (i.e. a morphological process encoding intensification and vivification, e.g. *pjeːn˧˥˧-pje·n˨-pje·n˧* 'in a fully prepared manner'). According to Du's (1988) experimental results, the initial syllables are substantially lengthened in this morphological environment, which is conventionally analyzed as realization of a floating mora. Of course, this may well be due to O(utput)-O(utput) correspondence effects, so that vowel quality in the base is faithfully realized in the derivatives. But the real challenge is this: if we produce the LVR-ed forms, e.g.

[pjeˑn˧] ‘ready’, at an extremely slow speech rate, the presumably lengthened low vowel might then be protected by the long vowel faithfulness constraint in (38). Thus, in the absence of OO correspondence effects, the prediction is that LVR would be blocked, resulting in an ungrammatical form *[pjaːn˧].

In fact, it is well known that neutralization is, by and large, rate-independent. To account for this robust generalization, Steriade (1999) proposes that effort and distinctiveness are evaluated with respect to some normal, canonical speech rate and style, while Flemming (2001) hypothesizes that since the grammar is primarily concerned with potential lexical contrasts, the neutralization of the /jan/-/jen/ contrast occurs even though it could be faithfully realized in slow, careful speech. This is mainly attributed to the assumption that no desirable “cost” over a sufficient range of speech rates would be attained. That is, in Flemming’s (2001) weighted constraint-based analysis, well-formedness is solely determined on the basis of the summed costs imposed by individual constraints (cf. Prince & Smolensky’s 2004 Harmonic Grammar; see also Pater 2009 for a general survey of recent developments), rather than of strict dominance in classic OT. I suggest, though not explored here, that both treatments above may be, *grosso modo*, formalized by a faithfulness constraint militating against allophonic variation of a potential lexical contrast (cf. Kenstowicz’s 1996 UNIFORM EXPONENCE). To conclude, it is not necessarily the case that phonetically driven constraints always result in rate-dependent allophonic variations.

4.3 Mid vowel fronting

It should be further noted that unattested instances of vowel fronting are eliminated, if IDENT[bk] outranks AGREE[bk], as in (45a) and (46a). Notice that this re-ranking does not undermine the analysis developed in §4.1, since LVR is guaranteed as long as *CNTPALCLO and ANTCLO → FR dominate IDENT[bk]. It is also remarkable that the schwa is realized as an unrounded back vowel /ɤ/ in open syllables (Lee & Zee 2003:11), suggesting that ANTCLO → FR does cause/keep the schwa more fronted in (45), as in the case of [an] in (35) and discussion thereof.

(45) Mandarin: Central vowel fronting is blocked in VN

	sən	AGREE $[bk]_2$	ANTCLO → FR	IDENT-[ht]	IDENT [bk]	AGREE [bk]	ANTREL → FR
	a. s^{i}e^{i}n				*!		
	b. s^{ɨ}ə^{ɨ}n		*!				*
	c. s^{i}ə^{i}n	*!				**	
☞	d. s^{ɨ}ə^{i}n					*	*

(46) Mandarin: Back vowel fronting is blocked in VN

	nun	AGREE $[bk]_2$	ANTCLO → FR	IDENT-[ht]	IDENT [bk]	AGREE [bk]	ANTREL → FR
	a. n^iy^in				*!		
☞	b. $n^ɯu^in$					*	*

This basically completes the analytical part of LVR in Mandarin Chinese (and presumably Sinitic languages in general). One point on which I am silent is how the postnuclear glides are to be analyzed in the current framework. In particular, as has been pointed out by an anonymous reviewer (see also §3.3.2), it may well be the case that there are distinct assimilatory patterns as far as VG and VN structures are concerned, to which I shall return in the following section.

4.4 Postnuclear glides versus coda consonants

To understand the distinction between VG and VN, let us first look at an apparent counterexample to the current analysis: [jaj] sequences in Mandarin Chinese and Hakka (e.g. [kiai] 'street' in Meixian Hakka (Yuan et al. 1983:148, 156) and Meinong Hakka (Chung 2004:26)). There is no denying that [jaj] 'cliff' may be regarded as an exception because there are just one or two words following this pattern in the entire lexicon of Mandarin Chinese (and perhaps in Hakka). In addition, [jaj] is highly marked and vulnerable. For example, the loss of the postnuclear glide has been found in colloquial Taiwanese Mandarin, i.e. [jaː] 'cliff'. Similarly, in Taiwanese Hakka, reported in Chung (2004:26), vowel coalescence occurs, resulting in forms such as [kie] 'street' among middle-aged speakers in Meinong Kaohsiung, while this sound change takes a further step among young speakers: the prenuclear palatal glide deletes, yielding forms like [ke] 'street'. A proper treatment of sound changes of this sort is definitely beyond the scope of this paper. For our purposes, assuming that [jaj] is well-formed, I would like to explore the theoretical significance of the /jaj/ sequences in Sinitic segmental phonology.

We have learned that the palatal glide plays an important role in LVR. So LVR should be expected when the low vowel is flanked by the palatal glides; quite the contrary, the actual surface form is candidate (47c). Needless to say, (47c) poses a serious problem for the analysis developed in this work, especially due to the fact LVR is surprisingly blocked by its quintessential trigger.

(47) A counter-LVR effect?

jaj	AGREE [bk]$_2$	*CNTPAL REL	IDENT [ht]	IDENT [bk]	AGREE [bk]	*CNTPAL CLO
a. j^{i}a^{i}j	*!				**	
b. j^{i}e^{i}j			*!	*		
☞ c. j^{i}a^{ɨ}j					*	*

It is very likely that candidate (47b) is independently ruled out, since /jej/ sequences are marked cross-linguistically, to my knowledge.[18] However, I instead argue that (47) uncovers a deeper generalization. Specifically, in Mandarin Chinese, Vowel-glide sequences may not be subject to NC-HARMONY (or RIME HARMONY), requiring that the nucleus and the coda agree in backness and rounding (16). In tableau (47), this possibility is analyzed by ranking *CNTPALCLO (i.e. *[closure: central, front, tense], see also (32)) lower than the assimilation and faithfulness constraints. In other words, the present analysis bans regressive backness assimilation triggered by a *postnuclear* palatal glide.

It is important to note that *CNTPALCLO is by no means opportunistically ranked. That is primarily because /aj/ does not map to [ej], indicating that IDENT[height] must dominate AGREE[backness]. Moreover, we have learned in tableaux (45) and (46) that IDENT[backness] must outrank AGREE[backness] so as to block mid vowel fronting. So our analysis generally disallows vowel quality change, LVR being the only exception. Put differently, the higher ranked feature co-occurrence constraints, *CNTPALREL and ANTCLO → FR, are responsible for LVR; otherwise, vowel quality change is banned. I argue that this dominance relation crucially hinges on different coarticulatory patterns between the two structures. With regard to VN, it is well-known that the low vowel /a/ has two relatively distinct allophones, [an] and [ɑŋ]. Hsieh et al. (2009), by examining Mandarin adaptation patterns of coda nasals in English loanwords, propose that this allophonic variation is better analyzed as an enhancement effect (à la Keyser & Stevens 2006) that the speakers can use to identify the place of articulation of the nasal coda. The most likely motivation is that Mandarin coda nasals may be nasal liquids (based on Wang's 1993 aerodynamic data), decreasing the perceptibility of place contrasts, which is primarily due to the lack of nasal murmur and release. By contrast, postnuclear glides are not subject to enhancement effects because perceptual confusability is admittedly not an issue here (i.e. [j] vs. [w]). In sum, for present purposes, the ranking arguments can be accordingly motivated in (48).

[18] Anti-merger constraints might explain why /aj/ and /ej/ are not neutralized. But contrast preservation is not strictly obeyed: for example, both /jun/ and /jyn/ map to [jyn] according to our analysis.

(48) Why VG and VN are different

a. Enhancement in VN = more coarticulatory effects on the nucleus
ANTCLO → FR ≫ IDENT[backness]

b. No enhancement in VG = fewer coarticulatory effects on the nucleus
IDENT[backness] ≫ *CNTPALCLO

An immediate question arises, of course: how do the above rankings derive the attested surface diphthongs? Consider now (49), whereby the widely accepted alternations in Mandarin Chinese are repeated for ease of discussion.

(49) Some conventional examples of mid vowel assimilation

a. /əj/ → [ej], /əw/ → [ow], etc.

b. /jəw/ → [jow], /wəj/ → [wej], etc.

In our discussion of vowel fronting in (45) and (46), for example, the reason that [ən] does not map to [en] is due to the ranking IDENT[bk] ≫ AGREE[bk]. From (50), however, it seems that a ranking paradox emerges.

(50) A potential problem: obligatory VG harmony?

	əj	IDENT[bk]	AGREE[bk]	*CNTPALCLO
?☞	a. $ə^{i}$j		*	
	b. e^{i}j	*		

It remains to be seen whether or not rimes such as /əj/ or /əw/ are actually systematic gaps (cf. Duanmu's 2008 Spotty Data problem). But there is good evidence that, at least in some varieties of Mandarin Chinese, [ə] may co-occur with other vowels in surface forms. First, [əj], [əw], and so on are found in Li (1999), J. Wang (1993), and F. Wang (1963) and they are mentioned as phonetic variants of [ej], [ow], etc. in Lin (2007). Second, it has also been noted that in high-toned syllables (Tone 1 or Tone 2 in Mandarin), the schwa tends to be deleted if it occurs after a glide and before a high vowel, e.g. [wəi˨˩˦] 'tail' vs. [wiː˧˥] 'danger'; [juː˥] 'superior' vs. [jəu˨˩˦] 'to have' (e.g. L. Wang 1980:15, Xu 1980:75, cited in Duanmu 2007:69). Third, Lin (2007:161) describes the phenomenon dubbed "rime reduction", whereby [aj] may be reduced to [əj] in unstressed syllables. Finally, my personal judgments, shared by some other native speakers, do not find forms like [əj] or [əw], etc. utterly unacceptable. All in all, it is evidently reasonable that (50a) and the like should be accidental gaps in Mandarin

Chinese.[19] A proper assessment of this issue is again beyond the scope of this paper, awaiting experimental results from well-formedness rating tasks in the future.

Finally, suppose that [əj], [əw], etc. are actually ill-formed (due to a possible grammar). A potential solution, implicitly suggested by an anonymous reviewer, will be to decompose AGREE[backness] into AGREE[backness]$_{\text{VOWEL-NASAL CODA}}$ and AGREE[backness]$_{\text{VOWEL-GLIDE}}$, as formulated in (51) below.[20] As we can see in the tableaux below, this analysis derives the desired results; meanwhile LVR is guaranteed as long as both *CNTPALREL and ANTCLO → FR dominate IDENT[height], as in (34).

(51) AGREE constraints indexed to distinct postnuclear elements

a. AGREE[backness]$_{\text{VN}}$
'A nasal closure (V^{CLO}N) must have the same feature value of backness as the vowel adjacent to that phase of the consonant.'

b. AGREE[backness]$_{\text{VG}}$
'A glide closure (V^{CLO}G) must have the same feature value of backness as the vowel adjacent to that phase of the consonant.'

(52) Decomposing the AGREE constraint

əj	AGREE[bk]$_{\text{VG}}$	IDENT[bk]	AGREE[bk]$_{\text{VN}}$
a. $ə^{i}$j	*!		
☞ b. e^{i}j		*	

19 The reader may wonder about the cases of [ej] or [ow], given (50). This is not a problem if there are three (3) underlying mid vowels in Mandarin (i.e. [e], [o] and [ə]). Specifically, /ej/ maps to [ej], for example. Notice that mid vowel assimilation is entirely based on the standard phonemicization procedure, namely that Mandarin Chinese has only one underlying mid vowel /ə/ just because the schwa vs. [e]/[o] are in complementary distribution. Nevertheless, it is well-established that redundancy is *not* necessarily minimized in the underlying representation, particularly with the advent of Optimality Theory.

20 An anonymous reviewer questioned [jəː] or [jɤː]. According to my analysis, these forms should be well-formed, since (phonetically) long vowels are not subject to backness assimilation. So it may well be the case that these forms are accidental gaps, too. Notice that the de facto standard analysis does not fare better: If /jəː/ maps to [jeː] in order to avoid a violation of (top-ranked) GN-HARMONY (but see (17) and fn.5), then it is predicted that /jan/ and /jaŋ/ should both undergo LVR, contrary to fact. In addition, analyses in this vein also wrongly predict that /jaː/ maps to *[jeː]. Finally, another attempt I know of so far is found in Duanmu (2000:68, ex.(37a)). He stipulates this constraint: GVV-[–bk]: 'A long vowel should agree in [back] with the preceding glide.' Given that, it is not clear why some phonetically short vowels fail to do so, e.g. [jɑŋ˦] 'sheep' (cf. long vowel faithfulness in §4.2).

	sən	AGREE[bk]$_{VG}$	IDENT[bk]	AGREE[bk]$_{VN}$
☞	a. sə^{i}n			*
	b. se^{i}n		*!	
	jaj	IDENT[ht]	AGREE[bk]$_{VG}$	AGREE[bk]$_{VN}$
☞	a. ja^{i}j		*	
	b. je^{i}j	*!		

5. Conclusion

In this paper, I have firstly shown that cross-linguistic/dialectal variation of LVR is amply evidenced, indicating that this process cannot be entirely reduced to an automatic consequence of speech physiology. Previous approaches, be they ruled-based or constraint-based, have been reviewed and some problematic analytical issues have been raised. Subsequently, I have developed a unified account for the full array of the Mandarin Chinese data related to LVR and this analysis is in general applicable to most Sinitic languages. In essence, LVR is special backness assimilation in the wake of duration-induced vowel centralization (or, target undershoot). Of particular importance is that LVR (a phonological phenomenon) is motivated only when the benefit of contextual neutralization exceeds that of the sum of the cost of faithfully implementing the coarticulatory patterns. In other words, there is no separation between "phonological" vowel change and "phonetic" coarticulatory effects (see, for example, Hayes et al. 2004 for more contributions along this line of research).

Finally, for a clearer overview, the essential parts of the proposed analysis are itemized as follows.

(53) Summary of the complete analysis

a. Only this combination: a prenuclear glide plus a coronal coda trigger LVR (i.e. additive effects):
AGREE[bk]$_2$ ≫ IDENT-[bk/ht]

b. LVR is licensed only in the presence of a prenuclear palatal glide:
*CNTPALREL is vacuously satisfied in syllables such as [nan], [tan], etc.

c. Flanking anterior coronals do not induce LVR:
IDENT-[bk] ≫ AGREE[bk], ANTREL → FR

d. Non-coronal codas do not condition LVR, even though a prenuclear palatal glide is present:
*CNTPALREL alone does not suffice to trigger LVR: IDENT-[bk/ht] ≫ AGREE[bk];

ANTCLO → FR (motivating regressive backness assimilation) is vacuously satisfied here

e. Prenuclear palatal glides alone do not trigger LVR in open syllables:
Long vowel faithfulness ($\text{IDENT[ht]}_{\text{LONG V}}$) is prioritized

f. LVR is licensed if and only if the low vowel /a/ appear between a prenuclear [j] and a coronal coda [n]:
Both *CNTPALREL and ANTCLO → FR ≫ IDENT-[bk/ht]

g. LVR may be blocked in r-suffixation:
Rhotics motivate vowel retraction in VC transitions, namely, RETROCLO → BACK ≫ AGREE[bk]_2

While there are some more interesting issues left unanswered (e.g. the variegated LVR in Meixian Hakka (4) and the loss of the prenuclear palatal glide among younger Taiwanese speakers (6)), this work has demonstrated that violable feature co-occurrence constraints relating distinct features, together with phonetically driven constraints (e.g. long vowel faithfulness), provide a unified account of why the low vowel /a/ is raised only when following a palatal glide and preceding a coronal coda.

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漢語族語言的低元音抬升現象：是同化、縮減，抑是兩者兼具？

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許多漢語族語言裡的低元音 /a/ 在介音 /j/ 與舌尖韻尾之間會變爲 /e/ 元音（亦即「低元音抬升」）。藉由爬梳跨語言的語料，本文首先指出此現象與韻核元音音長、韻首的種類乃至於捲舌音之有無皆息息相關，因此將其視爲純然協同構音之結果難免有以偏概全之虞。本文更進一步論證低元音抬升的動因應係輔音與元音間舌位前後同化作用加上音長縮減所誘發之舌位高低不到位現象的總合結果。兩者缺一不可。理論分析則採用 Flemming (2003) 所提倡之將元音的舌位前後與輔音的舌尖性分開標註、且以共存制約連結兩者的處理模式，並佐以以語音爲本的優選理論制約。本研究結果顯示低元音抬升（典型的「音韻」現象）其實應源自於種種協同構音（典型的「語音」現象）「加總」後所致，也讓我們對標準漢語音段層面音韻現象裡的標準分析進行了一些反思。

關鍵詞：元音抬升，元音縮減，同化作用，音段層面音韻現象，漢語