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# Equivalence and differences: Formant patterns of labialization and pharyngealization in Tashlhiyt

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## Abstract

Labialization and pharyngealization are secondary articulations that are produced with different vocal tract modifications. In Tashlhiyt, a language that has both secondary articulations in its consonant system, labialization is produced with lip protrusion and a backing of the tongue, while pharyngealization is articulated by a backward movement of the tongue towards the pharynx. Despite this difference, both secondary articulations are reported to have similar acoustic effects regarding F2 across languages.

The current study investigates the impact of labialization and pharyngealization on the formant structure of adjacent vowels in the same language. The analysis of VCV logatomes containing /i, a, u/ produced by 35 Tashlhiyt speakers revealed that both secondary articulations show equivalent patterns related to F2, which are strongest in /i/, followed by /a/, whereas differences between labialization and pharyngealization depend mainly on F1 and vowel quality.

**Index Terms**: secondary articulation, labialization, pharyngealization, formant patterns, Tashlhiyt

## 1. Introduction

Secondary articulations are minor constrictions in the vocal tract superimposed to another primary constriction ([1]). Labialization and pharyngealization belong to the major types of secondary articulations, alongside palatalization and velarization (e.g., [2, 3]). There is a certain asymmetry in the literature regarding labialization and pharyngealization: Labialization is the most common secondary articulation in the languages of the world ([4]), while phonetic investigations are sparse and consist usually of a small sample of speakers. In contrast, pharyngealization is one of the least common secondary articulations ([5]), but its phonetics is well-investigated (e.g., [6, 7, 8, 9, 10, 11, 12, 13, 14]), especially on data from Arabic where it is a prominent feature of the phonological system. Although both secondary articulations refer to distinct articulatory patterns, they both target F2 as their primary acoustic exponent (e.g., [15, 16, 17, 18]). In this regard, [19] mentioned an ”equivalence of labialization and pharyngealization” that is reflected by the substitution of pharyngealized consonants in Arabic loan words with corresponding labialized consonants found in Bantu languages. This raises the question whether labialization and pharyngealization are indeed acoustically equivalent. Most languages have only one secondary articulation, which makes a comparison hard given language-specific differences. Only a small number of languages have two secondary articulations and the specific configuration of having labialization and pharyngealization is a rather rare phenomenon and occurs in only approx. 0.4% of the world's worlds ([5]). Tashlhiyt Amazigh belongs to the small number of languages that have both labialization and pharyngealization in its consonant system and provides thus a rare opportunity to compare both secondary articulations in the same language.

### 1.1. Tashlhiyt Amazigh

Amazigh languages form an own branch in the Afro-Asiatic language family, with Tashlhiyt being one of the three varieties of Moroccan Amazigh. Tashlhiyt is spoken in an area covering the High-Atlas and Anti-Atlas mountains as well as the southern plains by approximately 7 to 8 million speakers, as well as by a considerable amount of speakers outside of Morocco ([20, 21]). Regarding its phoneme inventory, Tashlhiyt has a three-way vowel system consisting of /i, a, u/ and the consonant inventory comprises 72 segments, including singletons and geminates. Secondary articulations are distributed in different subsets of Tashlhiyt's consonant system: Labialization is found in the set of dorsals, where each of the plain dorsal consonants /k, kː, g, gː, q, qː, χ, χː, ʁ, ʁː/ has a labialized counterpart /kʷ, kʷː, gʷ, gʷː, qʷ, qʷː, χʷ, χʷː, ʁʷ, ʁʷː/. Conversely, pharyngealization is a contrastive feature in the set of coronals, where each plain coronal (/t, tː, d, dː, s, sː, z, zː, l, lː, r, rː/) can be pharyngealized (/tˤ, tˤː, dˤ, dˤː, sˤ, sˤː, zˤ, zˤː, lˤ, lˤː, rˤ, rˤː/).

### 1.2. Previous studies

Previous articulatory and acoustic research on labialization in Tashlhiyt was conducted based on a sample of six speakers. [22] showed that labialized consonants exhibited a clearly lowered F2 in the following vowel and an additional lowering of F1 in following [a]. The results related to F2 replicated previous findings on labialization, where a lowered F2 is the major acoustic correlate for labialization (e.g., [18, 17, 23]). Pharyngealization in Tashlhiyt was analyzed by [24] with the same speakers and the same logatome structure. That study found a lowered F2 and a slightly raised F1 and F3 in [aCa] logatomes, thus confirming previous results found within Arabic (e.g., [6, 25]) and non-Arabic languages (e.g., [26, 11, 27]). The convergence of F2–F1, that was previously used as an invariate correlate to distinguish pharyngealized from plain consonants ([8]), has not yet been applied to Tashlhiyt data or to data on labialization. Given the rarity of languages having two secondary articulations, a direct comparison was rarely done. One study ([28]), which investigated labialization and pharyngealization in Moroccan Arabic, is based on only two speakers and did not explicitly contrast the two secondary articulations.

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### 1.3. Current study

This study addresses a gap in phonetic research by conducting a direct comparison of labialization and pharyngealization within a single language, using a larger sample size of speakers. It specifically examines the effect of these two secondary articulations on the formant structure of adjacent vowels. Unlike previous work on Tashlhiyt, the current study investigates the language's full vowel space. The analysis assesses the effect of each secondary articulation separately – starting with labialization, followed by pharyngealization – before conducting a comparative assessment of their effects on vowel formants.

## 2. Methods

### 2.1. Participants

For the production study, 35 native speakers of Tashlhiyt were recruited in Agadir, Morocco, of whom 16 were female (mean age = 24, SD = 9) and 19 male speakers (mean age = 27, SD = 7). All speakers were raised in the Tashlhiyt-speaking areas of Southern Morocco and reported to further speak Moroccan Arabic, Standard Arabic and French. None of the speakers reported any speaking or hearing-related issues.

### 2.2. Materials

The analysis carried out in this study is based on a subset of a larger corpus designed to investigate Tashlhiyt labialization and pharyngealization in different contexts. The target words analyzed here consisted of VCV logatomes, where V was occupied symmetrically by one of the three Tashlhiyt vowels /i, a, u/, while the consonant was either a plain vs. labialized dorsal or a plain vs. pharyngealized coronal, e.g., /aga/, /agʷa/, /iti/, /itˤi/. It must be noted that [uCu] logatomes containing a labialized dorsal are artificial in Tashlhiyt, as [u] and labialized consonants are subject to a co-occurrence restriction ([29]). In this study, only logatomes containing singleton consonants were analyzed. For dorsals, the target consonants were /k, kʷ, g, gʷ, q, qʷ, χ, χʷ, ʁ, ʁʷ/. The coronal target consonants were /t, tˤ, d, dˤ, s, sˤ, z, zˤ, l, lˤ, r, rˤ/.

Logatomes containing dorsal consonants were embedded into the carrier sentence *Innayak _ dari* ('He told you (masc.) _ at my place') and logatomes containing coronal consonants were embedded into the sentence *Innayam _ bahra* ('He told you (fem.) _ a lot.). The stimuli were presented in the modified Latin alphabet on a computer screen in front of the speaker and repeated two times.

### 2.3. Recording procedure

The recordings were conducted in a quiet and calm room using a Roland R-26 field recorder and an AKG C520 headset microphone (frequency response: 60 – 20 000 Hz). The acoustic recordings were sampled at 48 000 Hz and with a resolution of 16 bit.

### 2.4. Measurements

The formants F1, F2 and F3 in Hz were extracted at 90% of the preceding vowel and at 10% of the following vowel, because these were the locations where the maximum difference was found in [24, 22]. The formants were extracted using the Burg algorithm as implemented in Praat ([30]) and the maximum formant was adapted to the speakers' sex (female = 5500 Hz, male = 5000 Hz). The measurements were done using a custom script written in PYTHON ([31]) and utilizing PARSELMOUTH ([32]), which interfaces to PRAAT ([30]).

### 2.5. Statistics

Hierarchical linear models were performed for the statistical analysis by using BAMBI [33] and PYMC [34]. Separate models were run for each formant F1, F2, F3 and also on the difference between F2–F1 and for each place of articulation. The model structure was identical: Each formant and F2–F1 were entered as response variable and TYPE (plain, labialized or plain, pharyngealized), VOWEL (a, i, u) and VOWEL POSITION (preceding, following) and the interactions TYPE×VOWEL and TYPE×VOWEL POSITION and TYPE×Vowel×VOWEL POSITION as common-level effects. By-speaker intercepts and slopes for TYPE were added as group-level effects. The data was standardized prior to the analysis to ensuring comparability between the dimensions and the secondary articulations. Each model was run with four chains and 8000 samples for tuning and 8000 draws, thus yielding 32000 samples for the analyses. Reported are the mean and the lower and upper boundary of 95% of the posterior distribution. For decision-making, the HDI+ROPE decision rule [35] was applied: Evidence for a statistical effect was determined if 95% of the posterior estimate (highest density interval, HDI) was located outside a Region of Practical Equivalence (ROPE). The ROPE was set uniformly to [-0.1, 0.1] following [36] for standardized variables.

## 3. Results

### 3.1. Labialization

A total of 1880 tokens for plain (N=1003) and labialized dorsals (N=877) was retrieved for the analysis. Figure 1 displays the F1-F2 and F2-F3 vowel space of plain and labialized productions, with the vowel symbols representing the means and the ellipses indicating one standard deviation. The summary statistics for F1, F2, F3 and F2–F1 are given in Table 1 by vowel quality and type.

Table 1: *Means and standard deviations (in Hz) of F1, F2, F3 and F2-F1 by vowel (a, i, u) and type (lab = labialized). Averaged across speakers, dorsals and vowel position.*

| V | type | F1 | F2 | F3 | F2-F1 |
|---|---|---|---|---|---|
| a | plain | 583 (197) | 1597 (388) | 2781 (410) | 1014 (470) |
| | lab | 517 (160) | 1117 (277) | 2749 (419) | 601 (250) |
| i | plain | 365 (103) | 2255 (366) | 2996 (332) | 1890 (405) |
| | lab | 360 (91) | 1574 (536) | 2664 (416) | 1214 (549) |
| u | plain | 372 (75) | 809 (174) | 2788 (461) | 437 (164) |
| | lab | 365 (69) | 768 (172) | 2768 (457) | 403 (162) |

There was evidence of F1 lowering in [a] ($\beta$=-37 [-0.52, -0.21]), where labialized productions had a mean F1 of 517 (160) Hz and plain articulations averaged at 583 (197) Hz. In contrast, neither [i] ($\beta$=-0.07 [-0.23, 0.09]) nor [u] ($\beta$=0.01 [-0.13, 0.17]) displayed significant F1 modification due to labialization, with mean differences of only 5-7 Hz for these vowels. Additionally, no evidence was found for F1 differences in labialized [a] ($\beta$=-0.05 [-0.17, 0.07]), [i] ($\beta$=0.04 [-0.09, 0.16]) or [u] ($\beta$=0.06 [-0.06, 0.18]), based on positional context, whether the vowels preceded or followed the target consonants.

As can be seen in Figure 1, F2 was clearly lowered in [a] and [i], when adjacent to labialized consonants compared to their plain counterparts. The strongest effect was observed for [i] ($\beta$=-1.16 [-1.33, -0.99]) with a mean difference of 681 Hz. F2 in [a] was 480 Hz lower on average ($\beta$=-0.83 [-0.99, -0.66]). By contrast, no difference was observed for [u] ($\beta$=-0.14 [-0.3, 0.3]). Additionally, there was no evidence of positional differences in the effect of labialization for [a] ($\beta$=-0.03 [-0.11, 0.03]), [i] ($\beta$=0.07 [-0.01, 0.15]) or [u] ($\beta$=0.14 [0.07, 0.22]).

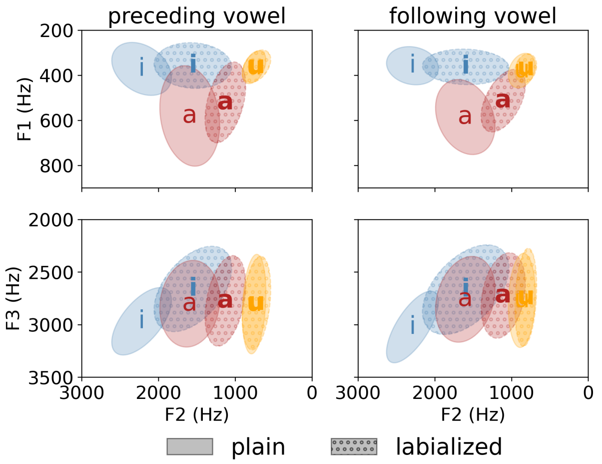


Figure 1: *F1-F2 (top row) and F2-F3 (bottom row) vowel spaces of plain and labialized productions in Hz by vowel position (columns). Vowel symbols mark the mean (bold = labialized) and ellipses display one standard deviation (hatched = labialized).*

Given the important lowering of F2 in [a] and [i], F2–F1 was consequently reduced in labialized productions of these vowels. The largest effect was observed for [i]($\beta$=-1.17 [-1.35, -0.99]) with a mean difference of 676 Hz, followed by [a] ($\beta$=-0.75 [-0.93, -0.57]), with a mean difference of 407 Hz. As expected, the vowel [u] displayed no difference in F2–F1 due to labialization ($\beta$=-0.17 [-0.34, 0.01]). There was also no evidence that the effect of labialization differed by position for [a] ($\beta$=-0.02 [-0.1, 0.06]), [i] ($\beta$=0.06 [-0.03, 0.15]), or [u] ($\beta$=0.13 [-0.04, 0.21]).

F3 was lowered by labialization only when the surrounding vowel was [i] ($\beta$=-1.01 [-1.24, -0.77]), with a mean difference of 332 Hz. For [a], the F3 in labialized productions (mean of 2749 (419) Hz) was similar to [a] in plain productions (mean of 2781 (410) Hz), showing no difference ($\beta$=-0.3 [-0.54, -0.07]). Similarly, the F3 of [u] showed a negligible difference of 20 Hz between plain and labialized contexts ($\beta$=-0.26 [-0.49, -0.03]). As for previous parameters, there was no evidence that the effect of labialization on F3 varied by vowel position for ($\beta$=-0.12 [-0.23, -0.01]), [i] ($\beta$=0.02 [-0.1, 0.13]) or [u] ($\beta$=-0.13 [-0.24, -0.02]).

### 3.2. Pharyngealization

A total of 2387 tokens for coronals was retrieved, consisting of 1197 tokens for plain and 1190 tokens for pharyngealized productions. Figure 2 depicts the F1-F2 and F2-F3 vowel spaces of all three Tashlhiyt vowels surrounding plain and pharyngealized consonants (bold, hatched). The summary statistics are given in Table 2.

Pharyngealization led to a raised F1 across all three vowels, with the largest effect observed in [i] ($\beta$=0.72 [0.53, 0.92]),

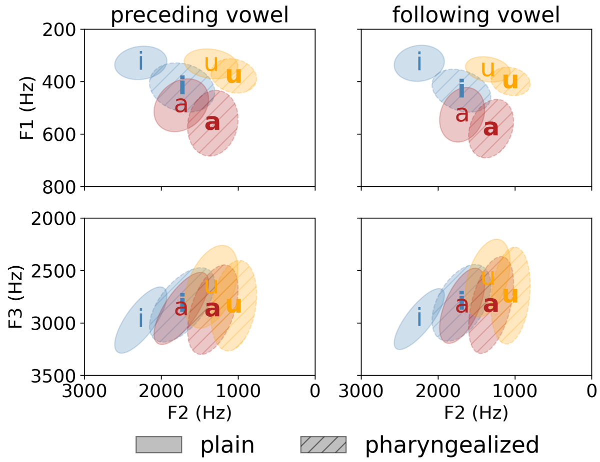


Figure 2: *F1-F2 (top row) and F2-F3 (bottom row) vowel spaces of plain and pharyngealized productions in Hz by vowel position (columns). Vowel symbols mark the mean (bold = pharyngealized) and ellipses display one standard deviation (hatched = pharyngealized).*

where F1 was 99 Hz higher. In [a], F1 was 60Hz higher in pharyngealized than in plain productions ($\beta$=0.51 [0.31, 0.71]). The smallest effect was found in [u] ($\beta$=0.33 [0.14, 0.53]), where F1 was 46 Hz higher in the vicinity of pharyngealized consonants. Additionally, there was no evidence that the effect of pharyngealization on F1 differed by vowel position for [a] ($\beta$=0.17 [0.09, 0.25]), [i] ($\beta$=0.1 [0.02, 0.18]) or [u] ($\beta$=0.17 [0.09, 0.26]).

As shown in Figure 2, pharyngealization clearly lowered F2 in across all vowels: The lowering of F2 in [i] exhibited the greatest magnitude of 542 Hz ($\beta$=-0.95 [-1.13, -0.77]), followed by [a] ($\beta$=-0.66 [-0.84, -0.47]) with a mean difference of 393 Hz. The smallest effect was found in [u], where F2 was lowered by 296 Hz ($\beta$=-0.47 [-0.65, -0.28]). There was no evidence that this effect of pharyngealization varied by vowel position for [i] ($\beta$=-0.07 [-0.14, 0.01]), [a] ($\beta$=-0.04 [-0.11, 0.04]) or [u] ($\beta$=-0.01 [-0.07, 0.08]).

Table 2: *Means and standard deviations (in Hz) for F1, F2, F3 and F2–F1 by vowel (a, i, u) and type (pha = pharyngealized). Averaged across speakers, coronals and vowel position.*

| V | type | F1 | F2 | F3 | F2-F1 |
|---|---|---|---|---|---|
| a | plain | 509 (104) | 1712 (326) | 2850 (351) | 1204 (322) |
| | pha | 569 (119) | 1319 (311) | 2852 (445) | 749 (313) |
| i | plain | 330 (66) | 2254 (333) | 2968 (303) | 1925 (333) |
| | pha | 429 (88) | 1712 (404) | 2819 (360) | 1283 (433) |
| u | plain | 343 (54) | 1352 (321) | 2613 (384) | 1008 (335) |
| | pha | 389 (61) | 1056 (277) | 2788 (449) | 666 (293) |

Due to the raised F1 and the lowered F2, F2–F1 was consistently smaller in pharyngealized productions compared to plain articulations. The largest difference in F2–F1 was observed in [i], with an average difference of 642 Hz ($\beta$=-1.06 [-1.24, -0.88]). In [a], F2–F1 was 455 Hz lower in pharyngealized productions ($\beta$=-0.71 [-0.89, -0.53]). The smallest difference was found in [u], where F2–F1 decreased by 342 Hz ($\beta$=-0.51 [-

0.68, -0.32]). Regarding vowel position, there was no evidence that the effect of pharyngealization on F2–F1 varied for [a] ($\beta$=-0.08 [-0.15, -0.01]), [i] ($\beta$=-0.09 [-0.16, -0.02]), or [u] ($\beta$=-0.04 [-0.12, 0.03]).

Pharyngealization affected F3 only in [i] ($\beta$=-0.56 [-0.8, -0.34]), where it was 149 Hz lower on average. In [a], F3 remained virtually identical with an average of 2850 Hz in plain productions and 2852 Hz in pharyngealized productions ($\beta$=-0.19 [-0.41, 0.04]). For [u], there was no effect of pharyngealization on F3 ($\beta$=0.25 [0.02, 0.47]). Regarding vowel position, the effect of pharyngealization on F3 did not differ for [i] ($\beta$=-0.05 [-0.15, 0.05]) or [a] ($\beta$=-0.11 [-0.21, -0.01]). However, for [u], F3 was lower when preceding pharyngealized consonants compared to following them ($\beta$=-0.24 [-0.35, -0.14]).

### 3.3. Labialization vs. pharyngealization

Figure 3 compares the effects of labialization (blue) and pharyngealization (red) on F1, F2, F2–F1 and F3, showing 95% of the posterior estimates of the slopes. Both secondary articulations clearly lowered F2 in [i] and [a], with labialization exhibiting a tendency for a greater magnitude than pharyngealization.

The impact on F2–F1 was similar for both articulations in [i] (labialization: $\beta$=-1.17 [-1.35, -0.99], pharyngealization: $\beta$=-1.06 [-1.24, -0.88]) and [a] (labialization: $\beta$=-0.75 [-0.93, -0.57], pharyngealization: $\beta$=-0.71 [-0.89, -0.53]) and that is already observable in the summary statistics for [i] (labialization: 676 Hz, pharyngealization: 642 Hz) and [a] (labialization: 480 Hz, pharyngealization: 455 Hz). This similarity is also reflected, in a striking way, in the summary statistics, with F2–F1 differences of 676 Hz for labialization and 642 Hz for pharyngealization in [i], and 480 Hz for labialization and 455 Hz for pharyngealization in [a].

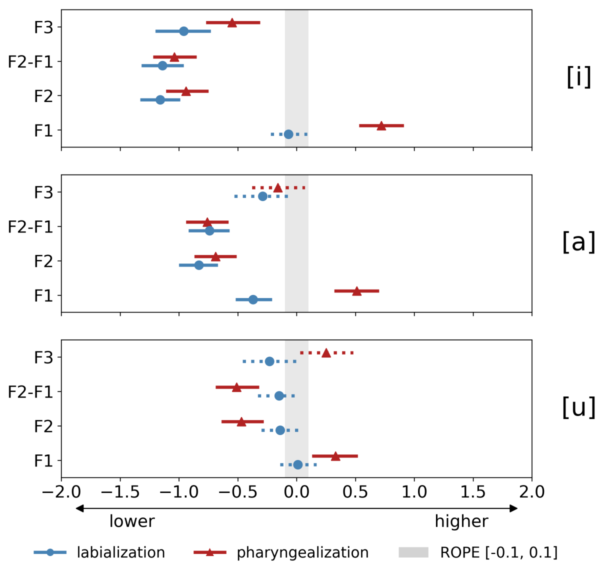


Figure 3: *95% of the posterior estimates of the slopes for labialization (blue) and pharyngealization (red) for F1, F2, F3 and F2–F1 for [i] (top), [a] (center) and [u] (bottom). The grey area represents the ROPE of [-0.1, 0.1]. Marginalized over speakers and vowel positions. Solid lines indicate statistical evidence, while dashed lines represent no clear statistical evidence.*

The most notable differences between two secondary articulations are related to F1: It was raised in all vowels adjacent to pharyngealized coronals, whereas labialization caused a lowering of F1 in [a]. In addition, [u] was affected by pharyngealization but not by labialization, as indicated by the strong overlap of the formant values in Figure 1.

## 4. Discussion

The present study revealed striking similarities in the formant patterns of labialization and pharyngealization in Tashlhiyt, but also differences depending on specific formants and vowel quality. A shared characteristic of these secondary articulations is their impact on F2, which serves as their primary acoustic attribute: Both labialization and pharyngealization lower F2 in adjacent vowels, aligning with findings from previous studies on a variety of languages (e.g., [6, 17, 28, 37, 12]). As a consequence, the formant difference F2–F1 is smaller for both labialized dorsals and pharyngealized coronals compared to their plain counterparts. Importantly, the magnitude of the F2–F1 differences in both labialization and pharyngealization display a strong overlap. In addition, these acoustic effects occur in both the preceding and the following vowel - for both secondary articulations. A further similarity involves their patterned influence on F2 and F2–F1 across vowel qualities: [i] exhibit the strongest modification in both secondary articulations, followed by [a], while [u] display the weakest effect in pharyngealized productions and no measurable effect in labialized dorsals. A key difference lies in their effect on F1: Pharyngealization raises F1 in all vowels, whereas labialization loweres F1 only in [a].

The observed equivalence and differences can be attributed to the distinct vocal tract configurations that underlie these secondary articulations. According to [38], a backward movement of the tongue towards the pharynx lowers F2 and slightly raises F1, while lip protrusion lowers all formants. The pattern of a raised F1 and a lowered F2 in pharyngealization is thus a direct consequence of the backward movement of the tongue towards the pharynx. Similarly, the clear lowering of F2 and the tendency for F1 and F3 to be lowered by labialization can be explained by tongue backing and lip protrusion. The stronger lowering of F2 in labialization compared to pharyngealization may result from an additional enhancing effect of lip protrusion. As a result, F2–F1 values are similar between labialization and pharyngealization: While F2 and F1 approximate in pharyngealized consonants, the stronger F2 lowering caused by labialization offsets any slight lowering of F1, leading to a comparable effect on F2–F1.

Vowel-specific differences between the secondary articulations for [u] may stem from phonological or phonetic factors. Phonologically, labialized consonants and [u] do not naturally co-occur within the same word in Tashlhiyt ([29]), which may have led speakers to produce [uCu] sequences instead of [uC$^{w}$u]. Phonetically, [u] inherently exhibits lip rounding and a posterior tongue position, aligning with the articulatory and acoustic features of labialization.

In summary, labialization and pharyngealization are produced with different articulatory mechanisms, but share striking similarities in their effects on F2. However, a direct equivalence between the two, especially in the same language is challenged by more nuanced differences, such as their effect on other formants beyond F2 and their interactions with different vowel qualities.

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