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Temporal organization in sibilant-stop clusters in Moenat Ladin

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Abstract

In this paper, we probe the temporal organization of word-initial consonant clusters in Moenat Ladin, a threatened and understudied minority Romance language in Italy. We focus on sibilant-stop clusters and hypothesize that the sibilant is external to a syllable onset. Our hypothesis is probed with an experiment that investigates the temporal coordination of gestures, which bears on the organization of elements in syllable structure. By employing the methodology of Ruthan et al. (2019) and Durvasula et al. (2021), we conduct acoustic analyses of sibilant-stop, sibilant-stop-rhotic, and stop-lateral clusters. The findings of this study suggest that word-initial sibilants before a stop in Moenat are organized external to the syllable onset, which is similar to the syllable structure of Italian. This research also highlights the utility of the acoustic methodology for probing the temporal organization of consonant clusters.

Keywords: Moenat, Ladin, temporal coordination, syllable structure, sibilants.

1. Introduction

In this paper, we probe the temporal organization of word-initial consonant clusters in

Moenat Ladin, focusing on sibilant-stop clusters with the goal of shedding new light on issues of syllabification in this language. Ladin is a threatened and understudied minority Romance language spoken in the Italian Central-Eastern Alps. The Ladin language exhibits a number of regional varieties. This study focuses on Moenat, a variety of Val di Fassa Ladin spoken in the village of Moena in the Trentino province (Yang et al. 2021).

The syllabification of word-initial sibilant fricative-stop clusters is a challenging issue in phonological theory (e.g. Goad 2011). In general, the question of whether word-initial sibilant fricative-stop clusters may form a complex syllable onset remains controversial, since they are an exception to the Sonority Sequencing Principle (e.g. Selkirk 1984; Clements 1990). Despite this exceptionality, it is nevertheless conceivable that sibilant fricative-stop clusters could form a syllable onset in at least some languages (e.g. Browman & Goldstein 1988; Marin & Pouplier 2010; Marin 2013). An experimental approach to this representational issue has been developed in the framework of Articulatory Phonology (e.g. Browman & Goldstein 1988, 1989, 2000). From the perspective of gestural coordination in Articulatory Phonology, a sequence of consonants that belong to the same syllable will show a pattern of temporal coordination with each other and the following vowel that is known as C-centering. This pattern of coordination contrasts with that of a prevocalic consonantal sequence for which only the second consonant forms the onset to the syllable with the following vowel. In the latter case, the second consonant shows systematic coordination with the vowel, while the first consonant does not. Research in this vein has found that the coordination pattern of sibilant fricative-stop clusters varies across languages, with implications for the associated syllable structure that can be inferred. For example, previous experimental studies have found that sibilant fricative-stop sequences can be viewed as a complex branching onset in English (Browman & Goldstein 1988; Marin & Pouplier 2010, among others), German (Pouplier 2012), and Romanian (Marin 2013), but a sibilant fricative is syllable-external before a word-initial stop in Italian (Hermes et al. 2013).

The status of sibilant fricative-stop clusters in Moenat Ladin is of particular research interest both because of the phonological properties of this language and its situation with respect to Italian and German. As pointed out by Yang et al. (2021), the Ladin linguistic community exhibits intricate multilingual repertoires, and the presence of Italian and German poses a threat to the sustainability of the Ladin language. With respect to sibilant fricative-stop clusters, Moenat presents word-initial clusters in which the sibilant fricative is post-alveolar (retroflex) and agrees in voicing with the following stop (e.g. /ʂp-/, /ʐb-/, etc.). Moenat is closely related to Italian; however, consonant phonotactics in Moenat are more complex. Moenat displays a richer set of consonant clusters in coda positions, some of which have been influenced by borrowings from German (Walker & Yang 2024).

The foregoing factors contribute motivation for our investigation of word-initial sibilant fricative-stop sequences in Moenat Ladin, in addition to the goal of phonological study of Moenat in its own right. Based on the findings for Italian, to which Moenat is closely related, and our pilot research, we hypothesize that the sibilant is external to a syllable onset that begins with the stop. Our hypothesis is probed with an experiment that investigates the temporal coordination of gestures, which bears on the organization of elements in syllable structure. In this experiment, we employ a methodology recently developed by Ruthan et al. (2019) and Durvasula et al. (2021) that uses measurements of acoustic production data to make inferences about temporal coordination. This is the first study of this kind in Ladin.[1] Furthermore, this research contributes on the current state of the language, with focus on the production of Moenat by young adults (age range 20s to early 30s). A previous description of Moenat phonology by Heilmann (1955) applies to a different generation of speakers. Our overarching goals for this paper are to present new empirical data on an understudied Romance language, apply a recently innovated methodology, and contribute to the understanding of the systematic temporal organization in consonant clusters of Ladin.

This paper is organized as follows. In section 2, we provide a description of the relevant word-initial clusters in Moenat Ladin. In section 3, we review the research on consonant clusters and introduce key concepts. In section 4, we describe the design of our experiment investigating temporal organization in clusters and discuss the data analysis. In section 5, we report the results. In section 6, we present some general discussion, and section 7 contains the conclusion.

2. Consonant clusters in Moenat Ladin

Our focus is on word-initial consonant clusters of Moenat, in particular, sibilant-stop clusters. The data and descriptive generalizations are based on our fieldwork on Moenat phonotactics (Walker & Yang 2024) with foundation from previous documentation by Heilmann (1955) and two dictionaries *PODLM (Prontuarie ortografich del ladin moenat dal vocabolario ladino moenese - italiano di Giuseppe Dell'Antonio (1972)* 2015.) and *DILF (Dizionario italiano-ladino fassano / Dizionèr talian-ladin fascian* 2013).

There are 19 consonant phonemes in Moenat, as listed in (1) (Yang et al. 2021); the permissible word-initial clusters are summarized in (2) (O = non-sibilant obstruent, L = liquid, S = sibilant fricative, N = nasal).

(1) Consonant phoneme inventory of Moenat

	Bilabial		Labio-dental		Dental/ Alveolar		Post-alveolar		Palatal		Velar	
Plosive	p	b			t	d					k	g
Affricate							tʂ	dʐ				
Fricative			f	v	s	z	ʂ	ʐ				
Nasal stop		m				n				ɲ		
Trill						r						
Lateral Approximant						l						

1 A report on preliminary findings for this study was provided in Walker & Yang (2023). In this paper, we include additional data (including an additional participant), and we report on further quantitative analyses of the data.

(2) Permissible word-initial consonant clusters

a.	O + L	[pr-], [br-], [tr-], [dr-], [kr-], [ɡr-], [fr-] [pl-], [pr-], [br-], [kl-], [ɡl-], [fl-]
b.	S + O	[ʂp-], [ʂt-], [ʂk-], [ʐb-], [ʐɡ-], [ʂf-], [ʐv-]
c.	S + N	[ʐm-], [ʐn-], [ʐɲ-]
d.	S + L	[ʐr-], [ʐl-]
e.	S + O + L	[ʂpr-], [ʂtr-], [ʂkr-], [ʐbr-], [ʐdr-], [ʐɡr-], [ʂfr-] [ʂpl-], [ʂkl-], [ʐɡl-], [sfl-]

Following Walker & Yang (2024), the generalizations regarding word-initial consonant clusters in Moenat are as follows. Consonant clusters that consist of an obstruent stop or fricative followed by a liquid (/r/ or /l/) occur word-initially, with the exception of *[tl-], *[dl-], *[vr-], and *[vl-]. On the other hand, sibilant fricatives show distinct distributional properties. A sibilant fricative (/ʂ/ or /ʐ/) can appear before any non-sibilant consonant (2b-d) and before any permissible two-consonant cluster (2e). However, triconsonantal clusters ending in /l/ are rare or absent.[2] In addition, Walker & Yang (2024) did not find examples of [ʐd] in word-initial position, except in the sequence [ʐdr-]; although [ʐd] may occur intervocalically. Affricates are prohibited from occurring in word-initial clusters.

The consonant clusters with which we are concerned in this study involve sibilant fricatives (S), plosive stops (C), and liquids (/l/, /r/). In particular, Moenat clusters include sibilant-stop (SC) sequences (3a), sibilant-stop-/r/ (SCr) sequences (3b), stop-/l/ (Cl) sequences (3c), and stop-/r/ (Cr) sequences (3d). Preconsonantal sibilants in Moenat tend to be post-alveolar and agree in voicing with the following consonant. We represent the post-alveolar sibilants as retroflex, although there is some variation as to whether speakers produce them as retroflex or non-retroflex.

(3) Word-initial consonant clusters in Moenat

a.	SC		b.	SCr	
	[ʂparpaˈɲa]	‘widespread’		[ʂpriseteˈnada]	‘splash N’
	[ʐbiˈaf]	‘faded’		[ʐbralˈdʐar]	‘sbralgiar’
	[ˈʂtala]	‘stall’		[ʂtraneˈos]	‘strange’
	[ˈʂkaʐi]	‘almost’		[ʐdraˈmatʂ]	‘mattress’
	[ˈʐɡaisa]	‘eagerness’		[ˈʂkrɔza]	‘shell’
				[ʐɡriˈfion]	‘scratch’
c.	Cl		d.	Cr	
	[plau]	‘rest, relax’		[preˈar]	‘to pray’
	[ˈblaɡa]	‘snooty/arrogant person’		[brøt]	‘broth’
				[troˈar]	‘to find’
	[klingeˈnar]	‘to ring, to clang’		[drak]	‘dragon’
	[ˈɡlɔria]	‘glory’		[ˈkreda]	‘clay’
				[ɡraˈmial]	‘apron’

[2] This gap could perhaps be due to the relative rarity of obstruent-/l/ clusters more generally, but investigating this possibility awaits a detailed examination of frequencies of consonants and cluster combinations.

Unlike other obstruents, the distribution of sibilant fricatives does not seem to be influenced by sonority sequencing (Clements 1990), because they can occur before any other consonant except a sibilant. Therefore, the current study focuses on the role of sibilants in word-initial consonant clusters. The research question will be further detailed in Section 3.

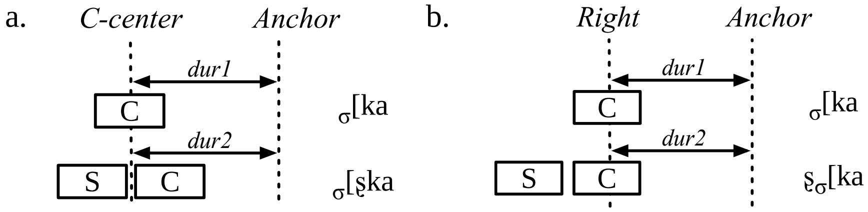
3. Temporal coordination of word-initial preconsonantal sibilant fricatives

The syllabification of word-initial preconsonantal sibilant fricatives remains a controversial topic. According to the Sonority Sequencing Principle (SSP, Selkirk 1984; Clements 1990), a well-formed syllable exhibits a pattern where sonority rises from the beginning of the syllable, reaches a peak at the nuclear vowel, and then decreases from the nucleus towards the end of the syllable (Parker 2011). Within the sonority hierarchy, sibilant fricatives are often considered to be more sonorant than plosives (e.g. Hankamer & Aissen 1974; Steriade 1982, 1988; Davis 1990; Kager 1999). However, a common exception to the SSP arises in the case of word-initial SC clusters in various languages, if they are viewed as a branching onset. Therefore, some researchers have proposed that S is a syllable-external element rather than an element of a complex branching onset (e.g. Steriade 1982; Goldsmith 1990; Goad & White 2006), while some others have posited that certain SC clusters form complex segments (e.g. Selkirk 1982; van de Weijer 1996; Wiese 1996; see Goad 2011 for a review).

From the perspective of gestural representations, it has been argued that whether a prevocalic consonant sequence is a complex onset or not can be diagnosed by the presence or absence of a C-centering pattern in the consonants' temporal organization. This diagnosis is often made based on stability analysis. Browman & Goldstein (1988, 2000) found that English word-initial consonant clusters exhibit a *C-centering effect*, which is diagnostic of a complex onset. In this pattern, the mean of the midpoints of the consonantal gestures, which forms the C-center of the cluster, is temporally aligned with a following anchor, such as the end of the following vowel. In Figure 1a, for instance, if an SC sequence such as Moenat /ʂk/ were organized as a complex onset, the durations between the mean of the temporal midpoints of the consonantal gestures and the end of the vowel gesture in $_\sigma$[ʂka and $_\sigma$[ka would resemble each other (*dur2* resembles *dur1* in Figure 1a), which causes a systematic rightward shift of the /k/ in /ʂk/ in comparison with a singleton prevocalic /k/ to ensure C-center-based alignment. The C-centering effect has been observed for at least some consonant clusters in a range of languages including American English (Marin & Pouplier 2010), Georgian (Goldstein et al. 2007), and Italian (Hermes et al. 2013), among others.

In Figure 1b, however, when a language disallows a cluster from forming a complex onset, it shows a *right-edge effect* in which the right-edge-to-anchor duration is the most stable. In this scenario, only the second consonant in a cluster forms the syllable onset and the first consonant is external to the syllable onset. As evidence of this organization, the duration from the center of the rightmost consonant in /ʂk/ to the anchor will most stably resemble the duration from the center of singleton /k/ (*dur2* resembles *dur1* in Figure 1b). With regard to Moenat, we hypothesize that word-initial SC clusters are structured with an onset-external sibilant, which is consistent with the right-edge-to-anchor stability pattern in Figure 1b.

Figure 1. (a) C-center-to-anchor stability pattern and (b) right-edge-to-anchor stability pattern.



Regarding SC clusters, the pattern of gestural coordination varies across languages. In Italian, Hermes et al. (2013) discovered a right-edge-to-anchor stability pattern in sibilant-obstruent clusters (e.g. /sp-/), suggesting that the word-initial preconsonantal sibilant is not part of the syllable onset. Nevertheless, obstruent-liquid clusters in word-initial position (e.g. /pr-/) exhibit a C-center alignment and can be viewed as complex onsets. In contrast, SC clusters in Romanian, English, and German demonstrate a C-centering effect. Although Romanian and Italian are both romance languages, Marin (2013) observed a C-center organization in word-initial /sp-/, /sm-/, and /sk-/ clusters in Romanian. Likewise, the C-centering effect is also found in word-initial /sp-/ and /sk-/ in American English (Browman & Goldstein 1988; Marin & Pouplier 2010, among others), as well as in the /sk-/ cluster in German (Pouplier 2012).

To summarize, the organization of word-initial preconsonantal sibilant fricatives appears to vary across languages. This study aims to examine the SC and SCr clusters in Moenat Ladin and investigate how the word-initial preconsonantal sibilant fricatives are organized in this language. Evidence from phonological and phonetic studies of Italian, which is closely related to Ladin, supports an analysis in which a word-initial sibilant in an SC cluster of Italian is external to a syllable onset beginning with a plosive stop (Chierchia 1986, Davis 1990, Hermes et al. 2013). A similar pattern is potentially expected for Moenat. Although this paper primarily focuses on SC and SCr clusters, Cl clusters are also examined to provide a more comprehensive understanding of the temporal coordination of word-initial clusters and further support the findings related to SC and SCr clusters. To address the issue, we will employ a stability analysis using acoustic data to investigate the temporal organization of word-initial clusters in Moenat.

4. Materials and method

Previous studies on other languages have in large part used articulatory data to investigate the temporal organization of consonants in syllables. In this study, we use a production experiment with acoustic data instead, since they are more amenable to being acquired in a fieldwork setting. In general, we follow the methodology developed by Ruthan et al. (2019), and Durvasula et al. (2021). These studies support the utility of acoustic techniques in the investigation of the temporal organization of consonant clusters. More details about data analysis and measurements will be introduced in the following subsections.

4.1. Participants

Five native speakers of Moenat were recruited in the experiment (two females and three males; labeled as S1, S2, S3, S4, and S5, respectively). The speakers were in their 20s or early 30s at the time of the experiment. They speak Moenat at home but learned “Standard Ladin” at school, a standardized variety based on the Cazet variety of Val di Fassa Ladin. All of the participants are Ladin-Italian bilingual while two of them (S3 and S4) also have good English proficiency.

4.2. Materials

The materials were prepared by the authors in consultation with a native speaker of Moenat. We designed (near-)minimal sets of target words where each set contains four words (real or nonce) with different word-initial consonantal patterns. The /r/ series sets (*n* = 5) (near-)minimally differ in the word-initial consonants and clusters C/SC/Cr/SCr, e.g. *bama*, *sbama*, *brama*, *sbrama*, while the /l/ series sets (*n* = 6) (near-)minimally differ in the word-initial consonants and clusters l/Cl/C/SC, e.g. *laca*, *placa*, *paca*, *spaca*. From among these, we made various pairwise comparisons. To ensure a natural production of clusters, we identified as many real words as possible for SC, Cr, SCr, and Cl clusters. Nevertheless, the Ladin lexicon is limited, so it was necessary to include a considerable number of nonce words.[3] All the nonce words were made to resemble a feminine noun or a conjugated verb, which can be embedded into the frame sentence “*dimo la* ___ *Maria!*” (‘say the ___ Maria!’) or “*dimo ela la* ___ *Maria*” (‘say she ___ Maria!’). A clitic element (*la* or *ela la*) was included before the target word to reduce the likelihood of a pause between the beginning of the target word and its preceding vowel. The target words are listed in (4).[4] There are more C/SC target pairs than pairs in the other comparisons, because they were drawn from both the /r/-series and /l/-series sets. Because the pair *bata*/*sbata* occurs in both of these two series, there are a total of 10 unique C/SC pairs in the stimuli. Words were presented in Ladin orthography, which corresponds to italicized forms in (4). See the appendix for more details.

(4) Target words in the experiment

a. *C/SC comparisons*

i.	*bama* [ˈbama] nonce	*sbama* [ˈz̡bama] nonce
ii.	*pita* [ˈpita] ‘hen’	*spita* [ˈs̡pita] nonce
iii.	*bata* [ˈbata] ‘cotton wool’	*sbata* [ˈz̡bata] nonce
iv.	*bòcia* [ˈbɔts̡a] nonce	*sbòcia* [ˈz̡bɔts̡a] ‘female friend’
v.	*bossa* [ˈbosa] ‘kiss 3SG.PRS’	*sboza* [ˈz̡bosa] nonce
vi.	*baga* [ˈbaga] nonce	*sbava* [ˈz̡bava] ‘slobber, drool (noun)’

[3] The design of the target words was assisted by a native speaker of Moenat Ladin with linguistic expertise. Nonce words were designed to closely resemble real words where possible. In addition, the word-initial clusters in the nonce words are commonly found in real words. However, we cannot rule out the possibility that nonce words differ from real words in their temporal coordination.

[4] We also collected data on r ~ Cr but do not report on it here. The status of Cr as a complex onset in Romance languages has not generally been in question. Furthermore, a comparison of r ~ Cr in Moenat is not amenable to investigation in parallel with the other singleton/cluster pairs investigated here, because post-clitic intervocalic /r/ is flapped, while post-consonantal /r/ in Cr is trilled. This allophony interferes with acoustically based comparisons of temporal coordination as structured in the stimuli for the present study, for which the focus is on the syllabification of sibilant fricatives.

vii. *pòta* [ˈpɔta] nonce *spona* [ˈʂpɔna] ‘bed, wagon train’
viii. *còssa* [ˈkɔsa] nonce *scòza* [ˈʂkɔsa] nonce
ix. *gàssa* [ˈɡasa] nonce *sgassa* [ˈʐɡasa] nonce
x. *paca* [ˈpaka] ‘blow (noun)’ *spaca* [ˈʂpaka] nonce

b. *Cr/SCr comparisons*
i. *brama* [ˈbrama] ‘sour cream’
sbrama [ˈʐbrama] ‘to remove sour cream from milk 3SG/PL’
ii. *prita* [ˈprita] nonce *sprita* [ˈʂprita] nonce
iii. *brata* [ˈbrata] nonce *sbrata* [ˈʐbrata] nonce
iv. *bròcia* [ˈbrɔtʂa] ‘nail’ *sbròcia* [ˈʐbrɔtʂa] nonce
v. *brossa* [ˈbrosa] nonce *sbroza* [ˈʐbrosa] nonce

c. *l/Cl comparisons*
i. *laga* [ˈlaɡa] nonce *blaga* [ˈblaɡa] ‘arrogant person’
ii. *lòta* [ˈlɔta] nonce *plota* [ˈplɔta] ‘stone, concrete slab’
iii. *lòssa* [ˈlɔsa] nonce *clòssa* [ˈklɔsa] nonce
iv. *lassa* [ˈlasa] nonce *glassa* [ˈɡlasa] ‘icing (for food)’
v. *lata* [ˈlata] nonce *blata* [ˈblata] nonce
vi. *laca* [ˈlaka] ‘lacquer, paint’ *placa* [ˈplaka] ‘calm down 3SG.PRS’

4.3. Procedure

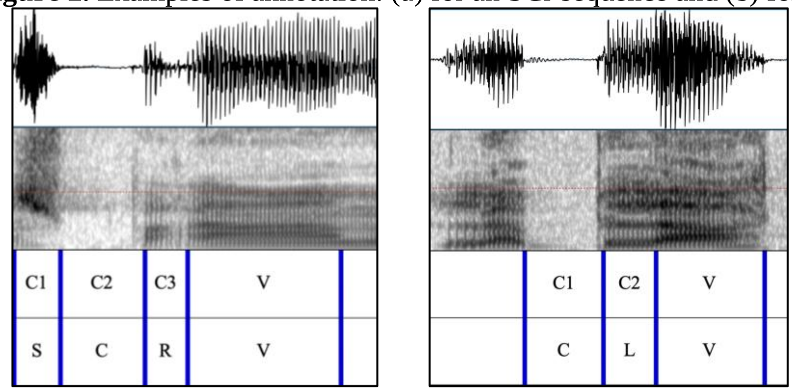
The data were acquired in Moena in 2019. The complete list contained 528 randomized sentences (12 repetitions × 44 target words, embedded in one of the carrier sentences above). The recordings were made onto a laptop computer using a head-mounted Logitech microphone and Praat software (Boersma & Weenink 1992–2022) at a sampling rate of 44,100 Hz.

4.4. Annotation

The audio files were segmented and annotated by trained research assistants. Annotation and segmentation were performed with reference to both the spectrogram and waveform, following a set of rubrics. Any tokens that posed difficulty for the research assistants were further examined and annotated by the authors. A total of 43 tokens were excluded due to problems with segmentation, disfluencies in production, or errors in pronunciation, yielding 2597 tokens for data analysis.

While the experiments of Durvasula et al. (2021) investigated sibilants and nasals, the current study examines sibilants, plosive stops, and liquids. The latter two segment types warrant careful consideration during segmentation. We made use of various acoustic cues to determine the starting and ending points of segments. For vowel segmentation, the same criteria as those in Durvasula et al. (2021:180) were adopted, namely, the appearance and disappearance of strong formant structure and periodic energy in the waveform. For stops, the onset and offset were marked mainly based on formant structure and periodicity of the preceding and following vowel or sonorant, or by the offset of high-frequency noise in a sibilant, as in SC(r) words. For rhotic trills, the starting point was determined by the appearance of formant structure associated with the rhotic, as well as an associated change in the waveform. The end of the rhotic was marked at the beginning of formant structure associated with the following vowel. For laterals, the onset was marked based on the appearance of formant structure associated with the lateral, as well as an associated change in the waveform, while the offset was marked at the beginning of formant structure for the following vowel. Finally, the onset and offset of sibilants were mainly identified by the appearance and disappearance of a noisy, high-frequency spectrum, assisted by formants of surrounding vowels and reference to waveforms. Two annotated examples are given in Figure 2 (only the first syllable in the target words was annotated).

Figure 2. Examples of annotation: (a) for an SCr sequence and (b) for a Cl sequence.



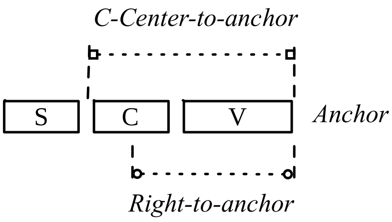
a. [ˈʐbrama] b. [ˈblata]

4.5. Data analyses

The time points were extracted from the annotated TextGrids with the package *rPraat* (Bořil 2016) in R (R Core Team 2020). Relevant intervals and durations were calculated based on the extracted time points. The stability analyses conducted in this study rely on acoustic measurements, following the methodology of Durvasula et al. (2021). The results were also analyzed statistically using mixed-effect regression modeling.

The relevant acoustic landmarks in the analysis include the temporal midpoint of each consonant and the end of the following vowel which is referred to as the *anchor*. The C-center of a consonant cluster is calculated by averaging the midpoints of the consonants in the cluster, while the right edge of the cluster is the midpoint of the rightmost consonant. We calculated the duration of two intervals in this analysis, i.e., the C-center-to-anchor interval and right-edge-to-anchor interval, illustrated in Figure 3 for a word-initial SC cluster. Note that these intervals are identical in a word with a singleton onset, both being from the center of the single prevocalic consonant to the anchor.

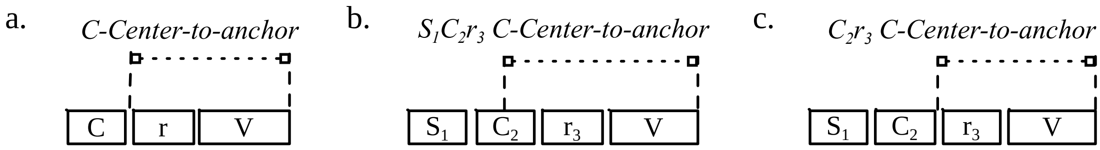
Figure 3. C-center-to-anchor interval and right-edge-to-anchor interval for an SC cluster.



Based on the measurements, we made three target comparisons for (near-)minimal word pairs with the following types of word-initial consonants: C/SC, Cr/SCr, and l/Cl. For the comparisons that involve singleton/two-consonant clusters, if the C-center-to-anchor interval for both types of words in a target pair is the least variable (or has greater stability), that would suggest that the consonant cluster exhibits a C-center effect and is organized as a complex onset. If instead, the right-edge-to-anchor interval of both types of words in a target pair is the least variable, that would suggest that the initial consonant in the prevocalic cluster is organized as onset-external. In the comparison of Cr/SCr, where there is a three-consonant cluster, the Cr sequence can be treated as a unit. This point is elaborated below.

Among the comparisons, C/SC and Cr/SCr are designed to determine if a word-initial sibilant is external to the onset, while the pair l ~ Cl helps evaluate the status of a stop and lateral liquid in a prevocalic cluster. For Cr/SCr pairs, we treated Cr as a unit, similar to a single segment, for which the midpoint was calculated as the C-center of Cr.[5] We then compared the C-center-to-anchor interval of Cr words (Figure 4a) with two C-center-to-anchor intervals for SCr (Figure 4b-c). One interval is from the C-center of all three consonants in $S_1C_2r_3$ (Figure 4b), while the other is from the C-center of C_2r_3 in $S_1C_2r_3$ (Figure 4c). The alignment in Figure 4b is what is expected if the sibilant forms the beginning of an SCr onset, while that shown in Figure 4c is what is expected if the sibilant is external to a Cr onset. If a word-initial sibilant is onset-external in an SCr sequence, there should be less variation in the latter comparison, namely, between the C-center-to-anchor of Cr (Figure 4a) and the C_2r_3 C-center-to-anchor of $S_1C_2r_3$ (Figure 4c).

Figure 4. Comparisons between Cr and SCr words.



To evaluate which interval has less variance, we calculated the Relativized Standard Deviation (RSD) of the C-center-to-anchor duration and the right-edge-to-anchor duration for each target pair, using the formula in (5). For example, for [ˈbama]/[ˈʐbama], the RSD of this pair was calculated with 12 repetitions for each of 5 speakers. For pairs involving an SCr cluster, such as [ˈbrama]/[ˈʐbrama], we computed RSDs for the C-center-to-anchor of [ˈbrama] (Figure 4a) and that of [ˈʐbrama] (Figure 4b), as well as RSDs for the C-center-to-anchor of [ˈbrama] and the C_2r_3 C-center-to-anchor of [ˈʐbrama] (Figure 4c).

(5)

$$\mathrm{RSD} = \frac{100 \times \text{standard deviation}}{\text{mean}}$$

[5] This is based on the assumption that Cr clusters show C-centering, which is not generally controversial for Romance languages, though it would be useful to confirm this for Moenat in future research.

The utility of RSD in the study of temporal coordination has been supported by various authors (e.g. Shaw et al. 2009, 2011, Ruthan et al. 2019, Durvasula et al. 2021). This method gives an unbiased measure for a set of durations in comparison with an uncorrected measure such as standard deviation or variance, since longer durations (C-center-to-anchor compared to right-edge-to-anchor) inherently have larger variance. Therefore, an interval with a smaller RSD suggests less difference and greater stability, which relates to a pattern of temporal coordination. Readers are referred to Durvasula et al. (2021) for more detailed rationale of this method.

The results of the stability analysis and duration analysis were also analyzed statistically using mixed-effects regression modeling with the *lme4* package (Bates et al. 2015). The details of modeling will be introduced when reporting the results.

5. Results

5.1. Sibilant-stop (SC) cluster

We first present the results of word-initial C/SC comparisons. All the plots and analyses were performed in R (R Core Team 2020). Figure 5 shows the within-speaker comparison of durations between SC words and words with a singleton stop onset. From visual inspection, all the speakers demonstrate a tendency for right-edge stability, since the right-edge-to-anchor interval of #SCV words is closer to that of #CV words.

Figure 5. Durations for the C-center-to-anchor interval and right-edge-to-anchor interval for C/SC comparison (within-speaker).

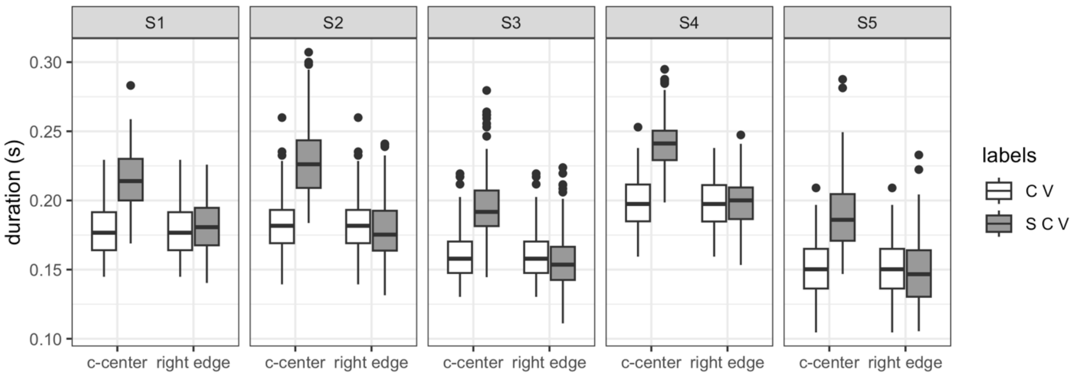


Figure 6 further shows the results pooled across sets and speakers. We observe that the right-edge-to-anchor interval is more stable for word-initial singleton consonants and clusters than the C-center-to-anchor interval. In addition, the RSD values of the right-edge-to-anchor interval are smaller, which indicates greater stability in comparison to the C-center-to-anchor interval, as shown in Figure 7.

Figure 6. Durations for the C-center-to-anchor interval and right-edge-to-anchor interval for C/SC comparison.

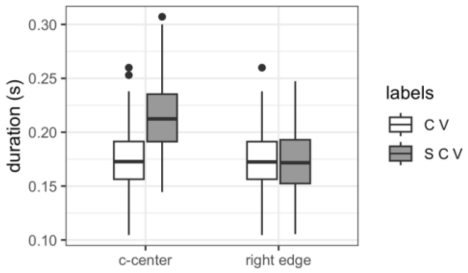
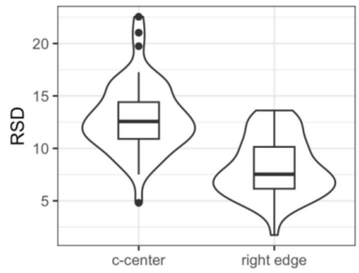


Figure 7. Overall RSDs for each interval.



Next, a statistical analysis was conducted using mixed-effects modeling to examine the C/SC comparisons. The dependent variable was RSD. The independent variables considered included interval type (C-center-to-anchor interval and Right-edge-to-center interval), C voicing (voiced and voiceless), and the interaction between the two.

The maximal model included a fixed-effects structure of an intercept, interval type, C voicing, and the interaction between interval type and C voicing, while the fixed-effects structure of the minimal model only included an intercept. The random structures included by-word pair and by-speaker random slopes and intercepts in all models. The models were compared using the likelihood-ratio test and a comparison of the Akaike Information Criterion (AIC). The one with the smallest AIC, as shown in Table 1, was considered the best model.

Table 1. Model comparison (the random structure is not listed in the table; the smallest AIC is in bold).

Model	AIC	Log-likelihood	χ^2	Df	p ($>\chi^2$)
Intercept	478.73	–231.37			
Intercept + Interval Type	466.61	–224.30	14.121	1	< .001
Intercept + C Voicing	478.19	–230.10			
Intercept + Interval Type + C Voicing	**466.01**	–223.00	14.184	1	< .001
Intercept + Interval Type × C Voicing	467.89	–222.94	0.121	1	0.728

We then looked into the fixed effects of the selected model. The results showed that interval type had a statistically clear effect (baseline: C-center; estimate = –4.411, SE = 0.580, t = –7.60, p = .00) but the voicing of C was not a significant factor (baseline: voiced), as in Table 2. This model indicated that the RSDs of right-edge-to-anchor interval were on average 4.411 smaller in relation to the C-center-to-anchor interval. Therefore, the results suggest a right-edge stability in #SC syllables, which in turn supports an onset-external status for a word-initial sibilant in an SC cluster in Moenat.

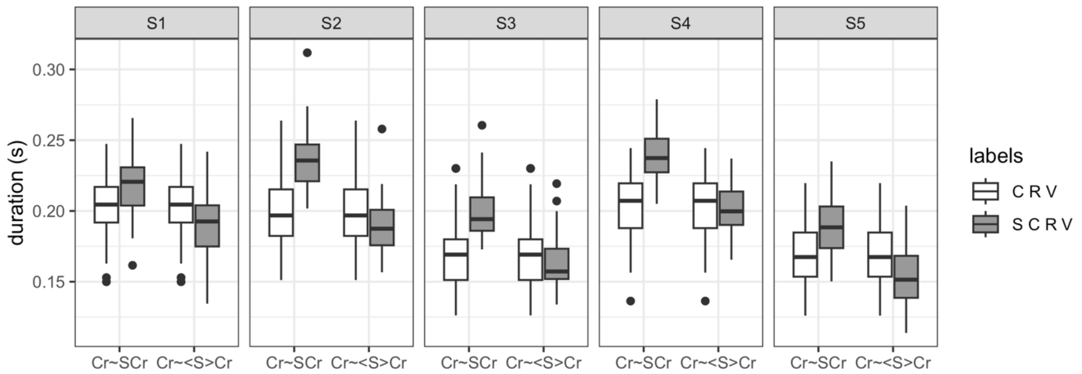
Table 2. The fixed effects of C/SC RSD comparison.

Fixed effects	estimate	*SE*	*df*	*t*	*p* (>| t |)
(Intercept)	12.285	0.546	6.529	22.492	0.00
Interval Type	–4.411	0.580	7.600	–7.604	0.00
C Voicing	0.816	0.500	89.003	1.633	0.106

5.2. Stop-plosive-rhotic (SCr) cluster

We further examined the words starting with SCr to investigate whether this cluster is also structured with an onset-external sibilant. The experiments of Durvasula et al. (2021) did not examine three-consonant clusters. For our analysis, we modified their general approach and treated Cr in the Cr/SCr comparison as a single unit in this scenario, as illustrated in Figure 4. We first present the within-speaker comparisons in Figure 8. In each panel, the label "Cr ~ SCr" indicates the comparison between the C-center-to-anchor interval of Cr and that of SCr, as in Figure 4b; the label "Cr ~ <S>CR" refers to the comparison between the C-center-to-anchor interval of Cr and that of C_2r_3 in a $S_1C_2r_3$ cluster, as in Figure 4c.

Figure 8. Durations for the C-center-to-anchor interval of Cr, $S_1C_2r_3$, and C_2r_3 (within-speaker). The label "Cr ~ SCr" indicates the comparison between the C-center of Cr and that of SCr; the lable "Cr ~ <S>Cr" indicates the comparison between the C-center of Cr and the C-center of C_2r_3 in $S_1C_2r_3$.



The data are pooled in Figure 9. Similar to our findings for SC clusters, Figure 9 suggests that the interval from the C-center of C_2r_3 to the anchor (labeled as <S>Cr) is more stable in comparison to the C-center of a word-initial Cr sequence than the interval from the C-center of SCr in comparison to word-initial Cr. Additionally, the former interval also shows a tendency of smaller RSD values in Figure 10, based on visual inspection.

Figure 9. Durations for the C-center-to-anchor interval of Cr, $S_1C_2r_3$, and C_2r_3 (labeled as <S>Cr).

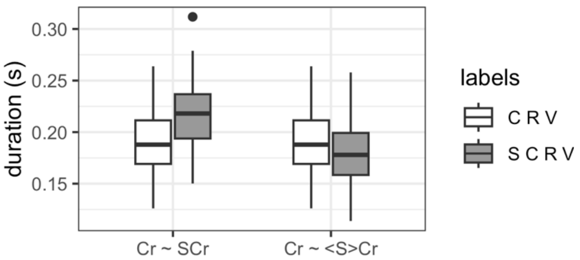
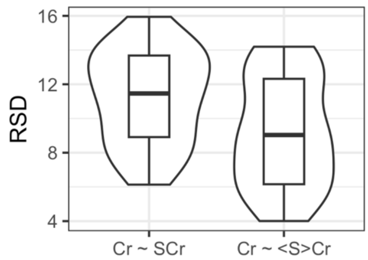


Figure 10. Overall RSDs for each interval: the C-center-to-anchor intervals for Cr/$S_1C_2r_3$, and Cr/C_2r_3 (labeled as <S>Cr).



A statistical analysis was also performed for this pair. However, we made some adjustments to the models designed for the C/SC pair. Recalling (4), there are only five Cr/SCr pairs in the target words, and four of them contain a voiced C (/b/). Further, in the pairs that contain /b/, the syllables under investigation are all [(ʐ)bra] or [(ʐ)brɔ], where the main vowel is low back or mid-low back. To make the model less complex, we only analyzed the four voiced pairs, leaving 40 RSD values for the analysis (20 RSDs for each interval type; 5 speakers × 4 pairs × 2 interval types). Additionally, we excluded the by-pair random slope, since the target words all begin with [(ʐ)br-] and contain a non-high back vowel. Given the limited number of data points, we could not construct a meaningful model for the Cr/SCr comparison if additional fixed effects and random structures were included.

In this analysis, the dependent variable was RSD, and the only fixed-effect structure considered was the interval type (the interval from the C-center of SCr to the anchor and the interval from the C-center of C_2r_3 to the anchor) and an intercept; the random structure has a by-speaker random slope and intercept. We omit the model comparison procedure to save space. The results of this model show a statistically clear effect of interval type (estimate = –2.100, SE = 0.997, t = 10.782, p = .00), as in Table 3, indicating that the C_2r_3 C-center-to-anchor interval is smaller by 2.100.

Table 3. The fixed effects of Cr ~ SCr RSD comparison.

Fixed effect	estimate	*SE*	*df*	*t*	*p* (>| t |)
(Intercept)	10.753	0.997	5.106	10.782	.00
Interval Type	–2.100	0.742	21.285	–2.829	< .01

The RSD values of the *voiced* pairs are plotted in Figure 11. It is evident that C_2r_3 C-center-to-anchor interval has smaller RSDs, which is consistent with the statistical results. Therefore, the C-center-to-anchor interval of Cr clusters and the C_2r_3 C-center-to-anchor interval of SCr clusters show greater stability, indicating a representation like that shown in Figure 12. This comparison further supports the onset-external status for word-initial sibilants in Moenat.

Figure 11. Overall RSDs for each interval: the C-center-to-anchor intervals for Cr/ $S_1C_2r_3$, and Cr/C_2r_3 (labeled as <S>Cr) (Voiced pairs only).

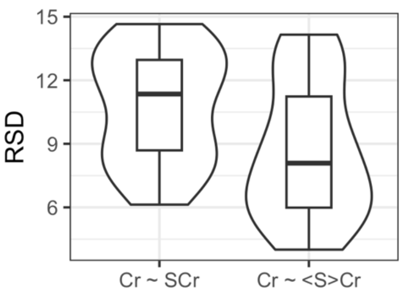
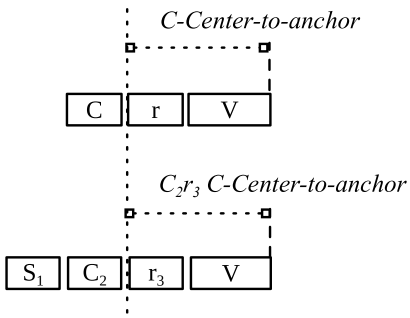


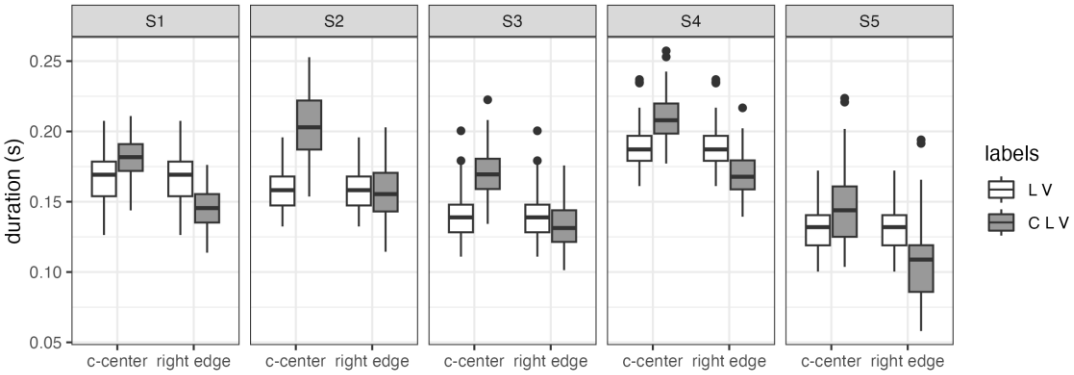
Figure 12. Stability pattern of Cr and SCr clusters.



5.3. Stop-lateral (Cl) cluster

Finally, we examined the Cl clusters. As shown in Figure 13, the results for word-initial Cl clusters demonstrate variation between speakers. After inspecting the results of each participant, we observed that the productions of S2 and S3 have a more stable right-edge-to-anchor interval, since the right-edge-to-anchor durations of Cl- and l-initial words show relatively less variability in the plots of these two speakers below.

Figure 13. Durations for the C-center-to-anchor interval and right-edge-to-anchor interval for l/Cl comparison (by speaker).



Thus, instead of combining all the speakers into a single plot, we categorized the speakers into groups based on the visual inspections of Figure 13. When S2 and S3 are grouped together, the raw durations of the right-edge-to-anchor interval are the least variable, as shown in Figure 14, and the RSDs of this interval are smaller, as shown in Figure 15. Nevertheless, Figure 16 and Figure 17 suggest that S1, S4, and S5 demonstrate a tendency for a C-centering effect for Cl clusters. This is more obvious in Figure 17, where the RSDs of the C-center-to-anchor interval are smaller.

Figure 14. Durations for the C-center-to-anchor interval and right-edge-to-anchor interval for l/Cl comparison (S2 and S3).

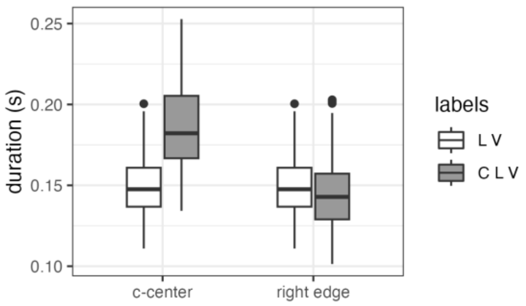


Figure 15. Overall RSDs for each interval for l/Cl comparison (S2 and S3).

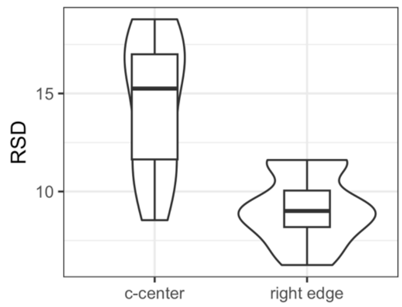


Figure 16. Durations for the C-center-to-anchor interval and right-edge-to-anchor interval for l/Cl comparison (S1, S4, and S5).

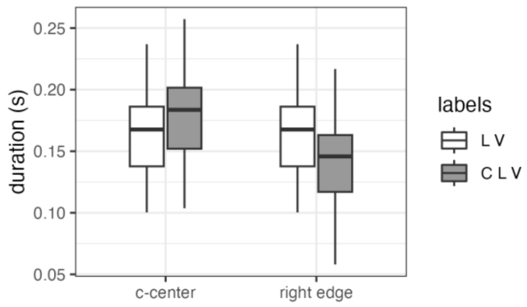
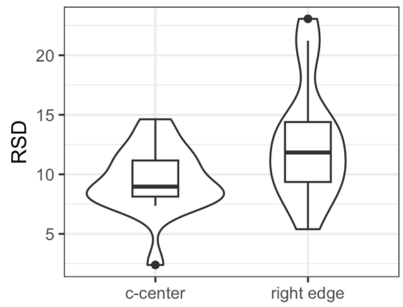


Figure 17. Overall RSDs for each interval for l/Cl comparison (S1, S4, and S5).



Upon closer examination of the data by set, especially for S1, S4 and S5, we observed a pattern of RSDs with regard to voicing. The RSD values of individual word sets are given in Table 4. For these three speakers, it is clear that, in the sets containing a voiceless plosive ([ˈlɔta]/[ˈplɔta], [ˈlaka]/[ˈplaka], [ˈlɔsa]/[ˈklɔsa]), the RSDs of C-center-to-anchor interval are in large part smaller than those of their corresponding right-edge-to-anchor interval in each l/Cl pair.

Table 4. By-set RSDs of Speaker 1, 4, and 5 (C-center-to-anchor RSDs are in bold if they are smaller than the corresponding Right-edge-to-center RSDs).

	RSD, Speaker 1		**RSD, Speaker 4**		**RSD, Speaker 5**	
	C-center	***Right edge***	***C-center***	***Right edge***	***C-center***	***Right edge***
Voiced C						
[ˈlaga] ~ [ˈblaga]	**2.39**	10.27	**7.54**	8.19	14.62	13.11
[ˈlata] ~ [ˈblata]	**8.11**	13.10	11.94	10.50	**10.20**	12.13
[ˈlasa] ~ [ˈglasa]	7.35	7.22	9.10	5.39	**13.68**	14.31
Voiceless C						
[ˈlɔta] ~ [ˈplɔta]	**8.35**	11.53	**8.50**	14.42	**11.15**	23.06
[ˈlaka] ~ [ˈplaka]	**7.62**	14.77	**8.82**	9.05	**10.17**	19.99
[ˈlɔsa] ~ [ˈklɔsa]	11.17	8.73	**8.19**	10.43	**12.36**	21.22

The qualitative inspections suggest a greater overall stability of the C-center-to-anchor interval for S1, S4, and S5, along with a tendency of a C-centering effect observed in clusters that contain a voiceless stop. However, the patterns cannot be statistically confirmed. Similar to the analysis of the Cr/SCr pair, the stimuli only include six l/Cl pairs (resulting in six RSD values per interval type, per speaker). When considering interval type, voicing, speaker, and word pair in the modeling, we cannot select a convergent mixed-effects model, probably due to insufficient data points. We will further discuss these observations in Section 6.

6. Discussion

Based on the review presented in Section 3, word-initial sibilant fricatives in an SC cluster form an exception to the Sonority Sequencing Principle if the cluster is tautosyllabic. This has contributed to the controversial status of SC clusters and given rise to studies finding evidence of their language-specific organization. A diagnosis of the organization of word-initial consonant clusters involves the C-centering effect. Although previous studies probed the organization of consonant clusters using articulatory data, Durvasula et al. (2021) demonstrated the validity of acoustic data in investigating this issue.

In this study, we asked the general question of how the word-initial preconsonantal sibilant fricatives are organized in Moenat Ladin, an under-threat Romance language that is closely related to Italian. In this study, acoustic data were collected in a production experiment and analyzed following the same basic methodology as that of Durvasula et al. (2021). Based on the results in Section 5, our findings are summarized as follows. For C/SC pairs, the right-edge-to-anchor interval is more stable, providing evidence for right-edge alignment of SC clusters. The same results were obtained for SCr clusters. For Cr/SCr pairs, we treated Cr as a single unit and compared the C-center-to-anchor interval of Cr words with (i) the C-center-to-anchor interval of SCr and (ii) the interval between the C-center of C_2r_3 in $S_1C_2r_3$ and the anchor. The results also show that the second comparison has greater stability. This analysis points to the preconsonantal sibilant being organized external to the syllable when followed by a Cr sequence.

The results for word-initial C/SC and Cr/SCr comparisons support a syllable-external organization of S in the clusters. Still, it is possible that the right-edge effects found for SC clusters could be due to syllabification of the sibilant in the coda of the preceding word. Nevertheless, the variable results for Cl suggest that SC(r) differs from Cl in the potential for onset-hood. Based on the results of qualitative analyses, we observed a tendency for a C-center effect for S1, S4, and S5, especially in the voiceless sets, though we remain cautious about this conclusion based on the number of speakers investigated and the limitations of the methodology. The C-centering effect suggests that at least some speakers permit Cl onsets. In addition, if intervocalic Cl clusters were regularly organized as heterosyllabic in the language, we would not expect to find any C-center effect for Cl clusters. The C-center effects for Cl observed in some speakers thus suggest that if SC(r) clusters were possible onsets for (some) speakers, they too would show a preference for C-centering. The consistent right-edge effect found in SC(r) clusters is instead indicative of a preference for the word-initial sibilant to be organized external to the syllable with the following stop.[6] The results suggest that the organization of SC clusters in Moenat is similar to that of Italian (Hermes et al. 2013).

Among the speakers who exhibited a C-centering effect for word-initial Cl clusters, our observation that C-centering is particularly stable for clusters beginning with a voiceless stop resonates with other research finding an interaction between stop voicing and syllabification in Cl sequences. A study of syllable structure in Attic Greek by Steriade (1982) found evidence for an asymmetry in syllabification of voiceless stop-lateral clusters versus voiced stop-lateral clusters in prevocalic position, with the former being tautosyllabic and the latter tending to be syllabified as heterosyllabic.

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6 We have adopted the common assumption that all singleton prevocalic consonants form a syllable onset. Our study has not investigated whether a singleton prevocalic sibilant shows temporal coordination consistent with syllabification like that of other singleton prevocalic consonants. Nevertheless, in future work it would be useful to confirm that sibilants are not simply exceptional in how they interact temporally with following elements, regardless of whether they are in a cluster or a singleton.

Steriade uses diagnostics such as patterns of perfect reduplication and syllabic divisions evidenced in meter to identify a distinction in syllabification of these clusters. For example, Steriade finds that intervocalic clusters consisting of a voiced stop followed by *r* or a voiceless stop followed by a sonorant consonant, including *pl, tl,* and *kl*, do not contribute weight to a preceding syllable; however, other consonant clusters cause a syllable with a preceding short vowel to behave as metrically heavy, suggesting a heterosyllabic assignment. Clusters consisting of a voiced stop followed by *l* fall in the latter category, although Steriade notes that "occasionally …bl, and more seldom, gl [are counted as] tautosyllabic" (1982: 192). The temporal alignment that we found in Moenat Cl clusters for S1, S4, and S5 points in a broadly similar direction, with voiceless stop-lateral clusters typically being organized into a syllable onset and voiced stop-lateral clusters showing variation with the potential for non-tautosyllabic organization.

The avoidance of onsets consisting of a voiced stop followed by *l*, in contrast to a voiceless stop followed by *l*, can be understood in terms of principles governing the sonority profile of onsets. Even though all stop-liquid clusters are rising in sonority, they may differ in the sonority distance between the consonants. Voiced stops have been classified as higher in sonority than voiceless stops (e.g. Steriade 1982, Parker 2011), and the class of rhotics have been proposed to be higher in sonority than laterals (Wiese 2001, cf. Parker 2011). With these differences in sonority, voiced stop-l clusters would have the smallest sonority distance among stop-liquid clusters, and their syllabification as an onset could be prevented using a condition on the minimum sonority distance for consonants in an onset (Steriade 1982, Parker 2011). More generally, a higher sonority value for rhotics than laterals predicts that Cl clusters will be dispreferred as onsets in comparison to Cr clusters, as evidenced by sound changes in Romance languages such as rhotacization of laterals in second position of an onset in Campidanese and lenition of /l/ to /j/ following an obstruent in Italo-Romance (Baertsch & Davis 2009, Krämer 2009, Walker & Yang 2023). Our observation that some Moenat speakers may show a right-edge effect for Cl clusters, especially when the stop is voiced, is thus not surprising in the context of cross-linguistic claims about sonority and syllable structure. Nonetheless, as our data on these issues are sparse for Moenat, our interpretation remains tentative and warrants further investigation.

7. Conclusion

In this paper, we have contributed new experimental data on the temporal organization of consonants in Moenat Ladin, an understudied minority Romance variety. Based on the acoustic analysis of SC, SCr, and Cl clusters, the findings of this study suggest that word-initial sibilants before a stop are organized external to the syllable onset, which begins with the stop. This finding suggests that Moenat Ladin has a similar syllable structure to Italian, a language to which it is closely related. This research also highlights the utility of the acoustic methodology for probing the temporal organization of consonant clusters. This method is particularly valuable in the investigation of understudied minority languages, since it offers more accessible means of data collection.

Although some progress has been made on these issues, many questions and paths for future research remain open. In relation to the experiment presented in this study, further investigation of the data with different methods would be valuable to further confirm the current results.

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