Moraicity, gemination, and syllable well-formedness in Shiwilu*

Abstract[1]
This paper argues that the central vowel /ɘ/ in Shiwilu, a language from the Peruvian Amazon, is non-moraic. In response to its non-moraic status, the syllable onset following /ɘ/ geminates in order to satisfy a syllable well-formedness condition requiring that every syllable has a mora. Phonological and phonetic data provide evidence for both the non-moraic status of this central vowel and the gemination repair strategy. We propose that unlike in most languages displaying mora augmentation, gemination in Shiwilu is not driven by a Stress-to-Weight constraint; rather, it is motivated by the combination of highly ranked constraints prohibiting non-moraic syllables and moraic non-low central vowels. The Shiwilu case fills a typological gap by instantiating a pattern predicted to occur given re-ranking of constraints independently needed to derive attested interactions between moraicity and prosodic headedness.

Keywords: central vowels, syllable weight, moraic theory, gemination, sonority hierarchy, Shiwilu

1. Introduction

Interior (non-low central) vowels like schwa often behave differently from peripheral vowels. They frequently appear as epenthetic or excrescent vowels, are positionally restricted, and tend to avoid stress. These properties reflect their prosodically light status, aligning with their shorter duration, lower intensity, and reduced articulatory effort. Phonological theory captures this via constraints that penalize stressed (Kenstowicz 1997) or moraic (Shih 2018b) interior vowels, and others that ban peripheral vowels in unstressed positions (Crosswhite 2004). Still, interior vowels can serve as syllable nuclei, and are preferred over consonants for this role—even in languages that permit consonantal peaks (Zec 1995, Recasens 2022).

While some interactions between interior vowels and prosodic constraints have been identified, the typological predictions of their full constraint ranking space remain underexplored. This article examines a relevant case in Shiwilu, a critically endangered Kawapanan language of Peruvian Amazonia with about 30 elderly speakers. In Shiwilu, consonants geminate after the non-moraic central vowel /ɘ/, not due to a Stress-to-Weight requirement, but in response to two constraints: one mandating that every syllable have a moraic head, and another banning moraic interior vowels. Both constraints cross-linguistically shape the prosodic behavior of interior

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[1] This paper uses the following abbreviations: 3=third person, CONT=continuative, IMP=imperative, LOC=locative, NFI=non-future indicative, NOM=nominalizer, PL=plural, POSS=possessive, PTCP=participle, SG=singular, SS=same subject.

vowels. Shiwilu is typologically unusual in enforcing both constraints without exception, resulting in /ɘ/ never being moraic.

The empirical foundation of this study relies on a combination of phonological observations and phonetic analysis of both naturalistic and elicited recordings of Shiwilu. It is shown that the phonetic manifestations of non-moraicity and its repair are robust in natural speech, thereby extending results that had previously been limited to controlled experimental conditions (e.g., Broselow et al. 1997, Gordon 2002) and demonstrating that phonetic manifestations of phonological weight are evident even in noisy data.

The structure of the paper is as follows: §2 provides a typological overview of non-moraic interior vowels. §3 summarizes Shiwilu segmental and suprasegmental phonology and the corpus used in this study. §4 presents durational evidence for gemination and the non-moraic status of the interior vowel in Shiwilu. In §5, we discuss the representation of geminates in Shiwilu, while §6 develops an Optimality-theoretic analysis of Shiwilu's interior vowel couched within the factorial typology of constraints governing the weight of interior vowels. §7 contextualizes the findings for Shiwilu relative to the cross-linguistic relationship between interior vowels, syllable weight, and stress. §8 concludes the paper.

2. Non-moraic interior vowels in the literature

It has long been observed that "heavy" syllables tend to attract stress or tonal contrasts, appear in metrically prominent positions, and/or satisfy morphological templates or minimality conditions. In phonological theory, syllable weight is typically encoded by mora count: syllables with more moras are heavier (Hyman 1985; Hayes 1989). Moras (μ) are usually projected based on contrasts in segment length or count in the syllable rime, though in rare cases syllable onsets may contribute weight (Topintzi 2008).

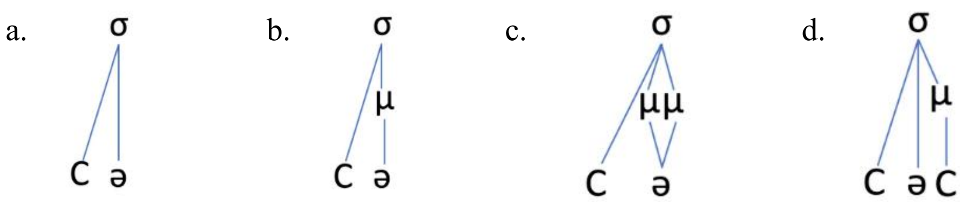
Moraic status can also vary by vowel quality (Kenstowicz 1997; de Lacy 2004), with lower-sonority vowels treated as lighter in some languages. Among such weight contrasts, the most robust—also operative in Shiwilu—involves a distinction between non-low central vowels (i.e., interior vowels) and peripheral vowels (front, back, and low). Gordon (2006) cites 12 cases of stress avoidance on interior vowels, usually schwa, versus only three involving peripheral vowel contrasts. Shih & de Lacy (2019) even question the validity of weight distinctions among peripheral vowels.

Non-moraic interior vowels show phonetic properties consistent with their light status: they are short (Crosswhite 2004) and exhibit greater quality variance. Their acoustic properties are plausibly grounded in articulation (Shih 2018b: 21–22), as their target lies near the vocal tract's default center, requiring less movement and effort than peripheral vowels (Gordon et al. 2012). Because of this centrality, interior vowels such as schwa often serve as epenthetic or excrescent elements inserted to meet phonotactic or syllabification demands (Piggott 1995).

Hyman (1985) proposes that schwa may be either moraic or non-moraic. Building on this, Shih (2018b) offers an enriched representation of interior vowels, showing that schwa can be non-moraic, monomoraic, or bimoraic—even within the same language. In Piuma Paiwan, for instance, schwa is typically non-moraic (1a), but is monomoraic in non-head positions of a foot (1b), and bimoraic as a foot head (1c) (Shih 2018a, 2018b). However, these configurations are not attested in Shiwilu: (1a) is ruled out by a ban on syllables lacking a moraic head, while (1b) and (1c) violate a constraint against moraic interior vowels. The only licit configuration in

Shiwilu is (1d), where the postvocalic consonant bears the mora. This consonant may be in word-final or preconsonantal position, or be the first half of a geminate.

(1) Possible moraic representations of syllables with a schwa-like vowel



3. Shiwilu phonology

This section describes phonological properties of Shiwilu. The description of segmental phonology, syllable structure, and stress patterns is based on previous work (primarily Valenzuela & Gussenhoven 2013) and confirmed with our study, while the discussion of segment distributions relies on our own corpus, which serves as the basis for the phonological analysis and assumed representations presented in §5 and §6.

3.1 Corpus data

The data for this study come from a 66-minute corpus of 13 narratives recorded in Iquitos, Jeberos, and Yurimaguas in July–August 2019. The speakers were 8 women and 1 man, aged 58–88, all bilingual in Shiwilu and Spanish. The narratives include folklore, legends, and anecdotes. Recordings were made with the built-in mic of a Tascam Linear PCM DR-100MKII at 44.1 kHz and 16-bit. A Shiwilu speaker assisted with transcription using ELAN (Sloetjes & Seibert 2016), and segmentation was done in Praat (Boersma & Weenink 2018). A customized Praat script was used to extract duration and vowel formant data. All examples not otherwise sourced come from this corpus.

3.2 Segmental phonology

Shiwilu has 18 consonant phonemes, shown in Table 1 (adapted from Valenzuela 2012 and Valenzuela & Gussenhoven 2013). The practical orthography is provided in angled brackets (< >). As can be noted from Table 1, voicing is not a distinguishing feature for any consonant.

Table 1. *Shiwilu consonants (adapted from Valenzuela 2012 and Valenzuela & Gussenhoven 2013)*

	Labial	Alveolar	Palatal	Velar	Glottal
Plosive	p <p>	t <t>		k<k>, kʷ <ku>	ʔ <'>
Affricate			t͡ʃ <ch>		
Nasal	m <m>	n <n>	ɲ <ñ>		
Fricative		s <s>	ʃ <sh>		
Trill		ɾ <r>, ˀɾ <r'>			
Lateral		l <l>	ʎ <ll>		
Approximant	w <w, u>	ð̞ <d>	j <y>		

The consonants /ɾ/ and /ˀɾ/ are contrastive word-internally and word-finally (Valenzuela & Gussenhoven 2013: 99). The latter segment's glottalization can be lost word-finally, leading to neutralization between these two sounds in word-final position. The glottalized tap /ˀɾ/, however, only occurs after the vowel /ɘ/, leading Bendor-Samuel (1961: 21) to analyze the glottalization of /ˀɾ/ as a prosodic feature of the syllable. The assumption that glottalization reflects a prosodic rather than a segmental feature is not shared in more recent accounts like Valenzuela & Gussenhoven (2013) or Madalengoitia Barúa (2018) and will accordingly not be adopted in the present study.

Shiwilu has four vowels: /i, u, a, ɘ/[2]. Figure i (see supplementary materials) shows the F1–F2 distribution of Shiwilu vowels /i, u, a, ɘ/, based on 5762 stressed tokens from nine speakers. Formants were measured over a 25 ms window using Praat (Boersma & Weenink 2018). Confidence ellipses (±1 SD) reflect vowel dispersion. The interior vowel /ɘ/ overlaps with all others, likely due to its central position and shorter duration. Vowels have no quantity or nasality contrasts, and all vowels can appear as the nucleus of a syllable. There is a phonologically relevant distinction between peripheral (/i, a, u/) and central (/ɘ/) vowels in Shiwilu, which will be further developed in the following sections.

3.3 Syllable structure and stress

The basic syllable structure in Shiwilu is (C)V(C). Complex onsets (limited to plosive + liquid/glide) are found in some loanwords, such as *ˈpwi. ɲu* 'water jar', borrowed from Quechua (Valenzuela & Gussenhoven 2013: 98), but these sequences are absent in native words. Complex onsets and codas in the native vocabulary arise in limited contexts on the surface due to the lenition and deletion of the interior vowel. Valenzuela & Gussenhoven (2013: 99) state that the only complex coda /rn/ is found in the words *ˈmuɾn.ka* 'bubbles' and *ˈsɘɾn.pa* 'pineapple' and potentially reflects an underlying /ɾɘn/ sequence, with loss of /ɘ/. Crucially, peripheral vowels can appear in both open and closed syllables, but the interior vowel is restricted to closed syllables on the surface.

According to Valenzuela & Gussenhoven (2013: 98), all consonants except /ʔ/ and /ˀɾ/ can occur in the onset, a generalization corroborated in the present study. /ɾ/ can only occur as an

[2] Occasionally, the vowel /o/ is found in loanwords from Spanish and in some native Shiwilu words. Valenzuela & Gussenhoven (2013: 101) find that the pronunciation of /u/ varies from [ṳ̈] to [o̞] and can be analyzed as the surface reflex of the sequence /wɘ/.

onset word internally, and the rest of the consonants may occur word-initially. Most coda consonants are either placeless, as in glottal stop, or have a dorsal component, either by virtue of being velar or palatal, the latter of which is assumed to involve a simultaneous dorsal and coronal constriction (Keating 1988). Nasals are realized as velars in coda position (we return to this in §3.5).

Stress in Shiwilu is largely predictable. There is only one stress per word; its location is fixed and thus not used to distinguish different lexemes. Regular stress occurs on the second syllable, as in *a.ˈma.naʔ* 'jaguar.', and *aʔ.ˈmər.t͡ʃiŋ.d͡ʒi* 'very small'. However, word-final stress is avoided. Hence, disyllabic words have initial stress, as in *ˈwam.piʔ* 'owner of the carnival (kind of spirit),' *ˈu.waŋ* 'k.o. frog,' and *ˈəʎ.ʎa* 'renaco tree (Ficus trigona)'. Morphology plays only a minor role in stress assignment and is irrelevant to the gemination pattern under discussion in the paper.[3]

Table 2 shows words with different syllable structures, differentiating between /ə/ and other vowels (V), that exemplify the stress in the default peninitial position of trisyllabic and longer words and on the initial syllable of disyllables. As can be seen, syllable weight does not affect stress patterns. Nor does vowel quality impact stress, as the interior vowel can attract stress even in words with peripheral vowels elsewhere in the word.

Table 2. *Syllable structures and stress patterns in Shiwilu words*

Syllable structure	Examples	
CV	*ˈð̞u*	'k.o. nettle'
CVC	*ˈnuŋ*	'canoe'
CəC	*ˈpəŋ*	'fire'
əC.CV	*ˈəʎ.ʎa*	'renaco (k.o. tree)'
V.CVC	*ˈu.waŋ*	'k.o. frog'
əC.CəC	*ˈəʎ.ʎək*	'k.o. snake'
CV.CV	*ˈpa.wi*	'k.o. jicara'
CVC.CV	*ˈtun.la*	'k.o. worm'
CəC.CVC	*ˈməŋ.miʔ*	'ranch'
CV.CəC	*ˈð̞u.kər*	'moon'
CVC.CVC	*ˈtun.tuŋ*	'small drum'
V.CV.CV	*u.ˈki.la*	'lightning'
əC.CəC.CV	*ə<u>t</u>.ˈt͡ʃək.la*	'termite'
V.CV.CVC	*a.ˈmi.kuʔ*	'ancestors'
CV.CV.CV	*mu.ˈð̞i.la*	'nipple'
CV.CV.CəC	*wa.ˈla.tək*	'k.o. fish'
CəC.CV.CV	*tək.ˈð̞a.pi*	'big forehead'
CVC.CV.CV	*paŋ.ˈwa.la*	'tapir'
CəC.CV.CəC	*tək.ˈð̞a.tək*	'slowpoke'
CVC.CV.CəC	*ð̞un.ˈsa. ð̞ək*	'shore'
CVC.CəC.CV	*laŋ.ˈgəŋ.na*	'fish gills'

[3] The vocative case shifts the stress toward the last syllable, and certain affixes attract stress. Additionally, there are some roots with an irregular stress pattern, such as *si.ˈmir* 'Varadero (place name),' *wi.ˈa* 'squirrel' (with unexpected final stress), and *ˈiŋ.ka.tuʔ* 'four' (with antepenultimate stress) (Valenzuela & Gussenhoven 2013: 102).

3.4 The central vowel /ɘ/ and gemination

The central vowel /ɘ/ (henceforth the "interior vowel" to avoid any confusion with /a/, which is also a central vowel) has exceptional phonetic and phonological features that differentiate it from the other vowels and bear resemblance to typological properties of its phonetically lower central vowel neighbor schwa. Based on our observations, and also reflected in the description of Valenzuela & Gussenhoven (2013), the interior vowel is very short and, in certain contexts can be inaudible, leading to a perceived sequence of consonants that would otherwise be disallowed. The central vowel /ɘ/ also often coalesces with a preceding /w/ to yield a high back vowel /u/. Finally, and central to this paper, the interior vowel cannot appear in an open syllable, unlike the other vowels in the Shiwilu inventory.

Despite being phonetically short, evidence indicates that the interior vowel in Shiwilu is underlyingly present rather than epenthetic or excrescent (see Hall 2011 on this distinction). It is receptive to stress, as in many languages with underlying non-low central vowels, e.g. British English (Parker 2002), Besemah (McDonnell 2008), Hindi (Dixit 1963, Kelkar 1968, Ohala 1977, 1999), Albanian (Trommer 2013), Aguaruna (Overall 2007), Moseten (Sakel 2011), and is also present for speakers in syllabification and syllable counting tasks and in careful or slower speech.[4] The interior vowel also does not participate in regular alterations with zero that would provide evidence for epenthesis. The situation for Shiwilu is thus different from other languages, e.g., Arabic (Broselow 1992), Kabardian (Gordon & Applebaum 2010), in which allomorphy offers two possible a priori analyses of the underlying vowel to the learner, one with the vowel and the other without.

As previously mentioned, an interesting feature of /ɘ/ is that it is the only vowel in the Shiwilu inventory that does not appear in an open syllable anywhere in a word. It does occur, however, in word-final and word-medial syllables before a coda consonant as in (2).

(2)	ð̞**ɘk**	'water'
	ˈm**ɘŋ**.miʔ	'ranch'
	ˈmi.l**ɘŋ**	'*ramiche* bee'
	ta.ˈkun.ð̞**ɘk**	'centipede'

Any time /ɘ/ would surface in an open syllable, it is followed by a geminate consonant, the first half of which serves as the coda of the syllable containing the interior vowel and the second half as an onset of the following syllable, as shown in (3). As the examples show, gemination after /ɘ/ occurs both before and after stress. In keeping with the generalization that codas (other than glottal stop) have a dorsal component (§3.3), the geminates in the last two examples begin with a velar phase (see §3.5 for discussion).

[4] While diachronic evidence does not directly support our synchronic analysis, it offers valuable context. Valenzuela (2011) and Nikulin (2022) trace Shiwilu /ɘ/ to Proto-Kawapanan, either via *i > /ɘɾ/ or from a reconstructed vowel (*ɘ or *ɨ). This suggests the interior vowel likely existed in earlier stages of the language. Its consistent correspondence with Shawi also supports its underlying status.

(3)	ˈə**ʎ.ʎ**a	‘renaco tree (Ficus trigona)’
	ˈə**k.k**əɾ	‘burp’
	ət̠.ˈ**t͡ʃ**ək.la	‘termite’
	ð̞u.ˈkə**ʎ.ʎ**əɾ	‘first menstruation’
	ð̞ə**k.**ˈ**k**əŋ.maʔ.tək	‘cushuri (k.o. bird)’
	ð̞ə**k.**ˈ**k**a.na	‘paca’
	ð̞ə**k.**ˈ**k**ə**t̠.tʃ**əˀɾ	‘cut! (imperative)’
	laŋ.ˈɣə**ŋ.n**a	‘fish gills’
	lan.ˈsə**ŋ.ɲ**a	‘sugar cane’

The consonants that are geminated following /ə/ are /k/ <k>, /tʃ/ <ch>, /ʎ/ <ll>, /n/ <n>, and /ɲ/ <ñ>, which constitute the only consonants other than rhotics and the glide /j/ <y> that can follow the interior vowel. The glide /j/ can sometimes occur as a coda of certain syllables with /ə/ as a nucleus but always word-finally or before another consonant, i.e., in contexts where it is already a coda and thus does not need to geminate.

The only intervocalic consonants that do not geminate following the interior vowel are the rhotic taps /ɾ/ and /ˀɾ/ (4). Concomitant with their failure to occur as geminates after the interior vowel is their characteristic syllabification by native speakers as a coda in intervocalic position rather than an onset. Their treatment by speakers intervocalically accords with their absence in word-initial position where they would unambiguously serve as an onset (if they were to occur).[5]

(4)	kwə**ˀɾ.**ˈaʔ.suʔ	‘heavy’
	ʃiŋ.ˈgə**ɾ.**a.pa.ʎi	‘sunrise’
	kə**ɾ.**ˈu.tək	‘k.o. fish’
	na.ˈnə**ɾ.**a.pa.ʎi	‘to forget something’

The articulatory nature of the tap accounts for its failure to geminate. There is an inherent antagonism between gemination and a tap, which involves a dynamic gesture that produces a rapid closure (Pellard 2016). If a tap is geminated, it loses its identity as a tap and instead becomes a trill (Kawahara & Pangilinan 2017: 20; Ladefoged & Maddieson 1996). Accordingly, it is typologically common for rhotics to avoid gemination. For example, in Romanesco Italian and some Dravidian languages, such as Tamil and Malayalam, all consonants except the rhotics can geminate (Nikolaev 2021: 173).

The distribution of Shiwilu vowels is summarized in (5).

[5] It should be noted, however, that speakers do accept as an option the syllabification of taps as an onset in intervocalic position, apparently in free variation with syllabification as a coda, though it is not known what factors might bias speakers in favor of one syllabification over the other.

(5) Distribution of vowels in Shiwilu

Vowel	Before Intervocalic C	Before Syllable-final C	Word-final
ɘ	ɘC.CV	ɘC.	No
$V_{peripheral}$	V_{per}.CV	V_{per}C.	Yes

Crucially, gemination is non-contrastive within morphemes; geminates following the interior vowel are the only tautomorphemic geminates in Shiwilu. Heteromorphemic geminates, in contrast, may occur after either /ɘ/ or peripheral vowels as the examples in (6) show.

(6) lanˈtɘ**k-k**ɘk ‘on the foot’
foot-LOC

aˈwilɘ**ŋ-ɲ**inaʔ ‘they stared’
stare-3PL.NFI

iˈju**ŋ-n**a ‘the dried one’
dry-NOM

luˈlu**ŋ-n**ɘŋ ‘his/her meat’
meat-3SG.POSS

ˈsa**k-k**ɘˀɾ ‘be happy!’
be.happy-IMP

Intervocalic consonants surface as geminates after /ɘ/ regardless of the position of the stress. Examples of gemination both before and after stress are shown below in (7).

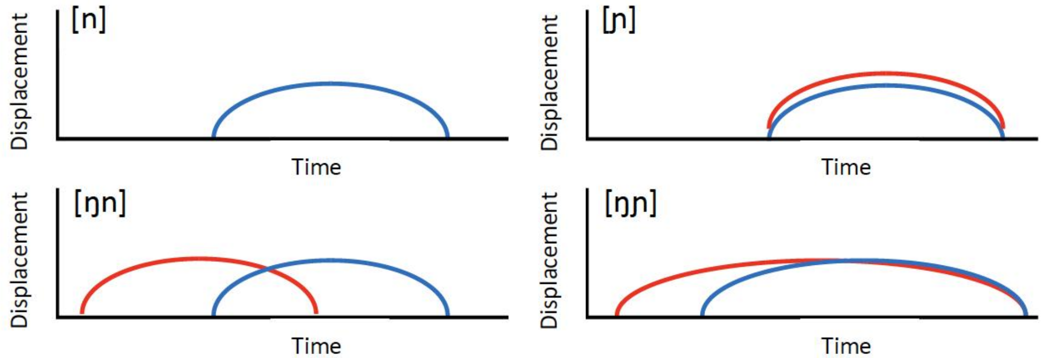
(7) ˈɘ**ʎ.ʎ**a ‘renaco tree (Ficus trigona)’
ˈɘ**k.k**ɘɾ ‘burp’
tɘ**k.ˈk**ʷa.tɘk ‘cowardly, fearful’
ɘ**t̠.ˈtʃ**ɘk.la ‘termite’
laŋ.ˈɣɘ**ŋ.n**a ‘fish gills’
ð̞u.ˈkɘ**ʎ.ʎ**ɘɾ ‘first menstruation’
ð̞ɘ**k.ˈk**ɘ**t̠.tʃ**ɘˀɾ ‘cut!’
lan.ˈsɘ**ŋ.ɲ**a ‘sugar cane’

3.5. Gemination and dorsality

Coda consonants—whether singletons or the first portion of a geminate (tauto- or heteromorphemic)— display a dorsal component if they are not homorganic with a following non-dorsal plosive. This results in a biphasal articulation. In geminate nasals, this biphasal realization involves an initial dorsal gesture followed by a coronal nasal closure. The parallel between within- and across-morpheme gemination supports the view that morpheme-internal gemination after /ɘ/ is phonological, not merely phonetic lengthening. The velar constriction furthermore appears even in careful speech, indicating it is part of the coda, while the coronal gesture forms the onset. Together, they create a single geminate with a mora and shared root node, exhibiting a posterior-to-anterior shift in place. This dorsal tendency in codas is broader in Shiwilu, including singleton codas, which generally disfavor non-dorsal places (§3.7). The presence of the velar phase in geminates following /ɘ/ varies by consonant, a point we explore below.

For nasals, the velar component in geminates parallels singleton coda nasals, which also are dorsal (unless immediately preceding an alveolar or bilabial consonant to which the nasal is assimilated, as seen in §3.3). Although we do not have articulatory data to assess precisely the gestural timing for geminate nasals, auditory impressions indicate that the velar constriction is initiated earlier than the coronal one and that the coronal constriction persists after the release of the velar closure in the geminate nasals corresponding to both singleton [n] and [ɲ]. Valenzuela & Gussenhoven (2013:100) describe similar patterns, noting that coda /n/, even before /n, ɲ/, shows “a variably wide area of contact... maximally [n͡ŋ̟]”. This early velar timing is likely universal, as cross-linguistic evidence from doubly articulated stops also shows velar gestures preceding others (Ladefoged & Maddieson 1996). We thus transcribe the resulting geminate consonants as [ŋ.n] and [ŋ.ɲ]. In the case of [ŋ.n], the dorsal component is solely a feature of the geminate and not a property of its singleton counterpart. In the case of palatal consonants, which are typically assumed (even as singletons) to be both [coronal] and [dorsal] (Keating 1998), gemination does not change the featural specification of the nasal. Rather, it is assumed that the additional duration associated with gemination allows for a phonetic reduction in temporal overlap between the coronal and dorsal constrictions, thereby allowing for auditory resolution of distinct velar and palatal components. The inferred timing relations between the dorsal and coronal gestures for the singleton and geminate alveolar and palatal nasals are shown schematically in (8).

(8) Schematic representation of the inferred timing of coronal (blue) and dorsal (red) constrictions for singleton and geminate nasals



It may be noted that the presence of a dorsal component in coda nasals is cross-linguistically common, attested in languages throughout the world, e.g. Spanish (e.g., Nuñez-Cedeño 1984, Trigo 1988), Midi French (Durand 1988a, b), Mongolian (Poppe 1970), Japanese (Yip 1991, Trigo 1998), Yamphu (Rutgers 1998), Misantla Totonac (MacKay 1994), Macushi (Abbott 1991), Carib (Peasgood 1972), Atayal (Rau 2000), Sulawesi (Sneddon 1993), Dagbani (Olawsky 2002), and Dutch (Hoeksema 1999).

In the case of the Shiwilu geminate lateral, gemination results in lengthening without an audible change in constriction location, i.e. [ʎ.ʎ]. We attribute the auditory realization of the palatal lateral to the incompatibility of the lateral with a purely velar constriction, which is consistent with the vanishingly rare status of velar laterals cross-linguistically (Ladefoged & Maddieson 1996) and their potential reanalysis as complex segments in languages in which they are reported to occur (see Staroverov & Tebay 2021). Rather, laterals involve synchronous (or nearly synchronous) gestures, one front, corresponding to the occlusion reflected in the transcription (in this case of a palatal), and one posterior (Sproat & Fujimura 1993).

Lengthening of the affricate /tʃ/ targets only the closure phase (see Pycha 2009; Di Benedetto & De Nardis 2021), i.e. yielding [t̠.ˈtʃ], which also involves a constriction in the palatal region that we assume to reflect a combination of the [coronal] and [dorsal] features.

Finally, although typically treated as coronal in terms of phonological features, taps share with other liquids a dorsal raising gesture in conjunction with the coronal place of contact (Proctor 2011). We thus assume that the production of taps, which do not geminate and are characteristically syllabified as codas, is consistent with the generalization that coda consonants are produced with a dorsal constriction in Shiwilu.

3.6. Tautomorphemic and heteromorphemic geminates

The tautomorphemic geminates following /ɘ/ perceptually mirror geminates that arise across morpheme boundaries, in particular at the root-suffix boundary where the first half of the geminate belongs to the root and the second half to a consonant-initial suffix. There are only a small number of consonant-initial suffixes and the only two combinations of consonants at morpheme boundaries that have parallels morpheme-internally involve suffixes that begin with /k/ and /ɲ/. Some examples are shown in (9).

(9) a.ˈwi.lə**ŋ-ɲ**i ‘to stare at’ (awilən ‘stare at’ - ɲi 3S.NFI)
lan.ˈtə**k-k**ək ‘on the foot’ (lantək ‘foot’ -kək LOC)
ˈð̞ə**k-k**əˀɾ ‘throw it!’ (ð̞ək- ‘throw’ -kəˀɾ IMP)

A preliminary analysis of the cases found in our corpus suggests phonetic equivalence between tautomorphemic geminates following /ə/ and geminates derived through morpheme concatenation , both with respect to duration and their obligatory velar component in the initial part of the geminate. However, due to the scarcity of heteromorphemic geminates in our corpus, we were unable to conduct a statistical comparison, and therefore this observation remains qualitative.

Figure 1 provides a three-way visual comparison of a heteromorphemic geminate with both a tautomorphemic geminate and a singleton /k/. All forms were produced in isolation and are representative of those found in naturalistic speech. As the figure shows, the two geminates are virtually identical in duration and over three times longer than their singleton counterpart. This difference is larger than the differences observed in our quantitative study of tautomorphemic gemination in §4, which we attribute to the fact that the quantitative analysis is based on naturalistic data.

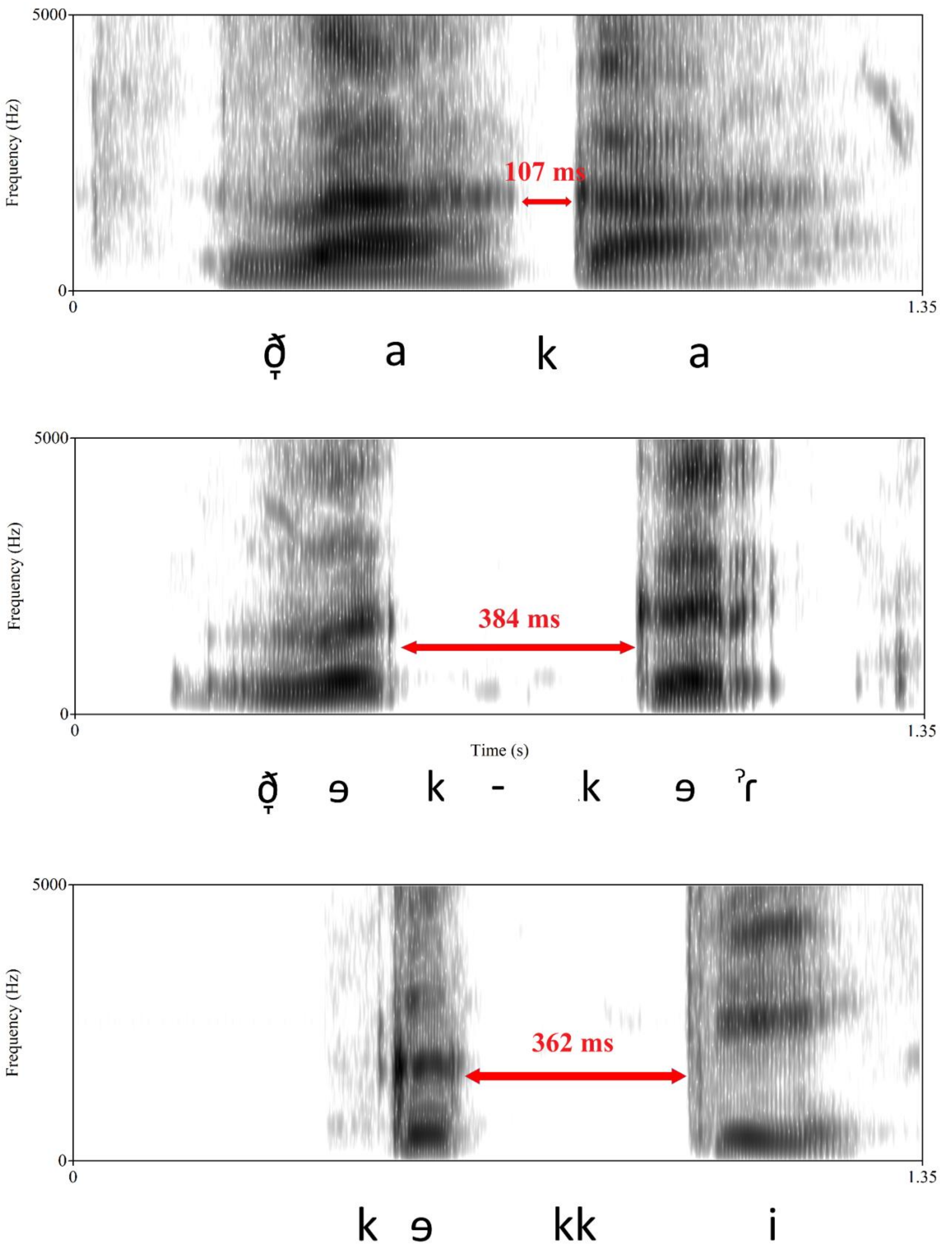


Figure 1. *Singleton velar plosive in ˈð̞a**k**a ‘muena tree’ (top), heteromorphemic geminate velar plosive in ˈð̞ɘ**k-k**ɘˀɾ ‘throw it!’ (middle), and tautomorphemic geminate velar plosive in ˈkɘ**kk**i ‘sun’ (bottom).*

3.7. Distribution of segments

Beyond the confinement of gemination to intervocalic position after /ɘ/, there are other salient asymmetries in the distribution of consonant phonemes in Shiwilu both as a function of the preceding vowel and the position in the syllable and word, as shown in Table 3.

Table 3. *Possible onsets and codas in Shiwilu*

	Onset		Geminate after ɘ	Coda (not geminate)
	Word-initial	Word-medial		Word-medial/final
p	✓	Not after ɘ	n.a.	--
t	✓	Not after ɘ	n.a.	--
ʧ	✓	✓	✓	--
k	✓	✓	✓	✓
ʔ	--	--	n.a.	Not after ɘ
m	✓	Not after ɘ	n.a.	--
n	✓	✓	✓	✓(ŋ)
ɲ	✓	✓	✓	--
s	✓	Not after ɘ	n.a.	--[6]
ʃ	✓	Not after ɘ	n.a.	--
ɾ	--	--	--	✓
ˀɾ	--	--	--	✓
l	✓	Not after ɘ	n.a.	--
ʎ	✓	✓	✓	--
w	✓	Not after ɘ	n.a.	✓
ð̞	✓	Not after ɘ	n.a.	--
j	✓	Not after ɘ	n.a.	✓

Looking first at onsets, every consonant except for the glottal stop and the taps can occur word-initially. Word-medially, only the glottal stop and the taps do not occur as onsets (though intervocalic taps may optionally be syllabified as onsets; see §3.5). However, the vast majority of consonants attested as a syllable onset are limited to occurring after peripheral vowels and do not follow the interior vowel. The only onset consonants occurring after /ɘ/ are the following: /ʧ, k, n, ɲ, ʎ/ and optionally /ɾ, ˀɾ/. As noted earlier, of these, all except the two taps geminate after /ɘ/ when in intervocalic position. Finally, the inventory of coda consonants is the same in word-medial and word-final syllables, encompassing a relatively small subset of consonants: /k, n, ɾ, ˀɾ, w, j/. Of these, coda /n/ is realized as a dorsal nasal unless it occurs before a following bilabial, alveolar or palatal segment to which it assimilates in place–this assimilation is not reflected in Table 3 (see footnote 6). Glottal stop does not occur after /ɘ/.

Frequency patterns illustrate further asymmetries in the distribution of consonants. Table 4 shows the frequency of coda consonants after /ɘ/ in our corpus, both singleton and geminated. Table 5 shows the relative frequency of codas (all singletons since monomorphemic geminates only occur after /ɘ/) following the peripheral vowels. The data in the tables are based on a token analysis; however, we also conducted a basic type frequency analysis by counting distinct lexical items bearing each relevant coda consonant. This yielded largely similar patterns to the token-based results.

[6] /s/ is found in word-medial coda position only in the expression *yuspainekketchun* [jus.ˈpaj.nek.ket.ʧuŋ] 'thank you,' which contains the root *yus* [jus] 'god', derived from the Spanish *dios* [djos]. All other instances of coda /s/ are word-final, where it is almost exclusively limited to a position following /a/ (see table 5).

Table 4. *Frequency of coda consonants after /ɘ/ in the corpus*

	Non-geminated		Geminated	
	Frequency	Percentage	Frequency	Percentage
/k/	616	46.80%	113	53.80%
/n/	333	25.30%	35	16.70%
/ɲ/	NA	NA	19	9%
/tʃ/	NA	NA	14	6.70%
/j/	15	1.10%	NA	NA
/ʎ/	29	2.20%	29	13.80%
/ɾ/	65	4.90%	NA	NA
/ˀɾ/	258	19.60%	NA	NA
Σ	1316	100	210	100

Table 5. *Frequency of coda consonants after peripheral vowels in the corpus*

	/a/	%	/i/	%	/u/	%	Σ
/n/	577	28.2	277	39.8	188	47.9	1042
/s/	48	2.4	6	0.9	8	2	64
/ʃ/	0	0	0	0	2	0.5	2
/j/	3	0.1	4	0.29	6	1.5	13
/k/	5	2.9	7	10.78	139	35.5	151
/w/	22	1.1	1	1.6	0	0	23
/ʔ/	1307	64.8	325	49.9	49	12.5	1681
Σ	2016	100	69	100	392	100	

Looking at Table 4, for both types of coda consonant phonemes following /ɘ/ (i.e., geminate and singleton), /k/ constitutes a majority of occurrences: over 46% of the non-geminated codas and 53% of the geminated ones. The nasal /n/, realized as velar [ŋ] in the default case not involving assimilation to a following plosive, is the next most frequent case in both types of codas: roughly 25% in non-geminated codas and 16% in geminated ones. The two kinds of coda consonants deviate from each other in the third most frequent case, which is /ˀɾ/ in the non-geminated type, with a rate of occurrence of roughly 19%, and /ʎ/ in the geminated type, with a rate of occurrence of approximately 13%.

As Table 5 shows, glottal stop is quite frequent as a coda consonant after peripheral vowels, which stands in sharp contrast to its complete absence after /ɘ/. While we do not have an explanation for the frequency of coda glottal stop after peripheral vowels, we attribute the absence of coda glottal stop after the interior vowel, which is itself non-moraic, to its non-moraic status, a feature shared with several other languages, e.g., Cha'palaa (Lindskoog and Brend 1962), Burmese (Lee 2007), Mohawk (Piggott 1995: 307-308), Nuxalk (Bagemihl 1991), Witsuwit'en (Hargus 2001). Glottal stop aside, /k/, the most common consonant following /ɘ/, is less common after the peripheral vowels, especially after /a/ and /i/. Instead, /n/ (=[ŋ] except before bilabials and alveolars), is the second (following /ʔ/) most preferred coda after a peripheral vowel. The remaining consonants (i.e., /s, ʃ, j, w/) are rarely found as codas.

4. A phonetic analysis of the Shiwilu interior vowel

This section explores phonetic evidence in support of the analysis of /ɘ/ as a non-moraic vowel that triggers gemination of a following intervocalic consonant. In particular, we focus on the duration of /ɘ/ relative to peripheral vowels and the duration of consonants following /ɘ/ as compared with peripheral vowels. We test two hypotheses in particular:

Hypothesis 1: /ɘ/ is shorter than peripheral vowels.

Hypothesis 2: Intervocalic consonants are longer following /ɘ/ than after peripheral vowels.

4.1. Duration of the interior vowel /ɘ/ in Shiwilu[7]

This section tests the hypothesis that the interior vowel in Shiwilu is significantly shorter than other vowels. We used the same corpus described in §3.1, excluding word-initial and word-final segments to minimize prosodic boundary effects (e.g., final lengthening, non-modal phonation) and related segmentation ambiguities. Vowels preceding a glottal stop or the preglottalized rhotic were also excluded, as these sounds often introduce glottalization on adjacent vowels, complicating boundary identification (see Madalengoitia-Barúa 2018). Monosyllabic words were discarded as well, since stress is analyzed here as the relative prominence among syllables within a word and is therefore inapplicable to monosyllables. Of the initial 10,042 tokens, 3,266 (32.5%) were excluded based on these criteria.

A total of 6776 individual tokens (ɘ=925, a=2773, i=1967, u=1111) were used in this model designed to examine vowel duration. The dependent variable is *DURATION*, the duration of each vowel, which was Box-Cox transformed (using version 3.1-2 of the car package on R, Fox & Weisberg 2019: Section 3, 4). The main predictor of interest was SGM (each individual vowel), and the control variables were *STRESS* (stressed vs. unstressed), *N_SYLL_WORD* (the number of syllables of the word containing each vowel, which was centered), and *SYLL_TYPE* (open or closed). However, apart from testing the hypothesis that /ɘ/ is shorter, we also wanted to see whether *SYLL_TYPE* affects the duration of the peripheral vowels, a result that will impact the interpretation of moraic configurations (see §5). Normally, one would include an interaction of *SYLL_TYPE* and *SGM* but since *ɘ*: O (/ɘ/ in an open syllable) is not attested, we created a new fixed-effect (fixef) predictor *SGM_x_SYLL_TYPE.orth* that featured the seven attested combinations of the four vowels and the two types of syllable and that featured an orthogonal-contrast matrix with 6 contrasts that codified our expectations as well as possible. Regarding the vowels, we compared *ɘ* vs. the other vowels, then *a* vs. *i* and *u* combined, then *i* vs. *u*. Regarding the syllable types, we compared each syllable type within the same pertinent segment (e.g.,

[7] From here onwards, the following abbreviations were used: *SGM*=segment, *N_SYLL_WORD*=number of syllables in the word, *SYLL_TYPE*=type of syllable (open vs. closed), *GEM.qual*=consonants that can geminate.

aO_vs_aC). Finally, the random-effects (ranef) structure of the initial model had varying intercepts and slopes for the newly created fixed-effect per speaker.

4.1.1 Statistical analysis

We analyzed the data with linear mixed-effects models using the lme4 package (version 1.1-35.5; Bates et al. 2015) on R (version 4.4.0, R Core Team 2024). This subsection covers the statistical analysis of the model designed to test the hypothesis that the interior vowel is shorter than the other vowels in Shiwilu.

Our initial model had (the transformed version of) *DURATION* as its numeric response variable, *N_SYLL_WORD* as a numeric control and *STRESS* as a categorical one, and the newly created *SGM_x_SYLL_TYPE*.orth as its main predictor of interest. For the *ranef* structure, we tried the maximal structure (following Barr et al. 2013) with varying intercepts and slopes for *SGM_x_SYLL_TYPE*.orth by speaker. This model was subjected to a stepwise backward model selection process using likelihood ratio tests and following the strategy proposed by Zuur et al. (2009: Section 5.7) and Gries (2021). We first tried to find the best *ranef* structure (*best* meaning 'the most comprehensive one that does not cause convergence or singularity problems') using REML estimation, followed by finding the best *fixef* structure (*best* meaning 'highest explanatory power (relative to Occam's razor of course) without causing numerical problems') using ML estimation. We followed the principle of marginality, meaning more complex terms were eliminated before their simpler terms and until (i) no more ranefs needed to be deleted (to achieve an unproblematically converging model) and (ii) no more fixefs could be deleted (because they were all significant); multicollinearity was checked at every step (using generalized variance inflation factors).

Upon arriving at a final model, we performed regression diagnostics by exploring (i) the overall distribution of the residuals of the model (to check for approximate normality), (ii) the distribution of the residuals of the model conditional on each predictor (to check for approximate homogeneity), and (iii) the distribution of the intercept/slope adjustments where applicable to check for approximate normality.

The model was then evaluated globally (based on R^2_{marginal} and $R^2_{\text{conditional}}$) and 'locally,' i.e., regarding the effects of the predictors/controls left in the final model with plots of model predictions for each predictor at a time and other predictors/controls held constant at typical values (means for *N_SYLL_WORD* and conditional distributions for *SGM_x_SYLL_TYPE*.orth and *STRESS*); see Fox (2003), Fox & Weisberg (2019). We used general linear hypothesis tests for specific follow-up tests or targeted contrasts of interest.

4.1.2 Results

The final model we arrived at using the above model selection process exhibited no collinearity problems (all *GVIF*s<1.1) and was overall highly significant (as compared to a model with the same ranef structure as the final model and no fixefs (*LR*-value=2401.2, df=8, $p<10^{-15}$), but with only intermediate R^2s: R^2_{marginal}=0.284 and $R^2_{\text{conditional}}$=0.333, which indicates that baseline speaker differences only explain a fairly small amount of variability. A table with the overview of this model can be found in the supplementary materials, under the name *Table A*.

Several of our expectations were confirmed by the coefficients for our manually-defined orthogonal contrasts: Coefficient 2 indicates that ɘ is indeed significantly shorter than the other vowels, and coefficient 5 indicates that the difference between *i* and *u* is not significant. Also, as per coefficient 9, vowels in stressed syllables are significantly longer than in unstressed syllables for peripheral vowels, but not for the interior vowel.

For ease of interpretation, the main result is represented in Figure 2. The *x*-axis represents the main predictor *SGM&SYLLTYPE*, whereas the *y*-axes represent predicted durations (Box-Cox-transformed values on the left *y*-axis, back-transformed durations on the right one for a more intuitive understanding of the predictions).[8] Each point is an observed duration value (horizontally jittered around the levels of the predictor) and the red points with their 95% confidence intervals are the effects predictions for the durations (as usual with *N_SYLL_WORD* set to its centered mean of 0 and *STRESS* to its proportional distribution). The black values shown correspond to the back-transformed mean values (in milliseconds).

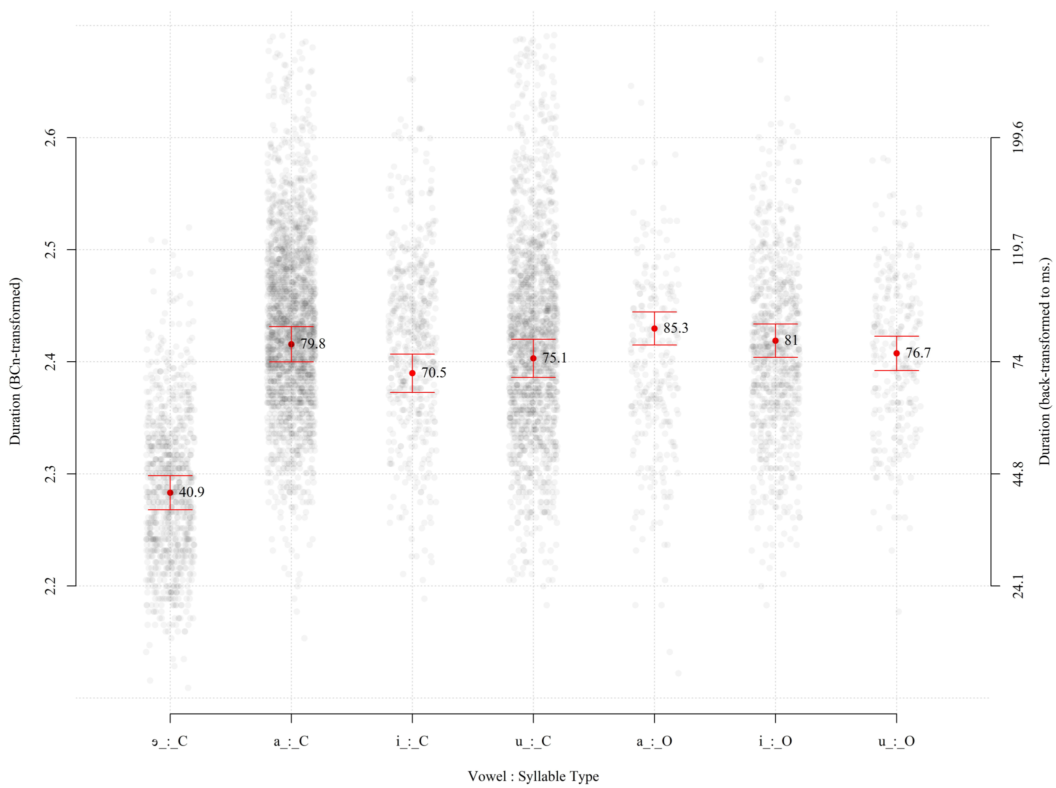


Figure 2. *Model-predicted vowel duration based on the effect of syllable type (open vs. closed) and vowel quality*

4.2. Duration of intervocalic consonants after /ɘ/ vs. after the peripheral vowels

This hypothesis states that the intervocalic consonants that can geminate (intervocalic consonants appearing after /ɘ/ other than the rhotics) are significantly longer when they follow the interior vowel than when they follow the other vowels in Shiwilu. For this model, the dependent variable is *DURATION.next*, corresponding to the following segment's duration. This variable was also Box-Cox transformed. Originally, we were interested in the predictors *SGM* (*ɘ* vs. *a* vs. *i* vs. *u*)

[8] Since the model was fit on the transformed values, the right *y*-axis serves only a heuristic purpose.

and *QUALGEM* (for "quality of geminated segment"), which is the name we gave to *k* vs. *ll* vs. *n* vs. *ñ* (and, respectively, correspond to /k/, /ʎ/, /n/, and /ɲ/) following the conventional Shiwilu orthography. For this model, we also used the variable *N_SYLL_WORD* (number of syllables in the word) since it is usual for segments to be shorter in longer words than in shorter ones. Finally, we added the variable *REL2STRESS* (standing for 'relative to stress'), which indicates whether the consonant to be analyzed is immediately post-tonic relative to the stressed vowel (im.post); post-tonic, but not immediately so (non-im.post), or immediately pretonic (im.pret). Some examples of words with these positions relative to the stressed vowel can be found in Table 6, where the analyzed consonant is highlighted.

Table 6. *Examples of words in the three different possibilities for the REL2STRESS variable*

im.post		non-im.post		im.pret	
wa.ˈku.**ʎ**in	'k.o. vine'	tɘk.ˈnan.pi.**ʎ**i	'save someone's life'	a.ˈ**ʎ**i.sɘk	'trap'
ð̞ɘk.ˈka.**n**an	'paca'	a.ˈmaʔ.wi.**n**a	'stream'	ka.ˈ**n**a.ɲi	'to find'
i.ˈla.**ɲ**i	'to shoot an arrow'	waʔ.ˈð̞an.pi.**ɲ**i	'to become crazy'	lu.ˈ**ɲ**i.naʔ	'to talk about smth.'
ˈkɘ.**k**i	'sun'	tʃĩn.ˈtʃĩ.tɘk.wɘ.**k**ek	'on the back of my knee'	tɘ.ˈ**k**wa.tɘk	name of city

We excluded monosyllabic words from this model since they do not have intervocalic consonants. A crucial subsetting also consisted of leaving aside consonants after the vowel [u] for a practical reason: many instances of this vowel correspond to an underlying /wɘ/ that is realized as [u] in some contexts (described in Valenzuela & Gussenhoven 2013). Because of [u]'s source as /wɘ/ the following consonant is longer (as would be expected following the interior vowel, according to our hypothesis). Since this change is unpredictable and can happen within the same speaker in different contexts, we discarded consonants following [u] from the model.

The preparation of these variables for the statistical analysis proceeded similarly to what we did for analysis 1. The numeric predictor *N_SYLL_WORD* was again centered, but this time, all combinations of our relevant categorical predictors *SGM*, *QUALGEM*, and *REL2STRESS* were attested often enough for us to consider their pairwise interactions for our initial model, which is why no creation of new variables or special contrast settings were required.

4.2.1 Statistical analysis

The statistical analysis of the current hypothesis—that intervocalic consonants are longer after /ɘ/ than after peripheral vowels—followed the same procedure described in §3.2.1. Using lme4, we began with a maximal model, with the (transformed) *DURATION.next* (duration of the intervocalic consonant) as the numeric response variable, *N_SYLL_WORD* (number of syllables in the word) as a numeric control, and *SGM* (vowel quality), *QUALGEM* (intervocalic consonant quality), and *REL2STRESS* (vowel position relative to stress), along with their pairwise interactions, as fixed-effect predictors.

For the random-effects structure, we initially used a maximal specification (random intercepts and slopes for all predictors and their pairwise interactions), but were prepared to simplify the model in case of convergence issues. As before, we used backward model selection via likelihood ratio tests on models fitted with maximum likelihood estimation to arrive at a final model from which no non-significant predictors could be removed. We then performed standard residual diagnostics and evaluated the model in terms of variance explained and the effect of each predictor; post hoc tests adjusted for multiple comparisons using Holm's method.

4.2.2 Results

The analysis of the random effects structure indicated that only the model with varying intercepts for speakers converged without issues. As for the *fixef* structure, the only insignificant predictor was the interaction of *SGM* and *REL2STRESS* (p=0.184). This final model was again unproblematic with regard to collinearity (all *GVIF*s<2.65) and residual diagnostics and was highly significant (*LR*-value=296.35, df=20, $p<10^{-15}$). However, the model returned intermediate R^2s of $R^2_{marginal}$=0.212 and $R^2_{conditional}$=0.333, which indicates that the baseline speaker differences here explain a more substantial amount of variability. A table with the overview of this model can be found in the Supplementary materials, under the name *Table B*.

For ease of interpretation, the results are presented using effects plots, and variable names have been simplified for clarity. Figure 3 shows the effect of the interaction *SGM:QUALGEM* (labeled as "Intervocalic consonants" on the x-axis). The black dots represent individual data points; the red dots correspond to model-estimated means for each vowel–consonant combination; the red error bars indicate 95% confidence intervals; and the numeric labels above each bar show the back-transformed means in milliseconds. The right *y*-axis again shows back-transformed durations (in milliseconds) and the black values correspond to the back-transformed mean values (in milliseconds). These results indicate that, regardless of the level of *QUALGEM*, the predicted duration for *SGM*: *a* does not differ from that for *i*. However, the predicted duration for *SGM*: *ɘ* is longer than that for *a*, and for all levels of *QUALGEM* except *k, ɘ* is also significantly longer than *i*—for *k*, no significant difference was found between *ɘ* and *i*. Additionally, the segments *ll, n*, and *ñ* are significantly longer after *ɘ* than after the other vowels, although *k* after *ɘ* is not significantly longer than *k* after *i*.

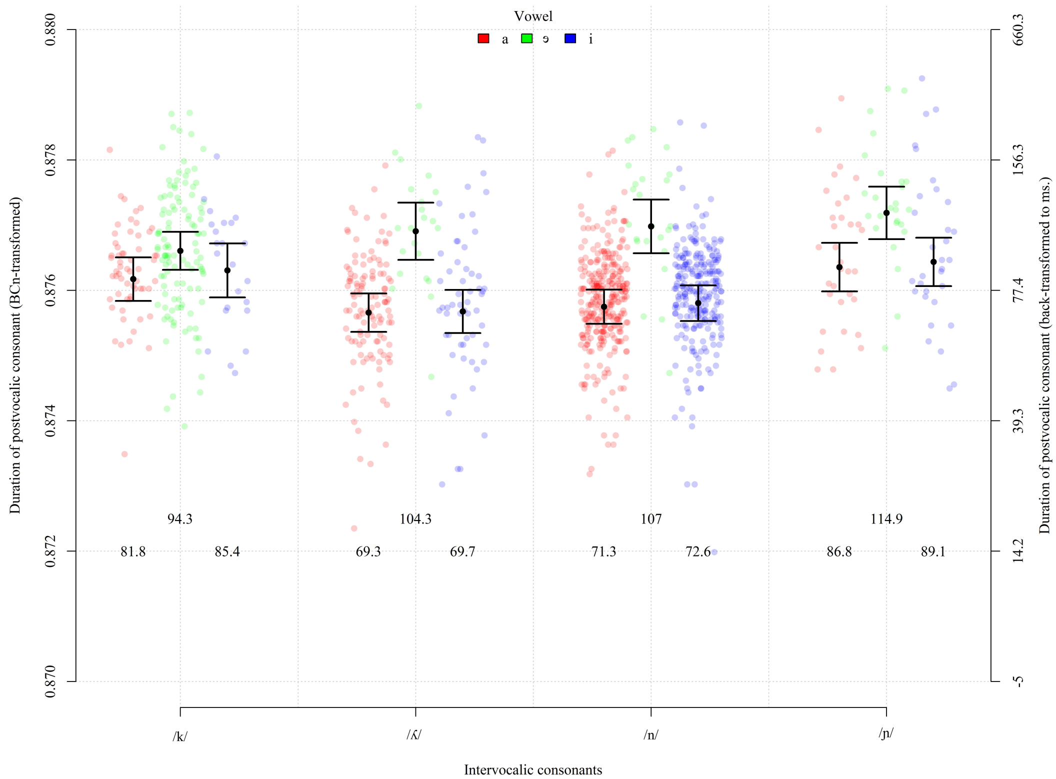


Figure 3. *Model-predicted intervocalic consonant duration based on the effect of the interaction of vowels with following intervocalic consonant quality*

Since the difference in duration between the consonants after ɘ vs. after the peripheral vowels a/i is the focus of this section, Table 7 presents a pairwise comparison between each consonant with different preceding vowels. The difference is shown both in milliseconds and in the percentual difference relative to the corresponding consonant after the peripheral vowel.

As shown in Table 7, in every case, the analyzed consonants were longer after the interior vowel than after the peripheral vowels /a/ and /i/. All pairwise comparisons between consonants after the interior vowel vs. those following peripheral vowels were significant with the exception of the comparison of /k/ following /i/ vs. /k/ following the interior vowel. Geminate vs. singleton duration ratios hovered between 1.3:1 and 1.5:1 in most cases with the smallest geminate:singleton ratios (<1.2:1) occurring for /k/.

Table 7. *Pairwise comparison of intervocalic consonants with different preceding vowels (difference of predicted durations, peripheral-preceding as base)*

	(a)__		(i)__	
	Difference in ms.	*Relative difference*	*Difference in ms.*	*Relative difference*
(ɘ)k	12.5	+15.2%	8.8	+10.3%
(ɘ)ʎ	35	+50.5%	34.9	+49.6%
(ɘ)n	35.6	+49.9%	34.4	+47.3%
(ɘ)ɲ	28.1	+32.3%	25.8	+28.9%

Cross-linguistically, Shiwilu shows relatively small geminate-to-singleton duration ratios. In many languages, geminates are at least twice as long as singletons (e.g., Finnish, Estonian, Bengali, Italian, Japanese, Levantine Arabic, Turkish). However, shorter ratios are attested in languages like Icelandic (~1.5; Oresnik & Pétursson 1977), Sinhala (1.8/1.69; Letterman 1995), Chickasaw (1.03–1.79; Gordon et al. 2002), and Norwegian (1.1–1.38; Fintoft 1961).

Shiwilu aligns with the lower end of this range. One reason may be that gemination in Shiwilu is non-contrastive, reducing the need for enhanced durational cues. The gemination of the consonant is also likely perceptually enhanced by the correspondingly short duration of the preceding vowel under the view that the duration of the consonant *relative* to the vowel is as important to cuing gemination as the duration of the consonant itself (see Port & Dalby 1982 for a similar view on the perception of the syllable-final voicing distinction in English). Support for this relational view of gemination comes from Norwegian and Icelandic, two other languages with relatively short geminate-to-singleton duration ratios and an inverse relationship between the duration of the consonant and that of the preceding vowel.[9] A final factor potentially contributing to the relatively short geminate-to-singleton ratios in Shiwilu is the source of the data in naturalistic speech, in which faster speech rates tend to reduce geminate:singleton contrasts (Arvaniti 1999; Mitterer 2018). This likely contributes to the modest length distinction observed in Shiwilu narratives compared to elicited speech.

5. Phonological representations

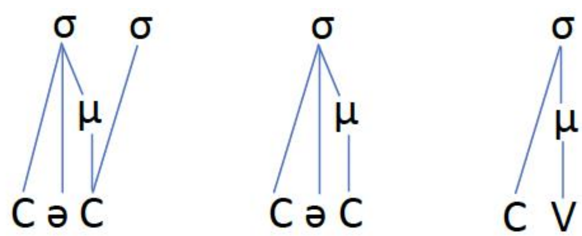
The short duration of the interior vowel and the asymmetric gemination of consonants following /ɘ/, but not peripheral vowels, suggest a distinct moraic status for /ɘ/. For typological consistency, references to "schwa" or "ɘ" below refer to interior (i.e., non-low central) vowels with similar properties, including the Shiwilu interior vowel. This vowel can be assumed to be non-moraic, as in other languages such as Piuma Paiwan (Shih 2018b), Dutch (Kager 1989; Kager & Zonneveld 1986), German (Féry 1995), and Amazigh (Bensoukas 2021). Under this view, illustrated in (10),

[9] We are grateful to the Associate Editor of *Phonology* for suggesting the inclusion of this relational perspective on geminate duration.

gemination in Shiwilu repairs prosodically ill-formed syllables that would otherwise lack a mora (a). Syllables closed by a singleton consonant and containing an interior vowel satisfy the requirement that every syllable bear a mora (b). Similarly, syllables with peripheral vowels, which project their own mora, also meet this condition (c), where V = /i/, /u/, /a/.

(10) Moraic configurations proposed for syllables in Shiwilu

a) b) c)



There is no evidence supporting mora sharing between the interior vowel and either a singleton coda or the first half of a geminate, as duration does not vary by syllable structure in Shiwilu. This contrasts with languages like Malayalam (Broselow et al. 1997), where stress distinguishes CVV and CVC: the former is heavy (i.e. bimoraic) and the latter is light (i.e. monomoraic with sharing of the single mora between the vowel and the coda). In Shiwilu, stress is insensitive to such weight differences. Lacking phonological or phonetic support for mora sharing, we adopt a simpler analysis without it—one that reduces structural complexity and aligns with our Optimality-theoretic account (§6).

Likewise, there is no phonological evidence (e.g., from stress or minimal word constraints) bearing on the weight status of codas after peripheral vowels. Since only heteromorphemic geminates follow peripheral vowels, we remain agnostic about their moraicity, though our analysis predicts they are non-moraic (§6).

In representing geminate length, we adopt the standard assumption that tautomorphemic geminates result from a single consonant (one root node) linked to both a mora and the onset of the following syllable, as in (10a) (Hayes 1989). This representation neatly captures the tautomorphemic geminates [k.k], [ʎ.ʎ], and [t̠.tʃ], which together account for over 76% of such tokens in our corpus.

As discussed in §3.5, coronal geminates shift in place during articulation—from velar in the coda to more anterior in the onset. For instance, geminated alveolar /n/ and palatal /ɲ/ approximate [ŋn] and [ŋɲ], respectively. While this place split could suggest two distinct segments (two root nodes; Selkirk 1990), we lack articulatory data confirming separate, non-overlapping gestures. We therefore assume a single segment with a broad constriction spanning both dorsal and coronal regions. The velar gesture consistently begins before the coronal one, though exact timing varies. In the absence of articulatory data, we leave for future research the featural representations of the dorsal element in coda position, which in other languages has been analyzed as the surface reflex of a consonant unspecified for place (Ito 1986, Trigo 1988).

6. An Optimality-theoretic analysis of mora augmentation

In this section, we develop a formal Optimality-theoretic analysis of mora augmentation in Shiwilu that enriches the factorial typology of interactions between moraic weight constraints and other prosodic constraints.

6.1. Gemination as a reflex of well-formedness constraints

As a precursor to examining the factorial typology, we consider the constraints driving the co-occurrence of the central /ɘ/ with a following geminate. The critical prosodic well-formedness constraint driving intervocalic gemination after /ɘ/ requires that syllables dominate a mora (11).

(11) HEADEDNESS-σ: Assign a violation for any syllable that does not dominate a mora (Shih 2018b)

HEADEDNESS-σ is satisfied in a syllable containing a peripheral vowel by simply having a mora linked to the peripheral vowel. This option is not available, however, in a syllable containing the interior vowel due to the highly ranked constraint banning moraic interior (i.e. non-low central) vowels in (12) (Kager 1989, 1990, Féry 1995, 1996, Shih 2018b)

(12) *μ/INTV: Assign a violation for every interior, i.e. non-low central, vowel that bears a mora (adapted from Shih 2018b)

*μ/INTV belongs to a family of constraints banning associations between moras and segments differing in sonority. Constraints against moraic segments of lower sonority, such as interior (i.e. non-low central) vowels, are universally ranked above constraints prohibiting moraic segments of higher sonority (Zec 2007). We adopt a streamlined theory of moraic association constraints that does not differentiate between head and non-head moras.[10]

Another relevant constraint for Shiwilu in the family of moraic association constraints is one that militates against moraic consonants (13).

(13) *μ/C: Assign a violation for every consonant that bears a mora (Sherer 1994)

In order to satisfy both higher ranked *μ/INTV and HEADEDNESS-σ, *μ/C is violated when the interior vowel is followed either by a singleton consonant eligible to be a coda, i.e. a preconsonantal or word-final consonant, or by the first half of a geminate.[11]

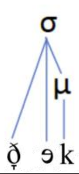
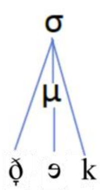
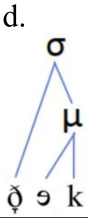
The tableau in (14) shows the output for a syllable containing /ɘ/ followed by a coda consonant. We follow the standard assumption that all vowels are underlyingly associated with a mora in (14) and tableaux that follow (Hayes 1989). Candidate (b) is ruled out by virtue of its moraic interior vowel in violation of *μ/INTV. Candidate (c) is doomed because the syllable

[10] This differs from Broselow et al. (1997), who posit mora sharing in their account of Malayalam.

[11] We return in §7.1 to cross-linguistic variation in the relative ranking of *μ/C and *μ/INTV relative to each other and to other moraic association constraints.

completely lacks a mora as required by HEADEDNESS-σ. Another candidate (d), involving sharing of a mora between the interior vowel and the coda consonant, is also precluded by a constraint against mora sharing, NOSHAREDMORA (Broselow et al. 1997).[12] There is no evidence that NOSHAREDMORA is violated in Shiwilu. The victorious candidate (a) is one with a mora linked to the coda consonant, in violation of only lowly ranked *μ/C.[13]

(14)

/ð̥ə$^{\mu}$k/ 'water'	*μ/INTV	HEAD-σ	NOSHARED MORA	*μ/C
✓ a. 				*
b. 	*!			
c. 		*!		
d. 			*!	

We now turn to the analysis of cases involving gemination in Shiwilu. The combination of the highly ranked constraints *μ/ə and HEADEDNESS-σ ensures that a syllable with an interior vowel must secure a mora regardless of whether that mora is present in the input or not. More generally, the input-output moraic faithfulness constraints DEP-IO (μ) and MAX-IO (μ) (McCarthy & Prince

[12] We assume that *μ/INTV and *μ/C are only violated in candidates in which a mora is *solely* linked to an interior vowel and a consonant, respectively.

[13] There is one consonant-specific constraint on mora association that is highly ranked, a constraint against moraic glottal stop, *μ/ʔ. Independent evidence for *μ/ʔ comes from other languages in which glottal stop is non-moraic, e.g. Cha'palaa (Lindskoog & Brend 1962), Burmese (Lee 2007), Mohawk (Piggott 1995: 307-308), Nuxalk (Bagemihl 1991), Witsuwit'en (Hargus 2001). In Shiwilu, this constraint exerts its impact on the lexicon since coda glottal stop following the interior vowel is banned.

1995) play no role in deriving gemination, which follows purely from well-formedness constraints like *μ/INTV and HEADEDNESS-σ.[14]

With the constraints thus far, we are in a position to account for mora augmentation through gemination (15).

(15)

/kəμkiμ/ 'sun'	HEAD-σ	*μ/INT V	*μ/C
✓ a. ˈkəkμ kiμ (root)			*
b. ˈkə.kiμ	*!		
c. ˈkəμ.kiμ		*!	

Candidate (b) is eliminated by virtue of having a moraless initial syllable, while candidate (c) fails because it has an interior vowel associated with a mora. The winning candidate is thus (a) with a geminate /k/ containing a single root node following the interior vowel, even though it violates *μ/C[15]

The gemination observed following the interior vowel contrasts with the lack of gemination after a peripheral vowel. An intervocalic geminate after a peripheral vowel is effectively ruled out by *μ/C since HEADEDNESS-σ is already satisfied by the moraic vowel, as shown in (16).

(16)

ð̞aμkaμ 'muena tree'	HEAD-σ	*μ/C
✓ a. ˈð̞aμ.kaμ		
b. ˈð̞aμkμ.kaμ		*!

The outcome illustrated in (16) does not preclude the possibility that a higher ranked constraint might coerce moraic status on coda consonants under certain conditions (Rosenthal and van der Hulst 1999, Morén 2000). For example, it is conceivable that a requirement that stressed syllables be heavy (bimoraic), the Stress-to-Weight Principle (SWP) (Prince 1990) could enforce moraic status on singleton codas in stressed syllables, e.g. on the coda /n/ of the stressed syllable

[14] Other faithfulness constraints, however, come into play in ruling out candidates employing alternative strategies to satisfy both *μ/INTV and HEADEDNESS-σ. These include deleting the interior vowel or changing it to a peripheral vowel that could be linked to a mora. That these tacks are not taken attests to the high ranking of the faithfulness constraints MAX-IO (ə) and IDENT-IO (V), respectively. Additionally, DEP-IO(C) plays a crucial role in ruling out candidates containing a non-underlying coda consonant, whether a completely new consonant or a duplicate root node of the following onset that creates a fake geminate.

[15] The insertion of the mora linked to the consonant and the deletion of the mora associated with the interior vowel in candidate (a) incurs violations of the moraic faithfulness constraints DEP-IO (μ) and MAX-IO (μ). Alternatively if analyzed as transposition of the interior vowel's underlying mora to the coda consonant, another lowly ranked moraic faithfulness constraint, IDENT-IO (μ), is violated

in *taˈkunð̥ək* ‘centipede’. Although typologically common (see §7.2), there is no evidence in Shiwilu for a requirement of bimoraicity under stress or in other circumstances. For this reason, we tentatively assume that coda consonants lack a mora after peripheral vowels in Shiwilu.

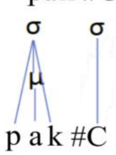
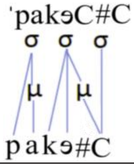
6.2. Conditions that block mora augmentation through gemination

Although mora augmentation through gemination is widespread in Shiwilu, there are certain contexts in which it is blocked. For one, gemination is not an option in word-final position, an effect that is captured by a constraint ensuring that consonants do not span word boundaries. This constraint belongs to the CRISPEDGE family of constraints (Ito & Mester 1999, Walker 2001) requiring that all material belonging to a prosodic unit be entirely contained in that unit, i.e. not span domains (17). In the case of Shiwilu, the relevant domain is the prosodic word, as a geminate spanning two prosodic words would violate CRISPEDGE (PRWD). This constraint need not reference particular phonological properties as there are no segmental features that belong to multiple prosodic words in Shiwilu.

(17) CRISPEDGE (PRWD): Assign a violation mark for each consonant that is dominated by two prosodic words

Assuming Richness of the Base, ranking CRISPEDGE (PRWD) above MAX-IO (INTV)[16] precludes the preservation of any underlying word-final central through gemination of the word-initial consonant of a following word (18).

(18)

/pa$^{\mu}$kə#C…/ (Hypothetical)	CRISPEDGE (PRWD)	MAX-IO (INTV)
✓ a. pak #C 		*
b. ˈpakəC#C 	*!	

The second candidate violates CRISPEDGE (PRWD) since the prosodic word with an interior vowel in the final syllable includes half of the initial consonant of the following word (the word boundary is indicated by #). This leaves as the winner the first candidate, the one without the

[16] MAX-IO (INTV) is ranked above *μ/C as syllable deletion through vowel syncope is never adopted as a strategy to avoid moraless syllables and moraic interior vowels, i.e. ˈəʎ.ʎa ‘renaco tree (Ficus trigona)’ not *ʎa.

interior vowel in the interest of ensuring that the initial consonant of the morphological word to the right does not geminate to close the preceding prosodic word.

More generally, CRISPEDGE (PRWD) also effectively precludes resyllabification of a coda consonant across a word boundary preceding a vowel-initial word, which could potentially strip a moraic coda from a word-final closed syllable containing an interior vowel. In such cases, the word boundary also aligns with the syllable boundary, as at the boundary between the words *ˈpi.ð̞ək* 'house' and *aʔ.ˈʎu.pi* 'big' in the phrase *ˈpi.ð̞ək. aʔ.ˈʎu.pi* 'big house'.

Another exception to gemination is provided by the taps /ɾ/ and /ˀɾ/, both of which fail to surface as geminates intervocalically after /ə/. This pattern follows from an articulatorily motivated constraint against geminate taps, *GEMTAP (19)[17] (see Kawahara 2007 on the typology of constraints governing geminates).

(19) *GEMTAP: Assign a violation for a geminate tap

Evidence for the syllable affiliation of the tap is inconclusive. Native speaker intuitions and the absence of the tap word-initially are consistent with analyzing the tap as a coda. However, speakers also report that syllabification as an onset is also an option (see §3.4).
This variation can be modeled through variable constraint ranking. If the tap is treated as a coda, it can be assumed to be moraic parallel to other coda consonants, in satisfaction of HEADEDNESS-σ and *μ/ə and at the expense of violating the constraint requiring syllables to have onsets, ONSET (Prince & Smolensky 1993/2004). The result is a moraic singleton tap and an onsetless following syllable, candidate (a) in (20).

(20)

/kə^{μ}ɾu^{μ}tə^{μ}k/ 'k.o. fish'	*GEM TAP	HEAD-σ	*μ/INT V	ONSET
✓ a. kəɾ^{μ}.ˈu^{μ}.tək^{μ}				*
b. kə^{μ}.ˈɾu^{μ}.tək^{μ}			*!	
c. kə.ˈɾu^{μ}.tək^{μ}		*!		
d. kəɾ^{μ}.ˈɾu^{μ}.tək^{μ}	*!			

On the other hand, if the tap is treated as an onset, either candidate (b) with coerced moraic status of the interior vowel or candidate (c) with a non-moraic interior vowel would be the winner. The choice between these candidates, which are empirically indistinguishable from each other, hinges on the relative ranking of HEADEDNESS-σ and *μ/ə, for which we otherwise have no probative evidence. In both scenarios, ONSET, outranks the lower ranked constraint between HEADEDNESS-σ and *μ/INTV, as shown in (21) and (22).

[17] *GeMTAP is similar in its effect to the constraint against moraic rhotics that Ryan (2019) posits to account for their light status in Tamil. However, in Shiwilu, the tap is moraic as a coda, demonstrating that it is not the moraic status that is problematic in Shiwilu but rather the length of the geminate. Ryan's constraint operative in Tamil also refers more broadly to rhotics, including not only the tap but also the retroflex rhotic approximant.

(21)

/kə$^{\mu}$ɾu$^{\mu}$tə$^{\mu}$k/ 'k.o. fish'	*GemTap	Head-σ	Onset	*μ/IntV
a. kəɾ$^{\mu}$.ˈu$^{\mu}$.tək$^{\mu}$			*!	
✓ b. kə$^{\mu}$.ˈɾu$^{\mu}$.tək$^{\mu}$				*
c. kə.ˈɾu$^{\mu}$.tək$^{\mu}$		*!		

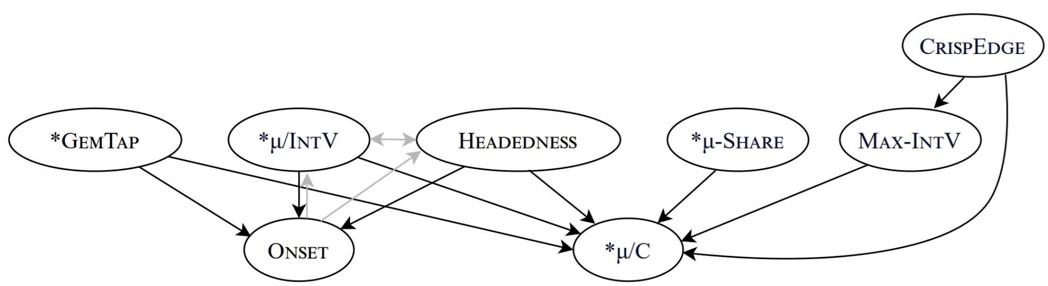
(22)

/kə$^{\mu}$ɾu$^{\mu}$tə$^{\mu}$k/ 'k.o. fish'	*GemTap	*μ/IntV	Onset	Head-σ
a. kəɾ$^{\mu}$.ˈu$^{\mu}$.tək$^{\mu}$			*!	
b. kə$^{\mu}$.ˈɾu$^{\mu}$.tək$^{\mu}$		*!		
✓ c. kə.ˈɾu$^{\mu}$.tək$^{\mu}$				*

6.3. Summary of analysis

The diagram in (23) summarizes the constraint rankings, checked using OTSoft (Hayes 2021). Ranking reversals yielding the alternative syllabification of the tap as an onset in (21) and (22) are captured using gray arrows.

(23) Shiwilu constraint rankings



7. Discussion

7.1. Shiwilu and the typology of moraic hierarchies

Mora augmentation in Shiwilu is typologically unusual and informs our understanding of the relationship between interior vowels and stress. Shih (2018b) proposes that there are three types of interior vowels like schwa: consistently moraic ones, consistently non-moraic ones, and ones that are conditionally moraic when in stressed positions. Under Shih's account, the moraic status of schwa is inextricably linked to its capacity to receive stress: in order to be stressed, it must be moraic. Shih analyzes Eastern Armenian as a language in which schwa is consistently moraic since stress falls on the final syllable even if it contains schwa (Haghverdi 2016). On the other hand, he cites Paipai (Joel 1966) and Aljutor (Kodzasov & Muravjova 1980) as languages with non-moraic schwa since words containing only schwa are reported to lack stress completely.[18]

Variably moraic schwa is observed in Piuma Paiwan, in which stress falls on the penultimate syllable as long as it does not contain schwa (24a). If the penult has schwa, whether it is open or closed by a coda consonant, stress instead falls on the final syllable (24b).

(24) Piuma Paiwan stress (Shih 2019:1)
(24a) ˈkaka 'sibling', ˈtidəq 'interval', viˈtsuka 'stomach', ʎaˈvatsaq 'horsefly'
(24b) kəˈri 'small', qurəˈpus 'cloud', tsəˈməɭ 'grass', masəŋˈsəŋ 'to make something', ʎisəˈqəs 'nit'

Crucially, in Shih's account, in words with only schwa, stressed schwa is coerced to take on a mora. Shih also demonstrates in an acoustic study of Piuma Paiwan that schwa falls into three different durational categories based on its position; he attributes the different durational profiles to differences in moraic status under the assumption that stress reflects a right-aligned bimoraic trochee and coda consonants are non-moraic. Unstressed schwa in the penult is shortest, which is consistent with its non-moraic (and unfooted) status in that position, i.e., k**ə**(ˈri$^{\mu\mu}$). Schwa is longer in an unstressed final syllable, reflecting its monomoraic status, i.e., (ˈti$^{\mu}$d**ə**$^{\mu}$q). Schwa is still longer in a stressed final syllable corresponding to its association with two moras, i.e., tsə(ˈm**ə**$^{\mu\mu}$ɭ).

Thus, regardless of the source of the stress, a stressed schwa is assumed to be at least monomoraic. Languages with consistently non-moraic schwa are those in which schwa always rejects stress. In most of the languages discussed by Shih, coda consonants do not contribute weight to a syllable. A coda consonant thus does not compensate for the inherently light status of schwa even in languages in which schwa is potentially moraic, as in Piuma Paiwan.

Shiwilu differs from Piuma Paiwan in that the interior vowel is non-moraic *even if it is stressed*. Whether stressed or not, however, a syllable containing the interior vowel is required to be moraic, a requirement that is satisfied through association of a mora with the following consonant rather than the interior vowel itself. Shiwilu demonstrates that the prosodic headedness constraint requiring that syllables contain a mora can be satisfied through a mora linked not necessarily to the syllable nucleus but rather to a consonant.

[18] In Aljutor, this lack of stress applies only to words with schwa in open syllables in initial or peninitial position of the word (see below for more details).

In the typology of mora–segment mappings by sonority, Shiwilu presents a reversal: it treats consonants as moraic but not interior vowels, despite an interior vowel's higher sonority (Parker 2008). This shows that the constraint ranking governing moraicity of interior vowels vs. consonants is language-specific. In many languages (e.g., Piuma Paiwan), *μ/C outranks *μ/Vint, favoring moras linked to interior vowels over those linked to codas. In Shiwilu, the opposite holds. Consonants outweigh interior vowels in other languages too—Gordon (2006:66–67) notes cases where interior vowels resist stress in open but not closed syllables (e.g., Literary Mari, Sentani, Sarangani Manobo), indicating the moraic status of codas (at least after interior vowels). More commonly, however, interior vowels are light in both open and closed syllables (e.g., Northwest Mari, Witsuwit'en, Lillooet), reflecting the non-moraic status of both interior vowels and codas. In summary, the relative weight of interior vowels and codas varies cross-linguistically, similar to other sonority-related patterns, such as the nuclear capacity of liquids vs. nasals (Bell 1978) or glottals vs. obstruents (Mielke 2008).

Typological variation also exists in how vowel type and coda sonority interact. In Kwak'wala (Boas 1947; Shaw 2009), stress treats syllables with peripheral vowels—or schwa plus a sonorant coda—as heavy, but syllables with schwa alone or with an obstruent coda as light. A similar pattern is found in Lamang (Wolff 1983), where schwa plus sonorant coda patterns with peripheral vowels in weight.

Conflating vowel and coda sonority yields cross-linguistic variation in the hierarchy of constraints governing the relative weight of interior vowels and coda consonants, as shown in (25), where R stands for a sonorant consonant, O for an obstruent, and V_{int} for an interior vowel. Following De Lacy (2004), equivalently ranked constraints referring to obstruents and sonorants are conflated as *μ/C.

(25) Mora association constraint hierarchy

Piuma Paiwan	*μ/C >> *μ/V_{int} >> HEADEDNESS-σ
Shiwilu	*μ/V_{int}, HEADEDNESS-σ >>*μ/C
Kwak'wala	*μ/V_{int},*μ/O >> *μ/R, HEADEDNESS-σ
Northwest Mari	*μ/V_{int},*μ/C >> HEADEDNESS-σ

In Piuma Paiwan and other languages in which interior vowels are light in both open and closed syllables, the constraints banning moraic coda consonants outrank the constraint against moraic interior vowels, which in turn supersedes the requirement that syllables contain a moraic head. In Shiwilu, the ranking of the mora association constraints for consonants and interior vowels are reversed since the interior vowel is never moraic whereas coda consonants are moraic after interior vowels. Kwak'wala differs from Shiwilu in drawing a distinction between coda obstruents, which are non-moraic, and coda sonorants, which are moraic. Finally, in Northwest Mari, any syllable containing an interior vowel, whether open or closed, is non-moraic.

Shiwilu appears to be exceptional among languages sensitive to a weight-distinction between interior and peripheral vowels in requiring that every syllable, whether stressed or not, have a mora in order to satisfy highly ranked HEADEDNESS-σ.

In virtually all languages in which syllables containing interior vowels are normally non-moraic in violation of HEADEDNESS-σ, their moraic status is nevertheless coerced on a syllable that receives stress by default in words consisting entirely of interior vowels (see Shih 2018 for typology). The best documented exceptional case appears to be Aljutor (Kodzasov & Muravjova

1980, Kenstowicz 1997), which does not assign stress at all to words consisting of only light syllables. Aljutor is also typologically interesting in treating open syllables with schwa as light but closed syllables with schwa as heavy. Stress in Aljutor falls on the second syllable of a three-syllable or longer word (26a) and on the first syllable of words with fewer than three syllables (26b). However, if the second syllable in a trisyllabic or longer word is open and contains schwa, stress retracts onto the initial syllable (26c). If both of the first two syllables are open and contain schwa, the word is reported to lack stress (26d).

(26) Aljutor stress (Kenstowicz 1997:172-174)
(26a) quˈraŋa 'reindeer, vaˈgəlŋen 'nail', naˈvitatən 'he would work', nuˈtagitanaŋ 'binoculars'
(26b) ˈtatul 'fox', ˈqapar 'wolverine', ˈjanut 'today'
(26c) ˈjiləjil 'tongue', ˈtərgətər 'meat', ˈtawəjatək 'to feed'
(26d) nəkəkaqin 'hot', jərəŋatəq 'to stick'

Crucially, closed syllables containing schwa pattern with syllables containing a peripheral vowel both in attracting stress when in peninitial position, cf. *vaˈgəlŋen* (26a), and in receiving stress that retracts from a second syllable that is open and has schwa as its nucleus, cf. *ˈtərgətər* (26c).

The Aljutor pattern is consistent with both peripheral vowels and coda consonants being moraic while interior vowels are non-moraic, as in literary Mari, Sentani, and Sarangani Manobo. Aljutor differs from these languages, however, in permitting stressless words containing only interior vowels. This difference follows from the fact that *μ/ə is never violated in Aljutor but is violated in the other languages in the interest of ensuring that every prosodic word has a stressed syllable.

7.2 The target of mora augmentation

Mora augmentation through consonant gemination is attested in the literature, typically as a strategy for bulking up stressed syllables, unlike in Shiwilu where it applies regardless of stress. Consonant lengthening through gemination of an onset consonant following a stressed vowel in an open syllable is attested, e.g. in Lenape (Goddard 1979) and Menominee (Bloomfield 1962) (see Hayes 1995 for more cases), although the typologically more common mechanism for adding moras is through vowel lengthening, e.g. in Chickasaw (Munro & Ulrich 1984, Gordon & Munro 2007) and Central Alaskan Yupik (Jacobson 1985, Miyaoka 1985, Woodbury 1987), Viewed through an Optimality-theoretic lens and setting aside language-specific factors, variation in the target of mora augmentation reflects a difference in the ranking of constraints governing mora associations between different segment types relative to the constraint driving augmentation–in most languages, the Stress-to-Weight Principle (Prince 1990). In languages with vowel lengthening, SWP and the constraint against moraic (i.e. geminate) consonants are ranked above a constraint against bimoraic (i.e. long) vowels, cf. Rosenthall (1997), Féry (2001). In languages in which consonants are moraically augmented, SWP and the constraint against bimoraic vowels outrank the prohibition against moraic consonants. These rankings are summarized in (27).[19]

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[19] It may be noted that faithfulness constraints are also relevant to the typology for languages in which length is contrastive for the target of augmentation, which includes many, but not all, languages with mora augmentation (see Hayes 1995 for specific cases).

(27) Constraint rankings deriving the typology of mora augmentation

SWP, *μ/C >> *μμ/V ⇒ Augmentation through vowel lengthening
SWP, *μμ/V >> *μ/C ⇒ Augmentation through consonant gemination

Shiwilu enriches the typology of mora augmentation in two ways. First, consonant gemination in Shiwilu is not motivated by stress; rather it occurs regardless of the location of stress. Furthermore, augmentation asymmetrically applies following only the interior vowel in Shiwilu, precisely because of its non-moraic status.

Interestingly, in certain Central Alaskan Yupik varieties (Jacobson 1985, Miyaoka 1985), stressed peripheral vowels asymmetrically lengthen while consonants following a stressed interior vowel geminate. Across Central Alaskan Yupik varieties, peripheral vowels lengthen in stressed open syllables where stress follows a left-to-right iambic pattern: /atata/ 'later' → [(aˈtaː)ta]. However, stressed schwa is not lengthened and in certain varieties, e.g., Norton Sound, the following consonant geminates to close the syllable containing the schwa, e.g. /(kəmə)**n**i/ 'his own flesh' → [(kəˈmə**n**)**n**i] (Miyaoka 1985:62). In most other varieties, a schwa that would be due to be stressed by iambic parse is instead deleted (subject to the constraint that schwa deletion does not yield a geminate) with retraction of the stress to the preceding syllable, e.g. /(kəmə)**n**i/ → [(ˈk**ə**m)ni] (Miyaoka 1985: 61).

The cross-variety variation in response to a (potential) stress on an interior vowel reflects different ranking of the ban against moraic consonants relative to other constraints. In varieties with post-schwa gemination, the faithfulness constraint MAX-IO (INTV) is ranked above the ban against moraic consonants *μ/C. In varieties with schwa deletion, conversely, *μ/C is prioritized above MAX-IO (INTV). In both varieties the constraint militating against associations between interior vowels and moras drives the avoidance of stressed schwa in an open syllable. In Central Alaskan Yupik, the relevant constraint differs from Shiwilu in prohibiting *bimoraic* rather than monomoraic interior vowels since schwa is moraic in Central Alaskan Yupik, as evidenced by its parallel treatment to peripheral vowels in the iambic parse (at least when unstressed). For example, the schwa in the first syllable is footed in (kəˈmə)ni 'his own flesh' (→ [ˈk**ə**mni] or [kəˈm**ənn**i] depending on the dialect).[20]

8. Conclusions

The Shiwilu interior vowel /ɘ/ shares many typologically prevalent features with schwa despite being slightly higher than canonical schwa (Valenzuela & Gussenhoven 2013). Shiwilu /ɘ/ patterns as non-moraic, evidence for which was gleaned from an instrumental study of duration using naturalistic data. Acoustic results of this study demonstrate that the duration of vowels and the following onset consonant stand in a compensatory relationship: the interior vowel is shorter than peripheral vowels while the consonant is longer following the interior vowel than after other vowels. The duration patterns can be analyzed in terms of moraic equivalence calculated over the syllable: peripheral vowels are moraic, whereas the central is non-moraic but followed by a geminated moraic consonant intervocalically. Since stress in Shiwilu is predictable and is

[20] As discussed in §7.1, Piuma Paiwan paints an interesting contrast to both Central Alaskan Yupik and Shiwilu in requiring that schwa be bimoraic under stress (Shih 2018b).

unaffected by /ɘ/, gemination is not driven by a Stress-to-Weight constraint requiring that stressed syllables be heavy; instead, it is motivated by a syllable-level constraint on headedness that complements more familiar constraints applicable to the prosodic word requiring a metrical head (McCarthy 2002). Gemination in Shiwilu is also noteworthy for creating monomoraic rather than bimoraic syllables.

The Shiwilu weight patterns can be analyzed within Optimality Theory via the interaction between a syllable headedness constraint and a set of hierarchically ranked constraints governing the association of segments to moras. Although the ranking of many of these mora association constraints is fixed across languages, variation between languages in the weight of interior vowels relative to coda consonants points to permutability in the ranking of different elements in the sonority hierarchy. In particular, constraints banning associations between consonants and moras may be lower ranked, as in Shiwilu, than their counterparts prohibiting moraic interior vowels. On the other hand, in languages with stressed interior vowels and weightless codas, constraints precluding moraic consonants outrank those militating against moraic interior vowels. This variation exemplifies what McCarthy (2002) describes as the "heterogeneity of processes," whereby similar markedness pressures are resolved through different strategies across languages. Shiwilu offers a case where gemination, rather than vowel lengthening or deletion, satisfies the need for moraic structure—contributing to the broader typology of weight effects.

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