

摘要

本文^①以纳西语（Naish Languages）中的 r 类元音（rhotic vowels）为主要研究对象，对纳西语的四个方言点（丽江话、波湾话、次瓦话、博树话）的 r 类元音及相关元音进行了系统的实证描写与对比分析，在此基础上探讨其历史音变轨迹。

本文通过实地采集四个方言点的声学信号和超声舌位成像（UTI），获取 r 类元音的声学参数和生理发音参数。声学参数按照研究需要进行差值填充、多种归一方法和 DCT 变换后比较共振峰模式，时长和嗓音数据；生理发音数据经 DeepLearnCut 模型提取后舌线数据，用于后续的发音模式比较。统计方法按照静态和动态分析两类，使用自动聚类，线性混合模型，广义加性模型等方法建模，并使用数据可视化手段比较 r 类元音的语音性质。

在声学特征分析方面，研究以各方言中表现基本一致的/a/元音作为跨方言比较的参考系，比较不同方言中 r 类元音的声学性质。通过共振峰模式的静态与动态比较发现，四个方言的 r 类元音/ɔ:/在声学表现上存在显著差异。波湾话与次瓦话的 F1×F2 共振峰模式较为接近，而丽江话与博树话更为相近。在 r 音性（rhoticity，主要体现为 F3 的下降）上，博树话最强，丽江话次之，次瓦话与波湾话相对较弱。基于广义加性混合模型（GAMM）的分析及时间结构表明纳西语 r 类元音在各方言中都存在动程，主要体现在 F1 和 F3 上。纳西语 r 类元音在没有后接辅音影响的情况下，其 r 音性更倾向于在音段的前期（约 30% 处）或末尾处实现，可以看作 r 类元音的内在特征。

在生理发音机制方面，超声影像揭示四个方言在发/ɔ:/时的舌面后部及舌根动作相对一致，但舌尖发音动作存在显著分歧。博树话与次瓦话的舌尖倾向朝下并伴随舌体后缩，而丽江话与波湾话则表现为舌尖抬起的卷舌模式。其中，波湾话的舌面后部与舌根位置显著低于其他方言。时间序列分析表明，/ɔ:/的最大位移速度集中出现在音段起始的 10%-20% 处，与声学数据 30% 的高频 r 音性声学目标吻合。且不同声母条件对 r 类元音的舌根位置与位移速度有明显的协同发音影响，卷舌和齿龈声母更有利于 r 类元音在起始部分实现发音目标，双唇次之，其他辅音又次之。

本文还研究了 r 类元音/ʋ/(vr)，咽化元音/æ^ʕ/，这两种元音都与/ɔ:/音位存在同源对应关系，能够作为 r 类元音在不同演变阶段的语音表现参考。次瓦话中存在独特的咽化元音/æ^ʕ/与普通元音/æ/的音位对立，其咽化表现主要是舌根位置的后移；波湾话和博树话的唇齿 r 类元音/ʋ/由于各自音系地位不同，呈现出不同的声学 and 共振峰模式。此外，针对丽江话先前的“松紧”元音之争，本文结果显示 r 类元音的发音动作的确会引

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发明显的 H1-H2 差异，验证了嗓音音质和喉上调音的交互现象。

最后，结合共时实验证据，本文重新审视了纳西语 r 类元音的历史音变和内部变异。研究提出次瓦话的咽化元音反映了 r 类元音在“去 r 音性”演变过程中经历的咽化阶段残留；丽江话内部的语流变异模式与博树话、永宁话方向一致，预示了 r 类元音向舌尖元音或普通元音演变的趋势。而博树话中的合音现象则展示了受声母影响形成 r 类元音的早期阶段。内部人际变异的比较显示，虽然 r 类元音生理发音有多种类型，但是方言内部有明显的趋向性。博树话和丽江话以舌尖向上抬起为主流（两者模式也有细微区别），而次瓦话和波湾话以舌尖后缩抬起为主流。再结合声学数据和历史比较，本研究提出了一种 r 类元音的演变模式。

关键词：纳西语，r 类元音，历史音变，超声舌位成像

A Study of Rhotic Vowels in Naish Languages

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ABSTRACT

This study investigates the rhotic vowels in the Naish languages, providing a systematic empirical description and comparative analysis across four dialects: Lijiang, Bowan, Ciwa, and Boshu. By examining rhotic and related vowels, the research explores historical phonological traces and outlines an evolutionary path for rhotic vowels in the context of general linguistics.

The methodology integrates field-collected acoustic signals with Ultrasound Tongue Imaging (UTI). Acoustic parameters, including formant patterns, duration, and voice quality data, were analysed using interpolation for missing values, various normalisation, and Discrete Cosine Transform (DCT). Physiological data were extracted using the DeepLabCut model to obtain tongue contours for articulatory pattern comparison. Statistical modelling involved both static and dynamic analyses, employing k-means clustering, Linear Mixed-Effects Models (LMM), and Generalised Additive Mixed Models (GAMM).

Acoustic analysis, using the cross-linguistic stable vowel /a/ as a reference, reveals significant differences in the acoustics of the rhotic vowel /ɤ/ across the four dialects. While Bowan and Ciwa exhibit similar $F1 \times F2$ patterns, Lijiang and Boshu are more closely aligned. Regarding rhoticity (manifested as $F3$ lowering), Boshu shows the strongest effect, followed by Lijiang, with Ciwa and Bowan being relatively weaker. GAMM-based temporal analysis indicates that /ɤ/ possesses a dynamic trajectory in all dialects, primarily in $F1$ and $F3$. Due to the simple syllable structure of Naish, rhoticity tends to be realised either early (at approximately 30% of the duration) or at the offset, suggesting it is an intrinsic feature of these vowels.

Physiological results indicate that while posterior tongue and tongue root movements are consistent across dialects for /ɤ/, tongue tip gestures diverge significantly. Boshu and Ciwa favour a "bunched" pattern (tongue tip down with body retraction), whereas Lijiang and Bowan exhibit a "retroflex" pattern (tongue tip raised). Specifically, Bowan shows significantly lower tongue root and posterior positions. Temporal analysis reveals that maximum displacement velocity occurs within the first 10% – 20% of the segment, aligning with the high-rhoticity acoustic target at 30%. Coarticulatory effects from initials are evident: retroflex and alveolar

initials facilitate earlier realisation of the articulatory target, followed by labials.

The study also examines the rhotic vowel /ʋ/ and the pharyngealized vowel /æ^ʕ/, both of which are cognates of /ə/ and can be considered as different stages in sound change. Ciwa preserves a unique phonemic contrast between /æ^ʕ/ and /æ/, where pharyngealization is characterised by tongue root retraction. In Bowan and Boshu, the labiodental rhotic /ʋ/ displays varying acoustic patterns depending on its phonological status. Regarding the "tense-lax" vowel debate in Lijiang, the results show that rhotic articulation induces significant H1-H2 differences, confirming the interaction between phonation (voice quality) and supraglottal articulation.

In conclusion, combining synchronic experimental evidence with historical comparison, this study revisits the sound change of Naish rhotic vowels. It is proposed that the pharyngealized vowels in Ciwa represent a residual stage of "derhoticization," while variation patterns in Lijiang suggest a universal trend toward apical or plain vowels. The coalescence in Boshu reflect the early stages of rhotic vowel formation influenced by initials. Despite varied physiological strategies, certain intra-dialectal consistency is observed. Boshu and Lijiang are dominated by a tongue-tip raising gesture, whereas Ciwa and Bowan primarily exhibit a retracted tongue-body gesture. By integrating these articulatory findings with acoustic data and historical comparison, this study proposes a general model for the evolution of rhotic vowels.

KEY WORDS: Naish Languages, Rhotic Vowel, Sound Change, Ultrasound Tongue Imaging