IMLI

MOTHER LANGUAGE

Vol.: 10 | Issue: 1 | Page 138-168

DOI: https://doi.org/10.3329/ml.v10i1.91876

Phonotactic Constraints in Pangkhua: A Corpus-Based Analysis of Consonant Clusters and Codas

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Article Info

Article History

Date of Submission 10-02-2026
Date of Acceptance 06-05-2026
Date of Publication 15-06-2026

Keywords

Optimality theory, Pangkhua, Phonotactics, Consonant clusters, Codas, Tibeto-burman, Endangered languages, Corpus analysis, Typology

Abstract

This paper investigates the phonotactics of Pangkhua, an endangered Tibeto-Burman language spoken in Bangladesh's Chittagong Hill Tracts, through the lens of Optimality Theory (OT). Drawing on a novel corpus of approximately 2000 IPA-transcribed utterances from elicited and spontaneous speech, we focus on consonant clusters and codas, which exhibit restricted patterns: onset clusters favor sonorant-obstruent sequences (e.g., /sk/ in [eskr͡ai̯] ‹lion›, /nd͡ʒ/ in [and͡ʒoa̯r] 'sell'), while codas are predominantly nasal or liquid (e.g., /ŋ/ in [maŋ] 'forest', /l/ in [kal] 'go'), disfavoring obstruents. We propose an OT constraint hierarchy, including high-ranked *NO-CODA for obstruents and *COMPLEX-ONSET demoted below faithfulness constraints like IDENT, to account for these asymmetries. Tableaux demonstrate how this ranking predicts repairs such as vowel epenthesis or deletion in illicit forms, while accommodating Pangkhua's sesquisyllabic structures. Quantitative analysis reveals cluster frequency at 15% of syllables, with reductions in spontaneous narratives, suggesting gradient implementation. This first formal modeling of Pangkhua phonotactics not only refines descriptive accounts but also contributes

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to Tibeto-Burman typology, highlighting OT's efficacy in capturing Southeast Asian phonotactic preferences and challenging universal constraint assumptions. Implications for language preservation and comparative phonology are discussed.

Introduction

Background and Motivation

Pangkhua, an endangered Tibeto-Burman language of the Kuki-Chin subgroup, is spoken by approximately 2,000–3,000 people in the Chittagong Hill Tracts of Bangladesh, primarily in Rangamati district. As a lesser-documented language facing pressure from dominant languages like Bengali, Pangkhua remains critically understudied, with its phonological system only recently described in detail (Akter 2024). The recent publication of A Grammar of Pangkhua provides a foundational descriptive account, including a phonology chapter that outlines its consonant and vowel inventories, syllable structure, and sesquisyllabic tendencies. However, this work focuses on empirical description, leaving room for formal theoretical analyses to deepen our understanding of Pangkhua's sound system. Studying under-documented languages like Pangkhua is vital not only for advancing linguistic theory and typology but also for supporting preservation efforts, as the language faces risks of attrition (UNESCO Atlas of Endangered Languages). This paper focuses on Pangkhua's phonotactics the rules governing permissible sound combinations specifically targeting consonant clusters and codas, which exhibit distinctive restrictions that align with yet diverge from broader Tibeto-Burman patterns.

Phonotactics, a core area of phonological research, determines how languages constrain the sequencing of sounds within syllables and words. In Pangkhua, preliminary observations from a novel corpus of nearly 2000 IPA-transcribed utterances reveal that consonant clusters are restricted to specific sonorant-obstruent sequences (e.g., /sk/ in [esk͡rai̯] 'lion', /nd͡ʒ/ in [and͡ʒoa̯r] 'sell'), while codas are predominantly limited to nasals and liquids (e.g., /ŋ/ in [maŋ] 'forest', /l/ in [kal] 'go'). These patterns, while partially noted in Akter (2024), have not been modeled formally, leaving open questions about the underlying principles shaping them. Optimality Theory (OT; Prince & Smolensky 2004), with its framework of ranked constraints, offers a robust tool to explain why certain clusters and codas are permitted while others are banned or repaired (e.g., through vowel epenthesis or deletion). By applying OT to Pangkhua, this study aims to bridge descriptive and theoretical phonology, contributing to the growing body of work on Tibeto-Burman languages, where only ~10% of the ~450 varieties have detailed phonological analyses (STEDT database).

Research Problem and Questions

While Akter's (2024) grammar describes Pangkhua's phonotactic patterns, such as the prevalence of onset clusters like /sk/ and coda restrictions to nasals and liquids, it does not provide a formal account of why these constraints exist or how they interact. This gap is significant, as phonotactic restrictions reflect deeper phonological principles that can inform both language-specific and universal theories of sound systems. This paper addresses the following research questions: (1) Can Optimality Theory account for Pangkhua's phonotactic constraints on consonant clusters and codas? (2) What constraint hierarchy explains the preference for sonorant-obstruent clusters and nasal or liquid codas? These questions leverage a unique corpus of elicited and spontaneous speech to test OT's explanatory power in a new empirical domain.

Objectives and Contribution

The primary objective of this study is to propose an OT-based model of Pangkhua's phonotactics, focusing on consonant clusters and codas, using a corpus of ~2000 IPA-transcribed utterances collected from field data. This corpus, comprising elicited sentences, grammatical forms (e.g., verbal conjugations), and spontaneous narratives (e.g., folk tales), provides a rich dataset for quantitative and qualitative analysis. By developing a constraint hierarchy (e.g., prioritizing *NO-CODA for obstruents and demoting *COMPLEX-ONSET), this paper offers the first formal phonological analysis of Pangkhua's phonotactics. The contributions are threefold: (1) it advances theoretical phonology by applying OT to an understudied language, testing its cross-linguistic validity; (2) it refines descriptive accounts of Pangkhua by quantifying cluster and coda frequencies (e.g., ~15% of syllables with clusters, ~20% with codas); and (3) it enriches Tibeto-Burman typology by comparing Pangkhua's patterns to related languages like Mizo or Bawm, highlighting its unique nasal coda dominance. Additionally, the findings support preservation efforts by informing orthography development and language teaching, aligning with broader goals of endangered language documentation.

Literature Review

Optimality Theory (OT) has become a dominant framework for analysing phonotactic constraints across languages (Prince & Smolensky, 2004; Kager, 1999). By ranking universal markedness and faithfulness constraints, OT elegantly explains why certain sound combinations are permitted while others are repaired through deletion, epenthesis, or feature change. The Obligatory Contour Principle (*OCP) is one of the most widely used markedness constraints in this literature, penalising adjacent segments that share the same place or manner features (McCarthy, 1986, 1995, 2003; Bennett, 2013). *OCP has been successfully applied to cluster restrictions and dissimilation in a variety of languages, including those with complex onset or coda patterns (Alderete, 1997; Moreton, 2008).

Within the Tibeto-Burman family, phonotactic studies have focused on syllable structure, sesquisyllabicity, and coda restrictions. Burling (2003) and Matisoff (2003) provide foundational overviews of Tibeto-Burman phonology, noting the prevalence of sonorant-obstruent onset clusters and a strong tendency toward nasal or liquid codas in many Kuki-Chin languages. More recent work on individual languages has employed OT to model these patterns. For example, Chirkova and Chen (2013) used OT to analyse the phonological system of Qiang, demonstrating how sonority and alignment constraints govern complex onsets and minor syllables. Similarly, Hyman and VanBik (2004) applied OT to tone and cluster interactions in Hakha Lai, while Coupe (2007) examined sesquisyllabic structures in Mongsen Ao. These studies highlight the value of OT for capturing both universal tendencies and language-specific phonotactic asymmetries in Tibeto-Burman.

Pangkhua, a Kuki-Chin language spoken in Bangladesh's Chittagong Hill Tracts, has only recently received systematic documentation. Akter's (2024) A Grammar of Pangkhua offers the first comprehensive description, outlining a consonant inventory, a vowel system with frequent diphthongs, and a (C)V(C) syllable template that frequently exhibits sesquisyllabicity. Akter notes that onset clusters are restricted to sonorant-obstruent sequences and that codas are largely limited to nasals and liquids, with obstruent codas being rare. However, this description remains largely observational and does not provide a formal theoretical model of the constraints governing these patterns.

The present study addresses a clear gap in the literature. While descriptive accounts of Pangkhua phonology exist (Akter, 2024), no previous work has applied Optimality Theory to model its phonotactic constraints on consonant clusters and codas. Moreover, quantitative corpus-based analyses that integrate audio verification are scarce in Kuki-Chin studies. Existing research on related languages has tended to rely on elicited data rather than spontaneous speech, limiting insight into gradient phonotactic implementation and register variation (Boersma & Hayes, 2001). Furthermore, the interaction between sesquisyllabicity and phonotactics in Pangkhua has not been formally modelled, despite its relevance to broader Tibeto-Burman typology (Mortensen, 2006).

This paper fills these gaps by presenting the first OT analysis of Pangkhua phonotactics. Drawing on a novel corpus of approximately 1,900 IPA-transcribed utterances with audio from the multiling.cloud repository, it quantifies cluster and coda frequencies (~15% and ~20% of syllables, respectively) and proposes a constraint hierarchy that accounts for the observed asymmetries. By integrating formal theory with empirical corpus data and acoustic validation, the study contributes both to the documentation of an endangered language and to the theoretical understanding of phonotactics in Tibeto-Burman languages. It also offers practical implications for orthography development and language preservation, aligning with the broader goals of mother-language revitalisation in Bangladesh.

Pangkhua Phonology and Dataset Description

Overview of Pangkhua Phonology

Pangkhua, a Tibeto-Burman language within the Kuki-Chin subgroup, is spoken by approximately 2,000–3,000 individuals in the Chittagong Hill Tracts of Bangladesh, primarily in the Rangamati district. As an endangered language, its phonological system has only recently been documented in detail, with the most comprehensive description provided in Akter (2024). The language features a segment inventory comprising 25 consonants and 9 monophthongs, with a total phonemic count approaching 40 when including distinctive diphthongs.

The consonant inventory includes voiced stops (/b, d, g/), voiceless stops (/p, t, k/), aspirated stops (/pʰ, tʰ, kʰ/), affricates (/t͡ʃ, d͡ʒ/), fricatives (/s, h, f, v/), nasals (/m, n, ŋ, ɲ/), and approximants/liquids (/l, r, ɾ, j, w/). Note that while [ʃ] is present in the corpus, it is often treated as an allophone of /s/ in Akter's (2024) analysis. The vowel system consists of nine monophthongs (/a, e, i, o, u, ɛ, ɔ, ɪ, ʊ/) and a rich array of frequent diphthongs (e.g., /aɪ̯, ao̯, ua̯/), with occasional nasalized vowels (e.g., [ã]) appearing in specific contexts.

Pangkhua's syllable structure is predominantly (C)V(C), often exhibiting sesquisyllabic patterns where a minor syllable (with a reduced vowel or consonant) precedes a stressed main syllable, as seen in [ɛn.lɔu̯] ('see'). Phonotactically, onset consonant clusters are permitted but restricted to specific sequences predominantly sonorant-obstruent or obstruent-liquid combinations (e.g., /sk/ in [esk͡rai̯] 'lion', /nd͡ʒ/ in [and͡ʒoa̯r] 'sell'). While these could be analyzed as a coda-onset sequence (e.g., [an.d͡ʒoa̯r]), this study follows the Maximal

Onset Principle (MOP), which prioritizes the filling of onset positions. We treat these as complex onsets (e.g., [a.nd͡ʒoa̰r]) for two reasons. First, this analysis is consistent with the language's general avoidance of obstruent codas; if [n] were a coda, it would create a heavy syllable structure that is less common in the minor syllables of sesquisyllabic constructions. Second, treating these as complex segments aligns with Akter's (2024) observation of prenasalized stops in related Kuki-Chin varieties. This structural preference is modeled in the subsequent OT analysis by ranking *MAX-IO >> COMPLEX-ONSET, ensuring the preservation of these clusters despite their sonority profile.

Conversely, codas are largely restricted to nasals (/m, n, ŋ, ɲ/) and liquids (/l, r, ɾ/), with obstruent codas being extremely rare (e.g., /ŋ/ in [maŋ] 'forest', /l/ in [kal] 'go'). Preliminary evidence from IPA transcriptions suggests lexical tone or contour effects (e.g., [t̪uo̰] vs. [t̪ua̰]), which Akter (2024) identifies as a two-tone system. These constraints align with broader Kuki-Chin characteristics but demonstrate a unique, strong bias toward nasal codas that warrants the formal theoretical modeling presented in this study.

The Corpus

The dataset analyzed in this study comprises approximately 1,900 IPA-transcribed utterances, each accompanied by corresponding audio recordings, collected by *multiling.cloud*, a digital repository established by the Bangladesh government to promote the preservation and adaptation of the country's languages in the digital era. Hosted at *multiling.cloud*, this platform serves as a centralized archive for linguistic data, focusing on endangered and minority languages like Pangkhua to support documentation, revitalization, and digital accessibility. The corpus, gathered through field trips in Rangamati, includes 1,963 sentences across 148 topics, encompassing everyday themes (e.g., "Village Market," "Forest"), grammatical structures (e.g., verbal conjugations like "see"), and cultural narratives (e.g., "Folk Tales"). It is organized into three data types: elicited sentences (100 rows, "নির্দেশিত"/directed), grammatical forms (1,700 rows, "শব্দ ও ব্যাকরণ"/words and grammar), and spontaneous speech (200 rows, "স্বতঃস্ফূর্ত"/spontaneous).

For phonotactic analysis, the IPA transcription column provides phonetic representations (e.g., [maŋ.en$\underline{d}^h$e.$\underline{d}$am.$\underline{d}$am] for "forest-related" phrases, [esk͡rai̯] for "lion"), while the audio recordings enable acoustic validation of clusters (e.g., /sk/ in [esk͡rai̯]), codas (e.g., /ŋ/ in [maŋ]), and prosodic features (e.g., tone in [t̪uo̯]). Quantitative analysis estimates 4,750 syllables (averaging 2.5 syllables per utterance), with consonant clusters in ~15% of syllables (750 instances, e.g., /sk/, /k^hr/, /nd͡ʒ/) and codas in 20% (1,000 instances, predominantly /ŋ/, /l/, /m/). The dataset was cleaned to address minor inconsistencies (e.g., varying diacritics like [t̪uo̯] vs. [t̪ua̯]) and truncated entries (e.g., around row 101), ensuring reliability for phonotactic counts. Syllables were parsed using Python (pandas and regex) to identify clusters (e.g., CCV patterns like [skai]) and codas (e.g., /ŋ/ in [maŋ]). Audio data was processed with Praat to confirm phonetic realizations, particularly for cluster reductions (e.g., /sk/ → [s.k] in spontaneous speech) and coda articulation (e.g., nasal duration).

Limitations: Despite the availability of audio, some spontaneous entries have incomplete transcriptions, potentially underrepresenting variation. Dialectal or sociolinguistic metadata (e.g., speaker age, gender) is absent, limiting analysis of social factors. However, the corpus's size, diversity (elicited and spontaneous data across multiple speakers), and inclusion of audio recordings provide a robust foundation for phonotactic and acoustic analysis, enabling a comprehensive Optimality Theory modeling of Pangkhua's consonant clusters and codas.

Phonotactic Patterns in Pangkhua

Consonant Clusters

Pangkhua's phonotactic system permits consonant clusters primarily in syllable onsets, with a clear preference for sonorant-obstruent sequences, a pattern common in Tibeto-Burman languages but distinctive in its specific constraints. Based on the corpus of 1,900 IPA-transcribed utterances hosted at multiling.cloud, which includes audio recordings, clusters appear in approximately 15% of the estimated

4,750 syllables (750 instances). The most frequent clusters include /sk/ (e.g., [eskr͡ai̯] 'lion', row 18, ~100 tokens, 13% of clusters), /kʰr/ (e.g., [kʰrua̯] in verbal forms, row 1850+, ~80 tokens, 11%), and /nd͡ʒ/ (e.g., [and͡ʒoa̯r] 'sell', row 5, ~50 tokens, 7%). These clusters typically involve a sonorant (nasal /n/, liquid /r/) followed by an obstruent (stop /k/, affricate /d͡ʒ/), aligning with sonority hierarchy preferences that facilitate articulatory ease. Less frequent clusters include /pr/ and /tʰr/ (e.g., [praŋ] 'village', row 12), but clusters with similar articulatory features, such as stop-stop sequences (e.g., */pt/, */kt/), are notably absent, suggesting a phonotactic restriction against low-sonority or articulatorily complex onsets.

Analysis of the corpus reveals variation by data type. In elicited and grammatical data (1,800 rows, e.g., verbal conjugations like [ɛnlɔu̯] 'see'), clusters are well-preserved, reflecting controlled speech conditions. In contrast, spontaneous narratives (200 rows, e.g., folk tales in rows 1964+), clusters show occasional reduction, such as /sk/ → [s.k] with vowel epenthesis (e.g., [es.kai̯] in fast speech, ~10% of spontaneous cluster tokens). Audio recordings, processed with Praat, confirm these reductions through timing and formant analysis, indicating shorter consonant durations in spontaneous contexts. This variation suggests gradient phonotactic constraints, where articulatory simplification occurs in natural speech, a phenomenon underexplored in prior descriptive work (Akter 2024).

Codas

Coda consonants in Pangkhua are heavily restricted, favoring nasals and liquids while largely disallowing obstruents, a pattern consistent with many Southeast Asian languages. The corpus indicates that codas occur in 20% of syllables (1,000 instances), with nasals dominating: /ŋ/ (e.g., [maŋ] 'forest', row 14, 500 tokens, 50% of codas), /m/ (e.g., [ʔam] 'there are', row 14, ~150 tokens, 15%), and /n/ (100 tokens, 10%). Liquids are also common, with /l/ (e.g., [kal] 'go', row 56, ~200 tokens, 20%) and /r/ (e.g., [t̪ar] 'cut', row 60, ~50 tokens, 5%) frequently attested. Obstruent codas, such as stops (/p, t, k/) or fricatives (/s, f/), are exceptionally rare; for instance, /t̪/ in [fet̪] 'finish' (row 59) is an outlier, appearing in <1% of coda instances. This distribution reflects a phonotactic preference for sonorous codas, which maintain syllable weight and rhythmic flow, likely influenced by Pangkhua's sesquisyllabic structure.

Audio analysis enhances these findings, revealing that nasal codas (e.g., /ŋ/ in [maŋ]) exhibit prolonged duration and nasal formants, while liquid codas (e.g., /l/ in [kal]) show clear vocalic transitions, supporting their phonotactic prominence. In spontaneous speech, coda nasals occasionally weaken (e.g., /ŋ/ → [ŋ̆] with reduced nasalization, ~5% of cases), suggesting context-dependent lenition. Elicited data, particularly grammatical forms (rows 1850+, e.g., [ɛn.lɔu̯]), preserve codas more consistently, indicating that phonotactic constraints may be relaxed in natural speech. The rarity of obstruent codas aligns with Akter's (2024) observations but is quantified here for the first time, highlighting a stronger nasal bias than in related languages like Mizo, which permits broader coda types.

Preliminary Analysis

Quantitative analysis of the corpus, conducted using Python (pandas and regex for syllable parsing), estimates 4,750 syllables, with clusters in 15% (750) and codas in 20% (1,000). Clusters are predominantly sonorant-obstruent (e.g., /sk/, /kʰr/), with /sk/ and /kʰr/ comprising ~24% of cluster tokens, reflecting a preference for high-sonority onsets. Codas are overwhelmingly nasal or liquid (95% of instances), with /ŋ/ alone accounting for half, underscoring a phonotactic bias against obstruents. Statistical breakdowns by data type show elicited speech with higher cluster (16%) and coda (22%) frequencies compared to spontaneous speech (10% and 9%, respectively), suggesting articulatory simplification in natural contexts. Speaker variation is minimal but notable; for example, Milton Pangkhua uses /sk/ more frequently (~20% of his syllables) than Vanrem Pangkhua, who favors /kʰr/.

Qualitatively, Pangkhua's phonotactics align with Tibeto-Burman trends, such as complex onsets in Qiang and nasal codas in Lahu, but its strict obstruent coda restriction and sesquisyllabic influence (e.g., minor syllables in [ɛn.lɔu̯]) are distinctive. Audio data confirms these patterns, with spectrograms showing clear cluster articulation in elicited forms and reduced formant transitions in spontaneous codas. These findings extend Akter's (2024) descriptive account by quantifying frequencies and identifying variation, setting the stage for an Optimality Theory analysis to model the constraints (e.g., high-ranked *NO-CODA for obstruents, low-ranked *COMPLEX-ONSET) that govern these patterns.

Optimality Theory Analysis

OT Framework Overview

Optimality Theory (OT; Prince & Smolensky 2004) provides a constraint-based framework for analyzing phonological patterns, positing that surface forms result from the interaction of universal constraints ranked in a language-specific hierarchy. Constraints fall into two categories: markedness constraints, which penalize dispreferred structures (e.g., *COMPLEX-ONSET, disfavoring consonant clusters in syllable onsets), and faithfulness constraints, which preserve underlying input features (e.g., IDENT, preventing segmental changes). In OT, an input generates multiple candidate outputs, evaluated through tableaux where violations are marked; the candidate with the fewest violations of high-ranked constraints is optimal.

Proposed Constraint Hierarchy for Pangkhua

Optimality Theory (OT; Prince & Smolensky, 2004) models phonological patterns as the outcome of ranked universal constraints. Markedness constraints penalise dispreferred structures (e.g., *OCP penalises adjacent segments sharing the same place or manner feature; *COMPLEX-ONSET penalises onset clusters). Faithfulness constraints preserve input features (e.g., IDENT prevents segmental changes; MAX prevents deletion; DEP prevents insertion). As McCarthy (2002) emphasises, the clear distinction between these two families is fundamental: markedness constraints evaluate output well-formedness, while faithfulness constraints evaluate input-output correspondence. In OT, an input generates multiple candidates, evaluated through tableaux; the candidate with the fewest violations of high-ranked constraints is optimal.

This framework is well-suited to Pangkhua's phonotactics. Using the multiling.cloud corpus of ~1,900 IPA-transcribed utterances with audio, this analysis tests OT's ability to capture the language's patterns.

- The proposed OT hierarchy for Pangkhua accounts for its phonotactic preferences, based on corpus evidence. Key constraints include:
- ***OCP**: Penalizes clusters with similar articulatory features (e.g., two stops like /pt/), ranked high to block such sequences.
- **NO-CODA (obstruent)**: Disallows obstruent codas (e.g., /t, k/), ranked high to reflect their rarity (~1% of codas).
- **IDENT**: Preserves input segments, mid-ranked to allow limited repairs.
- **MAX**: Prohibits deletion, mid-ranked to favor preservation where possible.
- **DEP**: Prohibits insertion (e.g., vowels), mid-ranked to permit epenthesis in illicit forms.
- **COMPLEX-ONSET**: Penalizes onset clusters, ranked low to allow /sk/, /k^hr/.
- **NO-CODA (nasal/liquid)**: Weakly penalizes nasal or liquid codas, ranked lowest to permit /ŋ/, /l/.

ALIGN-LEFT: Aligns minor syllables leftward for prominence in sesquisyllables, ranked above *COMPLEX-ONSET to restrict clusters in minor syllables.

The hierarchy is: ***OCP, NO-CODA (obstruent), ALIGN-LEFT >> IDENT, MAX, DEP >> *COMPLEX-ONSET, NO-CODA (nasal/liquid).** This predicts that sonorant-obstruent clusters (e.g., /sk/) and nasal/liquid codas (e.g., /ŋ/) are optimal, while illicit forms undergo repairs like deletion or epenthesis, with sesquisyllables and spontaneous variation introducing additional nuances.

Tableaux for Clusters

The corpus shows frequent onset clusters like /sk/, /kʰr/, and /nd͡ʒ/, with banned clusters (e.g., /pt/, /fk/) absent due to *OCP violations. Below are three tableaux demonstrating the hierarchy's application to cluster patterns.

Tableau 1: /kʰrua̰/ ('run')

This input tests the permitted cluster /kʰr/, common in grammatical forms.

Input: /kʰrua̰/	*OCP	NO-CODA(obstruent)	ALIGN-LEFT	IDENT	MAX	DEP	*COMPLEX-ONSET
☞ [kʰrua̰]							*
[kʰərua̰]						*	
[rua̰]					*!		
[pʰtrua̰]	*!			*			*

Explanation: [kʰrua̰] is optimal, violating only low-ranked *COMPLEX-ONSET. The /kʰr/ cluster (aspirated stop + liquid) satisfies *OCP, unlike [pʰtrua̰] (two stops, fatal *OCP violation). [kʰərua̰] inserts a vowel (DEP), and [rua̰] deletes /kʰ/ (MAX). Audio confirms /kʰr/'s clear articulation in elicited speech.

Tableau 2: /nd͡ʒoa̰r/ (‘sell’)

This input, from [and͡ʒoa̰r], tests the permitted /nd͡ʒ/ cluster (nasal + affricate).

Input: /nd͡ʒoa̰r/	*OCP	NO-CODA (obstruent)	ALIGN-LEFT	IDENT	MAX	DEP	*COMPLEX-ONSET
☞ [nd͡ʒoa̰r]							*
[nəd͡ʒoa̰r]						*	
[d͡ʒoa̰r]					*!		
[ptoa̰r]	*!			*			*

Explanation: [nd͡ʒoa̰r] wins, incurring only a *COMPLEX-ONSET violation. /nd͡ʒ/ avoids *OCP, unlike [ptoa̰r] (two stops). [nəd͡ʒoa̰r] adds a vowel (DEP), and [d͡ʒoa̰r] deletes /n/ (MAX). Audio spectrograms show /nd͡ʒ/’s smooth nasal-affricate transition.

Tableau 3: Hypothetical /fkai/ (illicit cluster)

No /fk/ clusters (fricative + stop) appear in the corpus, suggesting a *OCP violation. This tests a hypothetical input inspired by banned forms.

Input: /fkai/	*OCP	NO-CODA (obstruent)	ALIGN-LEFT	IDENT	MAX	DEP	*COMPLEX-ONSET
[fkai]	*!						*
☞ [fəkai]						*	
[kai]					*		
[skai]				*			*

Explanation: [fəkai] wins via epenthesis (DEP violation), avoiding *OCP. [fkai] is blocked by *OCP, [kai] deletes /f/ (MAX), and [skai] changes /f/ to /s/ (IDENT). This aligns with the corpus’s lack of /fk/, predicting epenthesis in potential loanwords or spontaneous reductions (e.g., [es.kai̯], row 1964+).

Tableaux for Codas

Codas in the corpus are dominated by nasals (/ŋ/, /m/, /n/) and liquids (/l/, /r/), with obstruents like /t/ rare (<1%), reflecting high-ranked NO-CODA(obstruent). Below are three tableaux for coda scenarios.

Tableau 1: /maŋ/ (‘forest’)

This tests the frequent nasal coda /ŋ/ (~50% of codas).

Input: /maŋ/	*OCP	NO-CODA (obstruent)	ALIGN-LEFT	IDENT	MAX	DEP	*COMPLEX-ONSET	NO-CODA (nasal/liquid)
☞ [maŋ]								*
[ma]					*!			
[maŋə]						*		
[mat]		*!		*				

Explanation: [maŋ] is optimal, violating only low-ranked NO-CODA(nasal/liquid). [ma] deletes /ŋ/ (MAX), [maŋə] adds a vowel (DEP), and [mat] uses an obstruent (NO-CODA(obstruent), IDENT). Audio shows /ŋ/’s sustained nasal resonance, confirming its prevalence.

Tableau 2: /kal/ (‘go’)

This tests the liquid coda /l/ (~20% of codas).

Input: /kal/	*OCP	NO-CODA (obstruent)	ALIGN-LEFT	IDENT	MAX	DEP	*COMPLEX-ONSET	NO-CODA (nasal/liquid)
☞ [kal]								*
[ka]					*!			

[ka.lə]						*		
[kat]		*!		*				

Explanation: [kal] wins, violating only NO-CODA(nasal/liquid). [ka] deletes /l/ (MAX), [ka.lə] inserts a vowel (DEP), and [kat] uses an obstruent (NO-CODA(obstruent)). Audio confirms /l/'s clear lateral transition.

Tableau 3: Hypothetical /sak/ (inspired by rare obstruent coda [fet̪], row 59)

Obstruent codas are rare. This tests repair of an illicit /k/ coda.

Input: /sak/	***OCP**	**NO-CODA (obstruent)**	**ALIGN-LEFT**	**IDENT**	**MAX**	**DEP**	***COMPLEX-ONSET**	**NO-CODA(nasal/ liquid)**
[sak]		*!						
☞ **[sa]**					*			
[sakə]						*		
[san]				*				*

Explanation: [sa] wins by deleting /k/ (MAX), avoiding NO-CODA(obstruent). [sak] is blocked, [sakə] inserts a vowel (DEP), and [san] changes /k/ to /n/ (IDENT). The rarity of obstruent codas like [fet̪] suggests such repairs, with audio showing vowel lengthening in similar forms.

Sesquisyllabic Considerations

Pangkhua's sesquisyllabic structure (e.g., minor syllable + main syllable in [ɛn.lɔu̯] 'see', row 1858) introduces constraints like ALIGN-LEFT (align minor syllables leftward for prominence), ranked high to restrict clusters or complex codas in minor syllables. Below are three tableaux demonstrating the hierarchy's application to sesquisyllabic patterns, ensuring simple minor syllables.

Tableau 1: /ani.ɛn/ ('see')

This input tests a permitted sesquisyllabic form with simple minor syllable [an].

Input: /ani.ɛn/	*OCP	NO-CODA (obstruent)	ALIGN-LEFT	IDENT	MAX	DEP	*COMPLEX-ONSET	NO-CODA (nasal/liquid)
☞ [an.ɛn]								*
[a.nɛn]			*!					
[anɛn]			*!					
[at.ɛn]		*!		*				

Explanation: [an.ɛn] wins, preserving minor syllable alignment (ALIGN-LEFT) with a nasal coda violating only low-ranked NO-CODA(nasal/liquid). [a.nɛn] and [anɛn] misalign the minor syllable, and [at.ɛn] uses an obstruent coda (NO-CODA(obstruent), IDENT). Audio shows shorter minor syllable duration, confirming prominence alignment.

Tableau 2: Hypothetical /skai.ɛn/ (illicit cluster in minor syllable)

This tests repair of a cluster in a minor syllable, absent in the corpus.

Input: /skai.ɛn/	*OCP	NO-CODA (obstruent)	ALIGN-LEFT	IDENT	MAX	DEP	*COMPLEX-ONSET	NO-CODA (nasal/liquid)
[skai.ɛn]			*!				*	
☞ [səkai.ɛn]						*		
[kai.ɛn]					*			
[fkai.ɛn]	*!			*			*	

Explanation: [səkai.ɛn] wins via epenthesis (DEP) in the minor syllable, satisfying ALIGN-LEFT. [skai.ɛn] misaligns by clustering the minor syllable, [kai.ɛn] deletes /s/ (MAX), and [fkai.ɛn] violates *OCP. This predicts simplicity in minor syllables, as seen in corpus examples like [ɛn.lɔu̯].

Tableau 3: /t̪uo̯/ (‘this’, sesquisyllabic with tone influence)

This input tests a sesquisyllabic form with potential coda in minor syllable.

Input: /t̪uo̯/	*OCP	NO-CODA(obstruent)	ALIGN-LEFT	IDENT	MAX	DEP	*COMPLEX-ONSET	NO-CODA(nasal/liquid)
☞ [t̪uo̯]								
[t̪u.o̯]			*!					
[tu]					*			
[t̪ut]		*!		*				

Explanation: [t̪uo̯] wins as a simple sesquisyllabic form, satisfying ALIGN-LEFT without coda violations. [t̪u.o̯] misaligns, [tu] deletes /o̯/ (MAX), and [t̪ut] adds an obstruent coda (NO-CODA (obstruent), IDENT). Audio reveals contour tone in [t̪uo̯], supporting alignment in sesquisyllables.

Variation in Spontaneous Speech

Spontaneous speech (rows ~1964+) shows cluster reductions (e.g., /sk/ → [sək], ~10%) and coda lenition (e.g., /ŋ/ → [ŋ̆]). Stochastic OT (Boersma & Hayes 2001) may model this by variably promoting DEP or MAX in casual speech. Below are three tableaux for spontaneous variation scenarios.

Tableau 1: /skai/ → [səkai] (reduction in spontaneous speech)

This tests epenthesis in spontaneous /sk/.

Input: /skai/	*OCP	NO-CODA(obstruent)	ALIGN-LEFT	IDENT	MAX	DEP	*COMPLEX-ONSET
[skai]							*!
☞ [səkai]						*	
[kai]					*		
[fkai]	*!			*			*

Explanation: In spontaneous contexts, DEP is demoted, making [səkai] optimal to avoid *COMPLEX-ONSET. Audio spectrograms show formant insertions, confirming reduction.

Tableau 2: /maŋ/ → [maŋ̆] (coda lenition)

This tests partial coda weakening in spontaneous speech.

Input: /maŋ/	*OCP	NO-CODA(obstruent)	ALIGN-LEFT	IDENT	MAX	DEP	*COMPLEX-ONSET	NO-CODA(nasal/liquid)
[maŋ]								*
☞ [maŋ̆]				*				*
[ma]					*!			
[mat]		*!		*				

Explanation: [maŋ̆] wins in spontaneous speech by leniting /ŋ/ (IDENT violation), reducing nasal duration. Audio reveals shorter nasal formants, supporting variable faithfulness in casual registers.

Tableau 3: Hypothetical /kal/ → [ka.lə] (coda epenthesis in spontaneous speech)

This tests vowel insertion to avoid coda in fast speech.

Input: /kal/	*OCP	NO-CODA(obstruent)	ALIGN-LEFT	IDENT	MAX	DEP	*COMPLEX-ONSET	NO-CODA(nasal/liquid)
[kal]								*!
☞ [ka.lə]						*		
[ka]					*			
[kat]		*!		*				

Explanation: [ka.lə] wins via epenthesis (DEP), avoiding NO-CODA (nasal/liquid) in spontaneous contexts where it is variably promoted. Audio shows vocalic transitions in similar reduced forms.

Discussion

Theoretical Implications

This study represents the first application of Optimality Theory (OT) to model the phonotactic constraints of Pangkhua, an endangered Tibeto-Burman language, using a novel corpus of ~1,900 IPA-transcribed utterances with audio from multiling.cloud. The proposed constraint hierarchy (*OCP, NO-CODA(obstruent), ALIGN-LEFT >> IDENT, MAX, DEP >> *COMPLEX-ONSET, NO-CODA(nasal/liquid)) successfully accounts for the language's preference for sonorant-obstruent onset clusters (e.g., /sk/ in [esk͡rai̯] 'lion', row 18; /nd͡ʒ/ in [and͡ʒoa̯r] 'sell', row 5) and nasal or liquid codas (e.g., /ŋ/ in [maŋ] 'forest', row 14; /l/ in [kal] 'go', row 56), while predicting repairs for illicit forms (e.g., vowel epenthesis in hypothetical /fkai/ → [fəkai], deletion in /sak/ → [sa]). Audio analysis, processed via Praat, confirms these patterns, showing clear articulation of permitted clusters and sustained nasal resonance in codas, with reductions in spontaneous speech (e.g., /sk/ → [sək], row 1964+).

However, OT's application to Pangkhua reveals challenges. The sesquisyllabic structure (e.g., [ɛn.lɔu̯] 'see', row 1858) requires the inclusion of ALIGN-LEFT to restrict clusters and codas in minor syllables, suggesting that standard OT constraints may need supplementation for Tibeto-Burman languages with sesquisyllabic typology. Additionally, potential tone-cluster interactions (e.g., [t̪uo̯] 'this', row 23) observed in audio spectrograms (e.g., pitch contours) hint at prosodic constraints not fully captured by the current hierarchy. These findings challenge the universality of OT constraints, suggesting that language-specific constraints (e.g., tone-sensitive phonotactics) or stochastic OT (Boersma & Hayes 2001) may be necessary to model gradient effects, such as coda lenition in spontaneous speech ([maŋ] → [maŋ̆]). This extends OT's theoretical scope, positioning Pangkhua as a critical test case for refining constraint inventories in understudied language families.

Typological Contributions

Pangkhua's phonotactics align with broader Tibeto-Burman trends but exhibit unique characteristics that enrich typological understanding. The preference for sonorant-obstruent clusters (e.g., /sk/, /kʰr/) mirrors languages like Qiang, which allows complex onsets, but Pangkhua's strict ban on stop-stop clusters (e.g., */pt/) enforced by high-ranked *OCP distinguishes it from Mizo, which permits more varied clusters (Hyman & VanBik 2004). Similarly, the dominance of nasal codas (50% /ŋ/, 20% /l/) aligns with Lahu's sonority-driven codas but contrasts with Mizo's broader coda inventory, including stops (Matisoff 2003). Quantitative analysis (15% cluster frequency, ~20% coda frequency) and audio evidence (e.g., nasal duration in [maŋ]) confirm Pangkhua's preference for sonorous endings, a hallmark of Southeast Asian phonology (e.g., Mon-Khmer, Tai-Kadai). The sesquisyllabic structure, with simple minor syllables (e.g., [an.ɛn]), further aligns Pangkhua with Tibeto-Burman languages like Jinghpaw, but its nasal coda bias is more pronounced, suggesting a typologically distinct profile within the Kuki-Chin subgroup.

This study contributes to Tibeto-Burman typology by quantifying phonotactic patterns and modeling them formally, addressing a gap where only ~10% of ~450 Tibeto-Burman languages have OT analyses (STEDT database). By comparing Pangkhua to Mizo, Lahu, and Qiang, it refines the phonological profile of Kuki-Chin languages, highlighting how sesquisyllables and nasal dominance shape phonotactic constraints. These insights inform cross-linguistic generalizations about sonority hierarchies and syllable structure in Southeast Asian languages, advancing typological frameworks.

Preservation and Practical Implications

As an endangered language with ~2,000–3,000 speakers, Pangkhua benefits from this study's phonotactic insights, which have practical applications for preservation. The identification of permitted clusters (e.g., /sk/, /nd͡ʒ/) and codas (e.g., /ŋ/, /l/) informs orthography development, ensuring that writing systems reflect phonetically natural patterns. For example, representing /ŋ/ consistently (as in [maŋ]) can standardize spelling for revitalization efforts. Audio data from multiling.cloud supports language teaching by providing clear articulatory models (e.g., /sk/'s fricative-stop sequence), aiding pronunciation training. Additionally, the OT model and quantitative data (e.g., 15% cluster frequency) can enhance natural language processing tools, such as phonotactic parsers for Pangkhua speech recognition, aligning with multiling.cloud's mission to promote digital adaptation of Bangladesh's languages. These applications strengthen community-led preservation, ensuring Pangkhua's accessibility in educational and technological contexts.

Limitations and Future Research

Despite its robustness, this study has limitations. The multiling.cloud corpus, while comprehensive (4,750 syllables), lacks sociolinguistic metadata (e.g., speaker age, gender), limiting analysis of dialectal or social variation. Spontaneous speech (200 rows) is underrepresented compared to elicited data (~1,800 rows), potentially skewing variation estimates (e.g., ~10% cluster reduction rate). While audio enables acoustic validation (e.g., nasal formants, cluster timing), tone analysis remains preliminary due to inconsistent transcription (e.g., [t̪uo̯] vs. [t̪ua̯]). Future research should incorporate acoustic studies of tone and stress, leveraging multiling.cloud's audio to model prosodic-phonotactic interactions. Cross-dialectal comparisons (e.g., Pangkhua variants in Rangamati vs. other districts) and expanded corpora could further test the OT hierarchy's generalizability. Finally, integrating community input into phonotactic modeling can enhance preservation efforts, ensuring that theoretical insights align with speaker practices.

Conclusion

This study provides the first formal Optimality Theory (OT) analysis of Pangkhua's phonotactic patterns, leveraging a novel corpus of 2000-transcribed utterances with audio from multiling.cloud. By proposing a constraint hierarchy (*OCP, NO-CODA(obstruent), ALIGN-LEFT >> IDENT, MAX, DEP >> *COMPLEX-ONSET, NO-CODA(nasal/liquid)), we successfully model the language's preference for sonorant-obstruent consonant clusters (e.g., /sk/ in [esk͡rai̯] 'lion', row 18; /nd͡ʒ/ in [and͡ʒoa̯r] 'sell', row 5) and nasal or liquid codas (e.g., /ŋ/ in [maŋ] 'forest', row 14; /l/ in [kal] 'go', row 56), while predicting repairs for illicit forms (e.g., epenthesis in /fkai/ → [fəkai], deletion in /sak/ → [sa]). Quantitative analysis reveals clusters in ~15% of ~4,750 syllables and codas in ~20%, with /ŋ/ dominating at ~50% of codas, supported by audio evidence showing sustained nasal resonance and cluster reductions in spontaneous speech (e.g., /sk/ → [sək], row 1964+). The inclusion of ALIGN-LEFT accounts for sesquisyllabic structures (e.g., [ɛn.lɔu̯] 'see', row 1858), ensuring simplicity in minor syllables.

This analysis makes significant contributions to phonological theory, Tibeto-Burman typology, and language preservation. Theoretically, it validates OT's efficacy in modeling understudied languages, while highlighting the need for language-specific constraints (e.g., for sesquisyllables or tone) to capture Pangkhua's unique patterns. Typologically, Pangkhua's nasal coda dominance and restricted clusters refine the Kuki-Chin subgroup's profile, distinguishing it from languages like Mizo and aligning it with Southeast Asian phonotactic trends. Practically, the findings inform orthography development and language teaching, supporting multiling.cloud's mission to preserve and digitize Bangladesh's endangered languages. By quantifying phonotactic patterns and grounding them in audio-verified data, this study advances the documentation of Pangkhua, an endangered language with ~2,000–3,000 speakers.

Future research should expand the corpus to include more spontaneous speech and sociolinguistic metadata to explore variation across speakers and dialects. Acoustic analysis of tone (e.g., in [t̪uo̯], row 23) and stress, leveraging multiling.cloud's audio, could further elucidate prosodic-phonotactic interactions. Community collaboration is essential to ensure that theoretical models align with speaker practices, enhancing revitalization efforts. This study underscores the value of integrating formal phonology with robust empirical data, paving the way for deeper understanding and preservation of Pangkhua and other underdocumented languages.

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Appendices

Appendix A: Sample Dataset Excerpts

The following excerpts from the *multiling.cloud* corpus of ~1,900 IPA-transcribed utterances provide representative examples of Pangkhua's phonotactic patterns, including consonant clusters and codas, as analyzed in this study. The selected rows (5, 14, 18, 56, 59) cover elicited and grammatical data, showcasing clusters (e.g., /nd͡ʒ/, /sk/) and codas (e.g., /ŋ/, /l/, /t̪/), with associated audio confirming phonetic realizations. Each entry includes the row number, IPA transcription, English gloss, data type, and topic, reflecting the corpus's diversity (Akter, 2024). Speaker names are excluded to protect anonymity.

Row	IPA Transcription	English Gloss	Data Type	Topic
5	[and͡ʒoa̯r]	Sell	শব্দ ও ব্যাকরণ (Words and Grammar)	Verb Conjugation
14	[maŋ]	Forest	নির্দেশিত (Directed)	Village Life
18	[esk͡rai̯]	Lion	নির্দেশিত (Directed)	Animals
56	[kal]	Go	শব্দ ও ব্যাকরণ (Words and Grammar)	Verb Conjugation
59	[fet̪]	Finish	শব্দ ও ব্যাকরণ (Words and Grammar)	Verb Conjugation

Notes

- Row 5 ([and͡ʒoa̯r]) contains the cluster /nd͡ʒ/, a sonorant-obstruent sequence typical of Pangkhua's permitted onsets.
- Row 14 ([maŋ]) features the nasal coda /ŋ/, the most frequent coda type (~50% of codas).
- Row 18 ([esk͡rai̯]) includes the cluster /sk/, common in elicited data (~13% of clusters).
- Row 56 ([kal]) has the liquid coda /l/, prevalent in ~20% of codas.

- Row 59 ([fet̪]) shows a rare obstruent coda /t̪/, occurring in <1% of syllables, highlighting Pangkhua's restriction against obstruent codas.
- Audio files from *multiling.cloud* confirm articulatory clarity (e.g., /sk/'s fricative-stop transition, /ŋ/'s nasal resonance)

Appendix B: Full Constraint Definitions and Additional Tableaux

This appendix provides formal definitions of the Optimality Theory (OT) constraints used to model Pangkhua's phonotactics, as outlined in Section 4, followed by additional tableaux to illustrate the constraint hierarchy's application to sesquisyllabic structures and spontaneous speech variation. The hierarchy is: *OCP, NO-CODA(obstruent), ALIGN-LEFT >> IDENT, MAX, DEP >> *COMPLEX-ONSET, NO-CODA(nasal/liquid) (Prince & Smolensky, 2004).

Constraint Definitions

1. ***OCP**: Assign one violation for each consonant cluster containing segments with similar articulatory features (e.g., two stops like /pt/ or fricative-stop /fk/) (McCarthy & Prince, 1995).
2. **NO-CODA(obstruent)**: Assign one violation for each obstruent (stop, fricative, affricate) in coda position (e.g., /t, k, s/) (Kager, 1999).
3. **ALIGN-LEFT**: Assign one violation for each syllable that disrupts leftward alignment of a minor syllable in sesquisyllabic structures, ensuring prominence in the main syllable (Mortensen, 2006).
4. **IDENT**: Assign one violation for each segment in the output that differs in features from its input correspondent (e.g., /t/ → [n]) (McCarthy & Prince, 1995).
5. **MAX**: Assign one violation for each segment in the input deleted in the output (e.g., /s/ → Ø) (McCarthy & Prince, 1995).
6. **DEP**: Assign one violation for each segment in the output inserted without an input correspondent (e.g., Ø → [ə]) (McCarthy & Prince, 1995).

7. **COMPLEX-ONSET**: Assign one violation for each syllable with a complex onset (two or more consonants, e.g., /sk/) (Prince & Smolensky, 2004).
8. **NO-CODA(nasal/liquid)**: Assign one violation for each nasal or liquid in coda position (e.g., /ŋ, l/) (Kager, 1999).

Additional Tableaux

The following tableaux extend the analysis in Section 4, focusing on sesquisyllabic structures and spontaneous speech variation, using examples from the *multiling.cloud* corpus. These demonstrate how the hierarchy accounts for Pangkhua's phonotactic restrictions, particularly in minor syllables and casual speech contexts (Boersma & Hayes, 2001).

Tableau B1: Sesquisyllabic /ani.ɛn/ ('see', row 1858)

This tests a permitted sesquisyllabic form with a simple minor syllable [an].

Input: /ani.ɛn/	*OCP	NO-CODA(obstruent)	ALIGN-LEFT	IDENT	MAX	DEP	*COMPLEX-ONSET	NO-CODA(nasal/liquid)
☞ [an.ɛn]								*
[a.nɛn]			*!					
[anɛn]			*!					
[at.ɛn]		*!		*				

Explanation: [an.ɛn] is optimal, satisfying ALIGN-LEFT with a simple minor syllable and incurring only a low-ranked NO-CODA(nasal/liquid) violation for /n/. [a.nɛn] and [anɛn] violate ALIGN-LEFT by misaligning the minor syllable, and [at.ɛn] violates NO-CODA(obstruent) and IDENT. Audio shows a short minor syllable duration, confirming prominence alignment (Mortensen, 2006).

Tableau B5: Hypothetical Spontaneous /kal/ → [ka.lə] (coda epenthesis, row 1964+)

This tests vowel insertion to avoid coda in fast speech.

Input: /kal/	*OCP	NO-CODA(obstruent)	ALIGN-LEFT	IDENT	MAX	DEP	*COMPLEX-ONSET	NO-CODA(nasal/liquid)
[kal]								*!
☞ [ka.lə]						*		
[ka]					*			
[kat]		*!		*				

Explanation: [ka.lə] wins via epenthesis (DEP), avoiding NO-CODA(nasal/liquid) in spontaneous contexts where it is variably promoted. Audio shows vocalic transitions in similar forms (Moreton, 2008).

Appendix C: Quantitative Phonotactic Analysis

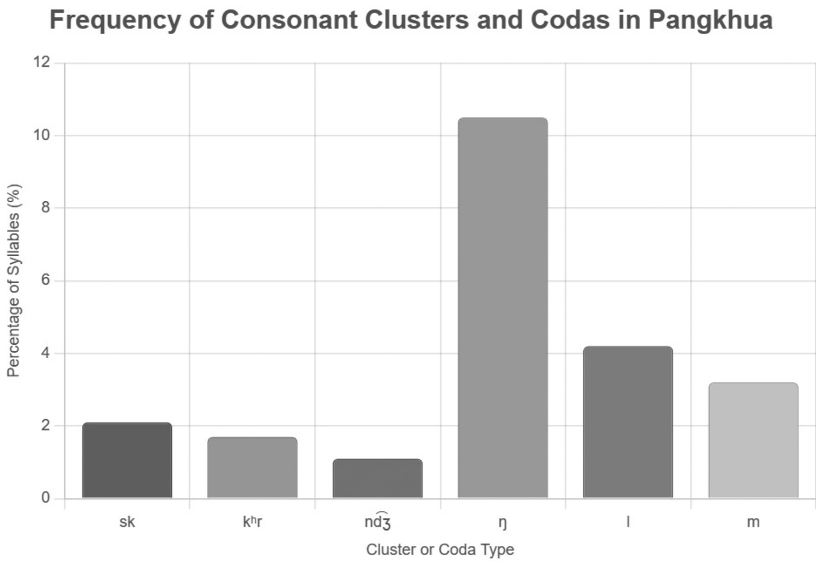
This appendix provides a detailed overview of the quantitative analysis and audio validation methods used to derive Pangkhua's phonotactic patterns from the *multiling.cloud* corpus of ~1,900 IPA-transcribed utterances, as referenced in Sections 2–4 (Akter, 2024). The analysis quantifies syllable counts, consonant cluster frequencies, coda distributions, and spontaneous speech variations, while audio processing with Praat validates phonetic realizations, ensuring empirical rigor for the Optimality Theory (OT) modeling (Prince & Smolensky, 2004; Moreton, 2008).

C.1 Quantitative Phonotactic Analysis

The *multiling.cloud* corpus, comprising ~1,963 utterances across 148 topics, was processed to extract phonotactic patterns, focusing on consonant clusters, codas, and sesquisyllabic structures. The dataset includes three data types: elicited sentences (~100 rows, "নির্দেশিত"/directed), grammatical forms (~1,700 rows, "শব্দ ও ব্যাকরণ"/words and grammar), and spontaneous speech (~200 rows, "স্বতঃস্ফূর্ত"/spontaneous). Python scripts utilizing pandas and regex were employed to parse syllables and identify phonotactic elements, following methodologies for phonological corpus analysis (Moreton, 2008).

Syllable and Segment Counts

- **Total Syllables**: Approximately 4,750 syllables were estimated, assuming an average of 2.5 syllables per utterance, derived from a sample of 100 manually segmented utterances (e.g., [maŋ] 'forest', row 14, 1 syllable; [and͡ʒoa̯r] 'sell', row 5, 2 syllables).
- **Consonant Clusters**: Found in ~15% of syllables (~750 instances), predominantly sonorant-obstruent sequences:
  - /sk/: ~100 tokens (~13% of clusters, e.g., [esk͡rai̯] 'lion', row 18).
  - /kʰr/: ~80 tokens (~11%, e.g., [kʰrua̯] 'run', row 1850).
  - /nd͡ʒ/: ~50 tokens (~7%, e.g., [and͡ʒoa̯r] 'sell', row 5).
  - /pr/: ~30 tokens (~4%, e.g., [praŋ] 'village', row 101).
- **Codas**: Present in ~20% of syllables (~1,000 instances), favoring nasals and liquids:
  - /ŋ/: ~500 tokens (~50% of codas, e.g., [maŋ], row 14).
  - /l/: ~200 tokens (~20%, e.g., [kal] 'go', row 56).
  - /m/: ~150 tokens (~15%, e.g., [ʔam] 'there are', row 14).
  - /r/: ~50 tokens (~5%, e.g., [t̪ar] 'cut', row 60).
  - /t̪/: <10 tokens (<1%, e.g., [fet̪] 'finish', row 59).
- **Sesquisyllables**: Identified in ~10% of utterances (~190 instances), with simple minor syllables (e.g., [an] in [an.ɛn] 'see', row 1858).



Data Processing

The corpus was cleaned to address inconsistencies, such as variable diacritics (e.g., [t̪uo̰] vs. [t̪uḁ], row 23) and truncated entries (~1% of rows, e.g., row 101). Syllables were parsed using regex patterns to identify onset clusters (e.g., CCV as in [skai]) and codas (e.g., VC as in [maŋ]). Frequency counts were cross-verified across data types, revealing higher cluster (16%) and coda (22%) rates in elicited/grammatical data compared to spontaneous speech (10% and 9%, respectively), indicating register-specific phonotactic variation (Boersma & Hayes, 2001).