

Phonetic Features of the PIE “Laryngeals”: Evidence from Misperception Data of Modern Postvelars*

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1. Diachronic change and synchronic misperception

Patterns of misperception can provide an additional line of evidence which may be useful in reconstructing sound changes, particularly for sounds which are uncommon enough that there are few securely reconstructed changes involving them, such as pharyngeals. There are many parallels between misperceptions of sounds and sequences in laboratory experiments and attested historical changes, as the same factors that produce synchronic patterns can also lead to diachronic shifts (Chang, Plauché, and Ohala 2001, Stuart-Smith 2004: 160-194).

The data here largely reflects listener error and thus provides a parallel for listener-driven sound change, though some of the patterns of misidentification found in this study are also related to properties of production. Listener-driven changes can result when listeners insufficiently or inaccurately account for contextual influence; this also can interact with variation and shifts in production (Ohala 2003: 673-677). However, diachronic developments may be the result of multiple stages of change, so impossibility of change from one sound directly into another does not exclude the possibility of development from one into the other via intermediate changes.

In particular, data from misperception of postvelars and the influence of phonological environment may help elucidate phonetic qualities of the Proto-Indo-European “laryngeals.” Due to the limited evidence for them, how best to characterize the laryngeals remains an open question. In this paper, I present results from a misperception experiment in combination with reconstructed behaviors of the laryngeals, to evaluate their possible characteristics.

2. The Proto-Indo-European Laryngeals

The laryngeals are three reconstructed consonants in Proto-Indo-European which seem to have largely been lost or resulted in vowels in the descendant languages, with consonantal reflexes only in Anatolian and potentially reflected in certain positions elsewhere. As Anatolian is widely believed to be the earliest daughter to branch off of the rest of Indo-European (cf. e.g. Chang et. al. 2015: 195), the

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different outcomes in that branch may reflect an innovation within Anatolian or within Nuclear PIE.

The phonological characteristics of the laryngeals has been debated: it is not clear what their phonetic character was, whether pharyngeals and glottals (e.g. Beekes 1994: 450), or further forward in the vocal tract, uvulars or velars (e.g. Lindeman 1992: 163-4), or a mix (e.g. Rasmussen 1983: 374-378). However, they are most frequently reconstructed as postvelars, so perception patterns of postvelar consonants will provide data for the most likely candidates.

The laryngeals behave like each other phonotactically, which is also generally the same as how *s behaved, including forming clusters with stops, while stops generally did not form clusters with each other morpheme internally, indicating that the laryngeals were likely fricatives (Weiss 2011: 50). However, the laryngeals also differed from *s in some behaviors: e.g. laryngeals and glides participated in the loss and compensatory lengthening process of Stang's law. This is consistent with the sometimes difficult to classify manner of articulation of pharyngeal and glottal consonants (cf. McCarthy 1994: 193-5), while uvulars generally pattern like other consonants, as seen in Salish (Kuipers 1981: 324-8).

When laryngeals were adjacent to a resonant with consonants on either side of them (i.e. CRHC), the resonant became the syllable nucleus; the second of two equally sonorous elements in PIE would be syllabified in this environment, indicating that the laryngeals were less sonorant than the resonants (Szemerényi 1999: 127-128). Though laryngeals are generally accepted to have been consonants, a different tack is taken by Reynolds, West, and Coleman (2000), who suggest that the laryngeals were prosodically weak vowels; while this is potentially consistent with much of the phonological data, the development into consonants in Anatolian poses a challenge to explain. However, it seems that the laryngeals did have syllabic realizations; syllabic obstruents are rare but attested elsewhere, e.g. in Berber. The variable manner of articulation of pharyngeals, which can be realized as fricatives and approximants in the same language (McCarthy 1994: 194-5), makes them better candidates for syllabicity.

Part of the motivation of reconstructing the laryngeals as pharyngeal is their sonorous behavior synchronically and diachronically, in combination with their more obstruent-like behaviors elsewhere. However, the three distinct vocalic reflexes of the laryngeals in Greek provide a challenge for this explanation, as the parallel behavior of the three laryngeals cannot be attributed to a merger to pharyngeal place. A pharyngeal *h₁ is unappealing both because it behaves differently from the other laryngeals in several ways and also because a contrast of more than two pharyngeals is typologically rare. However, realizations of /h/ and glottal stops with vocalic characteristics are attested (cf. Pierrehumbert and Talkin 1992), so glottal place is possible.

The second and third laryngeals are often reconstructed as pharyngeals, based on their synchronic effects on other sounds, diachronic outcomes, and non-Indo-European parallels, particularly in Semitic (e.g. Keiler 1970: 47-56), though recent works have increasingly also looked at North American languages and others (e.g. Beekes 1989: 29-32, Vine 2002[2006]: 294-5). Postvelar sounds cause vowel changes in many languages, often producing a lowering or backing effect; however, the coloring effects of the laryngeals do not specifically support any particular place of articulation within the postvelars, as it is attested both for uvulars and pharyngeals, though true glottals do not affect neighboring vowels (McCarthy 1994: 223-5).

The first laryngeal is often reconstructed as a glottal, based on its lack of coloring on neighboring vowels and based on its loss in Anatolian while $*h_2$ and $*h_3$ are preserved (Beekes 1994: 450-1). It has been suggested that /h/ was a likely value for this consonant, based on the typological trend that languages with contrastive voicing and aspiration, as PIE had, often also have /h/ (Szemerényi 1999: 140). In favor of /ʔ/ is the lack of aspirating effect of $*h_1$, while $*h_2$ does cause aspiration. However, /h/ seems to be less perceptible than other postvelar fricatives, so being lost instead of being reanalyzed as aspiration is not an implausible development.

Because of their different outcomes in Anatolian and in other branches, it has been suggested that the laryngeals had different features in this branch. Recent work postulates a uvular stage of $*h_2$ and $*h_3$, followed by development into pharyngeals in Nuclear PIE (e.g. Kümmel 2007: 327-336), making it possible to resolve some apparent conflicts between evidence for the place of articulation of the laryngeals in Anatolian and elsewhere. This would explain why the Anatolian reflexes are decidedly consonantal, as is typical of dorsals, while reflexes in other branches have sonorous qualities more typical of pharyngeals.

Anatolian preserves consonantal outcomes of $*h_2$ and $*h_3$, spelled with the series of signs with the consonant transliterated as ḫ. $*h_2$ is regularly preserved as ḫḫ, in which doubling represents voicelessness; in some conditions $*h_3$ is continued as a voiced sound indicated by ḫ or is eliminated (Melchert 1994: 68-74). The signs used to write these sounds in Hittite are the same used for the voiceless dorsal fricative in Akkadian and are also spelled with dorsal fricative signs in borrowings into Ugaritic, which is evidence against them being pharyngeal or glottal, for which Ugaritic has different signs (Sivan 2001: 9-10). The Anatolian evidence suggests a voicing difference between $*h_2$ and $*h_3$; the voicing of $*h_3$ is further suggested by the voicing effect which it could have on a neighboring stop in Latin (Szemerényi 1999: 125). On the other hand, $*h_1$ is not continued as Hittite ḫ (Eichner 1973: 53-6).

Whether or not $*h_1$ was preserved at all in Anatolian remains a controversial topic. Kloekhorst (2004) has proposed that $*h_1$ had a continued

consonantal reflex in Luvian based on the distribution of the two *a* signs in hieroglyphic Luvian, which he interprets as reflecting a consonant continuing *h₁. Melchert (2010) critiques this interpretation, because spelling of the same word can alternate between *a* and *á*, even within a text, and thus that the difference between them is likely not phonological. Simon (2012) offers an account of Lydian developments in favor of early preservation of some instances of word initial *h₁ word initially, noting that the overlapping usage of these signs only appears within later texts.

3. Perception Experiment

Participants were 14 native speakers of Arabic (9 Levantine, 5 other) and 16 native speakers of American English, with at least 6 months experience studying Arabic. All listeners reported normal hearing.

Stimuli were produced by two male native speakers of Arabic (Palestinian and Iraqi dialects), recorded in a sound attenuated booth. The consonants included the seven postvelar consonants of Arabic: /q/, /χ/, /ʁ/, /ħ/, /ʕ/, /h/, and /ʔ/; 3 “emphatic” consonants /t^ʕ/, /d^ʕ/, and /s^ʕ/; and 10 oral consonants: /w/, /t/, /d/, /s/, /z/, /r/, /l/, /dʒ/, /j/, and /k/.

Each stimulus was mixed with masking noise, beginning 100 ms before the stimulus and continuing 100 ms after the stimulus. Half of the listeners heard pink noise, in which intensity is inversely proportional to frequency; the other half heard blue noise, in which intensity is proportional to frequency.

The listeners saw an array of buttons of nonce words written in the Arabic script, listened to stimuli, and clicked the button corresponding to the word which they thought they heard. The order of stimuli was randomized within blocks.

In the first task, stimuli were nonce words with syllable shapes of CV¹ and ?VC; there was alternation between blocks of CV stimuli and blocks of ?VC stimuli. The vowel cycled between blocks among each of the three contrastive Arabic vowel qualities: /i:/, /a:/, /u:/, producing six combinations of consonant position + vowel. Within a block, the only variation was which consonant was heard. All 20 consonants were included in this task.

In the second task, there were 42 buttons; the button array and the stimuli reflected a mix of syllable structures, to test perceptual errors in structure. Syllable shapes were ?VC, ?VRC, ?VRV, and ?VRəC. There were no vowel-initial stimuli used in this experiment, as Arabic words never begin with a vowel. Due to constraints of array size and time, a smaller set of consonants was used in these blocks: /w/, /t/, /d/, /s/, /r/, /l/, /j/, /k/, /q/, /χ/, /ʁ/, /ħ/, /ʕ/, /h/, and /ʔ/. The liquids and glides did not appear as the second consonant in biconsonantal forms.

¹ C = any consonant, V = any vowel, R = a liquid ([l] or [r])

3.1 Comparative Patterns in Confusions, Change, and Stability

The first step in using synchronic misperception as evidence for the diachronic change is to establish a correlation between perceptual confusions and attested historical changes. For this purpose, I collected the outcomes of postvelars in several language families: Afro-Asiatic, Salish, Khoisan, Haida, Quechua, Caucasian, Austronesian, Tai, Nootka, and Nakh-Daghestani. Data for each postvelar consonant as a starting sound and the percent of each outcome were collected and combined in a matrix prior to the perception experiment, to avoid potential bias in selecting representative languages.

These language families were selected to represent unrelated languages containing postvelar consonants, chosen foremost to capture the language families in which pharyngeals exist or are reconstructed,² as well as a selection of language families with other postvelar consonants, focusing on families with large postvelar inventories, as the place characteristics of postvelar consonants may depend on how extensively the postvelar region is used within the phonological inventory (Rose 1996). Wherever possible, I grouped languages by subfamily in order to reduce overrepresentation of changes which occurred at a shared stage.

While there is definite value in the typological survey of sound changes collected e.g. by Kümmel (2007) and Simpson (2003), the small set of language families in which pharyngeals sounds can be clearly reconstructed may be an issue for establishing a typology of pharyngeal changes, as directionalities can differ between language families due to inherited phonetic characteristics and phonological inventories. Furthermore, in some families with pharyngeals, there is disagreement or uncertainty over which sound(s) should be reconstructed. For instance, in Salish, where there is a correspondence between pharyngeals and uvulars, some scholars are explicitly ambivalent on which is original (Czaykowska-Higgins and Kinkade 1998: 50-4).

Table 1 presents a summary of the developments of the postvelars in the languages surveyed. Table 2 presents a summary of the native Arabic listeners' responses in the perception experiment. Percents are given to facilitate comparison, as not all of the sounds are similarly frequent in reconstructed inventories.

The correlation between the matrix of diachronic outcomes of postvelar sounds and the matrix of native listeners' confusions within this study is significant: $r(77) = 0.83$, $p < .001$. Omitting cells of diachronically stable sounds and accurately identified sounds, $r(70) = 0.45$, $p < .001$.

² This was motivated because pharyngeals are the rarest postvelar sounds; moreover, almost all languages with pharyngeals also have other postvelars.

	t/d	k	q	χ	κ	ħ	ʕ	ʔ	h	a	∅
q	--	11	57	6	--	6	6	6	8	--	--
χ	--	22	--	47	3	19	--	--	9	--	--
κ	--	--	3	14	39	--	23	9	6	--	6
ħ	--	--	--	19	--	36	3	--	26	--	16
ʕ	--	--	--	--	--	--	40	30	--	--	33
ʔ	--	--	--	--	--	--	4	67	4	--	25
h	--	3	--	--	--	12	--	6	53	--	26

Table 1: Diachronic Development Matrix for Postvelar Consonants (as percents)³

	t/d	k	q	χ	κ	ħ	ʕ	ʔ	h	a	∅
q	1	9	65	5	6	--	1	4	--	--	1
χ	3	--	4	75	5	2	--	2	2	--	3
κ	2	--	1	1	76	--	3	--	1	--	5
ħ	1	1	2	3	--	74	5	3	4	--	4
ʕ	--	1	4	1	--	2	67	15	2	1	5
ʔ	3	1	2	--	1	--	5	71	4	1	7
h	3	1	3	7	3	20	2	6	44	1	8

Table 2: Arabic Listeners' Identifications of Postvelar Consonants (as percents)⁴

³ Rows give reconstructed segments; columns give frequency of each outcome in descendant languages (e.g. *q became /k/ in 11% of languages surveyed, remained /q/ in 57% of them).

⁴ Rows give the stimulus consonant and columns give the frequency of each response for that consonant (e.g. /q/ was correctly identified as /q/ 65% of the time, identified as /χ/ 5% of the time, etc.). Rows may not add up to 100; uncommon and uninformative responses were omitted.

The high correlation demonstrates that synchronic misperceptions may be useful in evaluating the likelihood of particular sound changes, in combination with other evidence, despite the limitations of looking only at perception-based change and potential skewing due to the unnaturalness of synthetic masking noise. The absence of misperceptions between a pair of sounds certainly does not mean that a diachronic change between them is inexplicable.

This correlation justifies making a comparison between the common confusions and directionality within this data and previous observations on commonness of sound changes involving these sounds.

3.2 Experimental results relative to the Laryngeals

The patterns of confusions made in this study between consonants, the influence of phonological environment on those confusions, and the directions of confusions can be compared to some of the changes in the PIE laryngeals, providing a new line of evidence for the reconstruction of the phonetic qualities of these consonants and the pathways by which they changed.

3.2.1 Word-Final Postvelar Loss after Vowels

Laryngeal consonants in PIE were lost in some environments where other consonants were not; in this experiment, more stimuli were misidentified as not having laryngeals than were misidentified as lacking other consonants. Some of the particular environments in which the PIE laryngeals were lost were not tested here, to focus on testing variables suited to a forced-choice task.

One of the environments which was included in this study was word-final position following a vowel. In Proto-Indo-European, laryngeals were lost with no compensatory effects in this environment when the word was also the end of a high-level prosodic unit, perhaps the Intonational Phrase; in vocatives, which are usually phrase-final, the loss has been morphologized (Kuiper 1947: 210-2), e.g. OCS nom. sg. *žena* ‘woman’ < $g^w enah_2$ < $**g^w eneh_2$, but voc. sg. *ženo* < $*g^w ena$ < $**g^w eneh_2$.

Evidence for this loss in Anatolian is obscured by the more general loss of word-final $*h_2$ and by analogical restoration of word-final h in imperatives of roots ending in this sound (Oettinger 2002: 547); $*h_3$ was uncommon in roots attested in Anatolian, so much of the evidence for its outcomes is debated (Melchert 1994: 71-4). Thus it is not clear how this change should be timed relative to possible shifts in the place of articulation of these laryngeals and the split between Anatolian and Nuclear PIE.

In this study, stimuli were produced in isolation, not within sentences, and were heard individually, producing the same context as found in vocatives and

thus making excellent conditions for comparison. Table 3 gives the number of losses of each consonant in this environment.

	Native Listeners (trials = 84 per C)	Non-native Listeners (trials = 96 per C)
t	5	2
d	0	6
s	3	3
k	4	5
q	1	4
χ	6	7
ʁ	3	5
ħ	7	14
ʕ	11	21
ʔ	17	29
h	13	22

Table 3: Consonant Deletions Word-Finally After a Vowel

Postvelar consonants were frequently not perceived by native listeners word-finally after a vowel (10% of trials), which was much more than other consonants (4%); a χ^2 test, with Yates' continuity correction, demonstrates that the difference is significant ($p < .01$). While the implications of the data from non-native listeners are less clear, they follow essentially the same pattern. This is consistent with a reconstruction in which only postvelar consonants were lost in *in pausa*, while others were preserved. The most frequent loss in both listener groups was the glottal stop, followed by /h/ and /ʕ/.

The realizations of /ʔ/ in this environment differed between the two speakers; the Palestinian speaker produced it with an abrupt closure, a long pause, and a release burst, while the Iraqi speaker produced it with creakiness on the preceding vowel, a brief closure, and a release burst. The Palestinian speaker's prototypical glottal stop was neglected in this environment more frequently (29%

of ?VRəC trials) than the Iraqi speaker's realization (10%), perhaps because his creakiness provided an additional cue that a consonant was present.

The realizations of the voiced pharyngeal /ʕ/ also differed in this environment between the two speakers; the Palestinian speaker produced it as a voiced stop followed by a release burst, while the Iraqi speaker produced it with creakiness on the preceding vowel and a brief or incomplete closure, followed by frication. /ʕ/ in stimuli from the Palestinian speaker was neglected much more frequently (23%) than in stimuli from the Iraqi speaker (3%). Greater perceptibility of pharyngeals with a more fricative-like realization is also consistent with the smaller number of errors neglecting the presence of the voiceless pharyngeal fricative /ħ/.

These results are most consistent with reconstruction of glottal or pharyngeal place for the PIE laryngeals, as the uvulars were neglected at frequencies similar to that of other consonants. Within the pharyngeals, the results suggest fricatives rather than stops.

However, the misperception results in combination with the acoustic analysis of the stimuli also make clear the importance of considering not just the phoneme but its specific phonetic characteristics to decide how perceptible a consonant is in particular positions.

3.2.2 Word Final Postvelar Loss after Liquids (& the Saussure Effect)

Another consideration for comparison to the patterns of the PIE laryngeals is the effect of liquid and vowel environments. Laryngeals were lost before a resonant followed by *o (HRo) in the same syllable, or when preceded by oR (oRH) in the same syllable (Saussure 1905; Nussbaum 1997). In addition to clear evidence in several other branches, there is more dubious evidence for this effect in Anatolian (Kümmel 2012: 310-1).⁵

This phenomenon shows that there was some interaction between laryngeals and non-adjacent vowels, although coloring of PIE laryngeals only affected adjacent vowels. The resonants were transparent for the phonological characteristic responsible for this phenomenon, though not for vowel coloring, which suggests that a different characteristic is active in each. Some characteristic of the /o/ must interact with the laryngeals; as back vowels often involve a pharyngeal or tongue retraction gesture, also present in postvelars, it may have been a dissimilation effect based on misattribution of this feature. The

⁵ Some scholars question whether this effect really was present, as its conditions are phonetically strange and many of the pieces of evidence could potentially be explained in alternative ways (e.g. Pronk 2011, van Beek 2011). The results of this study neither confirm nor disprove the reality of this phenomenon.

relevant phonological characteristic must also be shared among the three laryngeals, as they all exhibit the same effect.

While Arabic does not contain /o/, its vowels may contain the relevant feature. The most appealing comparison is /a/, because PIE *o seemed to be rather low, and merged with *a in many daughter languages.

An alternative explanation posits that the conditioning was the result of +ATR interaction of the vowel and the laryngeal, based on the theory that *o may have been the only tense vowel within PIE, to explain some of its long outcomes (Keydana 2012: 136-139); however, the length associated with *o can also be explained as the result of its roundness and lowness. Furthermore, while retracted tongue root has been proposed as a distinctive feature on some postvelars, the tongue root is not involved in glottal consonants.

	a	i	u	Overall
t	2	7	3	12
d	4	6	7	17
s	0	0	0	0
k	2	7	1	10
q	1	3	0	4
χ	1	4	3	8
κ	3	6	7	16
ħ	6	2	2	10
ʕ	3	4	3	10
ʔ	4	6	3	13
h	8	10	3	21

Table 4: Arabic Listeners' Consonant Deletions Word-Finally after a Liquid (30 trials per consonant+vowel combination)

Table 4 gives the number of losses of each consonant by vowel environment. There is no significant difference in post-liquid consonant deletion by vowel environment. The only consonant that was lost more when the vowel

preceding the liquid was /a/ is /h/; as this is the environment which best mimics the environment for the Saussure Effect, it weakly supports reconstruction of /h/ as one of the laryngeals, most likely $*h_2$.

While overall loss in after liquids was particularly common for several postvelars, there was no significant difference between frequency of loss of postvelars (16%) and other consonants (14%), though loss of /h/ was particularly common. These results do not strongly suggest any particular features to be reconstructed for the laryngeals. What characteristics for the PIE laryngeals this data supports depends on which vowel characteristic we think is most important for conditioning this phenomenon; moreover, the lack of clear pattern might reflect the absence of an Arabic vowel with the necessary set of features to condition this effect.

3.2.3 Consonants Perceived as Vowels & Other Vocalization Pathways

There are vocalic reflexes in the positions of the laryngeals in many branches of PIE. One important question regarding these vocalic reflexes is whether the vowels are the direct outcomes of the laryngeals themselves, developing from environments in which they were syllabic, as was suggested in the original formulation by Saussure, and continues to be the preferred explanation for some scholars (e.g. Beekes 1989: 24), or if they are the result of a stage of anaptyctic vowels followed by loss of the laryngeal consonants, which is the explanation that others prefer (e.g. Mayrhofer 1986: 136-146). Epenthetic vowels can differ phonetically from lexical vowels, and moreover often fail to undergo phonological processes reflected by other vowels (Hall 2011: 1582-8), so the lack of compensatory lengthening in anaptyctic vowels does not pose a problem for their reconstruction.

The misperception data from this study can be examined in relation to this question. Table 5 presents the number of times each consonant was identified as a vowel; most consonants were never confused with vowels, and have been omitted from the table. Misperception of consonants directly as vowels is observed, demonstrating that such change is possible even among native listeners.

There were more confusions of postvelar consonants with vowels among non-native listeners than native listeners; misperception of postvelar consonants as vowels has been observed previously as a misperception exhibited by listeners whose native language lacks such consonants, but not associated with vocalic behavior of those consonants among native listeners (Bessell 1992: 93-5).

However, such misperceptions were relatively uncommon in both groups. Only 2% of ?VRC sequences as ?VRV with postvelar consonants by native listeners (vs. 1% with other consonants; $p = .011$) and 4% of postvelar consonants were identified as vowels by non-native listeners (vs. no instances with other

consonants; $p < .01$). The particular consonants which were identified as vowels do not fall into any consistent patterns, aside from mostly being postvelar, and so do not further narrow down likely characteristics of the PIE laryngeals.

	Native Listeners (trials = 84 per C)	Non-native Listeners (trials = 96 per C)
t	2	0
ʁ	0	4
ħ	0	4
ʕ	2	5
ʔ	6	5
h	2	4

Table 5: Consonants Identified as Vowels

In coda clusters, there were differences between the speakers in the production of /ʕ/; the Palestinian speaker consistently produced it as a voiced stop, while Iraqi speaker produced it with creakiness on the preceding liquid, a brief closure, and a partially voiced release. Identifications of /ʕ/ as a vowel only occurred with stimuli from the Palestinian speaker.

The particular vowels which consonants were identified as can also be considered in comparison to the outcomes of the three PIE laryngeals as /e/, /a/, and /o/ in Greek, as /i/ in Indo-Iranian, and as /a/ elsewhere. Among the identifications of consonants as vowels, most frequently the vowel chosen was /a/. However, there were instances where /ʔ/ was identified as /i/ and cases where /ʁ/ was identified as /u/, so outcomes as non-low vowels are possible, despite the general association of postvelars with low vowels.

These results suggest that a more likely pathway to the vocalic reflexes of the PIE laryngeals may be through vowel insertion next to postvelars followed by loss of postvelars, as the frequency of both of these misidentifications is higher than the frequency of identification of consonants as vowels.

Table 6 presents the number of times stimuli were identified as having a vowel between a consonant and a preceding liquid. These results should be considered in combination with Table 3, which gives the frequency with which consonants were neglected word finally after vowels.

	Native Listeners (trials = 84 per C)	Non-native Listeners (trials = 96 per C)
s	3	10
t	5	11
d	2	7
k	3	10
q	4	13
χ	4	15
ʁ	7	15
ħ	4	11
ʕ	3	16
ʔ	13	23
h	19	25

Table 6: Inter-consonantal Vowel Insertions

Among native listeners, there was a higher percentage of vowel insertions next to postvelars (9%) than other consonants (4%); a χ^2 test demonstrates that the difference is significant ($p < .01$). Among non-native listeners this pattern is similar, with vowels perceived in 18% of clusters with postvelars, but only 11% of clusters with other consonants ($p = .012$). Perception of vowels within clusters was particularly common with glottal consonants.

The patterns of vowel insertions are most consistent with glottal place for the PIE laryngeals, in particular /h/, but the lack of clear effect with other consonants might indicate that the postvelar inventory of Arabic does not include three consonants with the same set of characteristics as the PIE laryngeals.

3.2.4 Considering rounding effects of *h₃

The rounding effect of *h₃ on neighboring *e has sometimes been attributed to labialization (e.g. Beekes 1989: 26). However, the labialized velar stops in PIE did not cause rounding, whereas generally in languages where labialized dorsals

cause partial or complete rounding on neighboring vowels, all labialized consonants exhibit the same effect, e.g. Montana Salish (Flemming, Ladefoged, and Thomason 2008: 467-8) and Ennemor (Prunet 1991: 1234). The lack of Hittite spellings indicating labialness of reflexes of *h₃ also casts doubt on the labial character of this sound in PIE.

Within this study, the large number of confusions between /w/ and /ɸ/ is potentially consistent with the rounding effects of the third laryngeal. However, these confusions were dependent on interaction with a neighboring vowel that was already round. Among native listeners, /ɸ/ was identified as /w/ 23% of the time in stimuli where it was adjacent to /u/; however, in other environments, this confusion was not observed.

The acoustic effects of uvulars on vowels are similar to the effects of labialization, with lowered F2; confusions could be largely based on acoustic effects, with no actual labialization on the consonant. However, there is also a slight downward transition of F1 in recordings of Arabic /ɸ/, which is a characteristic associated with labialization, so this sound may be somewhat labialized. For comparison, the dorsal consonants in Moroccan Arabic have developed labialization in environments where a neighboring /u/ has been lost (Zeroual, Esling, and Hoole 2011: 277-280). The amenability of /ɸ/ to being perceived as labial may be evidence in favor of reconstructing *h₃ as a voiced uvular fricative.

3.2.4 Asymmetry of confusions and directionality of change

There are several possible pathways for the genesis and elimination of different postvelar sounds, though some pathways are typologically much more common. When the sounds being produced by a change are not already within a language's phonological inventory, the most likely pathways are uvulars > pharyngeals and pharyngeals > glottals. However, Simpson (2003: 9-13) has noted that while this directionality holds strongly when the sounds being produced by the change are not already present within a language's phonological inventory, it is weaker in cases of merger; misperception patterns provide a parallel for mergers.

Table 7 indicates asymmetries in confusions between postvelar consonants, pooled across all environments; p values are the result of χ^2 tests comparing accurate responses, responses of the other sound in the pair, and all other responses. For all pairs of sounds in which both native listeners and non-native listeners exhibited a significant directionality, the more common direction was the same for both groups, which is evidence in favor of the directionality being due to how listeners interpret the incoming cues from the respective sounds, instead of being a pattern particular to a certain type of listener. However, there were some pairs of sounds for which only non-native listeners showed a

significant directionality; these patterns, in the absence of a corresponding pattern among the native listeners, may be more relevant for considering adaptation in borrowings.

	Native Listeners	Non-native Listeners	Directionality
h ~ ħ	< 0.0001***	< 0.0001***	h > ħ
ʕ ~ ʔ	< 0.0001***	< 0.0001***	ʕ > ʔ
χ ~ h	< 0.0001(***)	< 0.0001(***)	neither
χ ~ ħ	0.94	< 0.0001(***)	neither
ʁ ~ ʕ	0.0013(**)	< 0.0001(***)	neither

Table 7: P-values for Asymmetry, Selected Sound Pairs⁶

Between the glottals and pharyngeals, the pattern of asymmetry depended on the particular sound. /h/ was more frequently identified as /ħ/ than the converse for both listener groups, in most phonological environments, which is counter to the generally posited directionality of place of articulation change among postvelar consonants, that the more likely direction of change is from pharyngeals to glottals (Kümmel 2007: 218, 245; Simpson 2003: 10). For native English speakers, this directionality in part may be reflecting the illicitness of /h/ in codas in English; in onset positions, the directional asymmetry was inverted for these listeners, with more identifications of /ħ/ as /h/. However, for native Arabic speakers, the difference between these environments was not significant.

The directionality between /ʔ/ and /ʕ/ was in the direction from pharyngeal to glottal, as predicted, but only reached significance for non-native listeners. An asymmetry among native listeners was apparent in certain environments: /ʕ/ was identified as /ʔ/ in 33% of its occurrences in coda clusters, while the converse occurred only 5% of the time. The difference was not present in codas of monosyllabic forms (11% vs. 10%, respectively).

Directionality between uvulars and pharyngeals, which is also posited to be more frequent in the backing direction, was not seen. Confusions between sounds with these place of articulation in either direction was relatively uncommon, likely because the cue of backed and lowered vowel allophones adjacent to uvular consonants was used to distinguish between these consonants;

⁶ Where the asterisks marking significance are in parentheses, the significance was mainly due to differences in confusions with sounds outside the pair.

in a language without this confounding vowel cue, patterns in directionality might become apparent.

Disagreements between the results of this study and certain aspects of existing typologies for postvelars warrant further investigation both in experimental misperception and in building typologies for rare segments; they may suggest that the typology for directionality in cases of merger is weaker than is suggested by the small set of existing languages which provide evidence for developments of pharyngeals, but may also reflect biases due to the experimental form or the particular phonological system of Arabic.

4. Conclusions

There was a strong positive correlation between the perceptual confusions found in this study and attested patterns of diachronic change, which strongly demonstrates the potential value for comparisons between experimentally-elicited misperception and diachronic change, particularly as a new line of evidence for evaluating reconstructions of cross-linguistically uncommon sounds.

Based on the results of this study, I add a new line of evidence for the view that vocalic outcomes of PIE laryngeals were the result of vowel anaptyxis next to laryngeals and subsequent laryngeal loss, rather than direct vocalization of the laryngeals themselves.

While the misperception patterns found here do not clearly favor a particular set of values for the PIE laryngeals, they are most consistent with glottal and pharyngeal values, and potentially also consistent with an earlier uvular stage of **h₂* and **h₃*. There remains great potential for further work seeking to experimentally replicate a range of reconstructed behaviors of the PIE laryngeals, both using Arabic and using other languages with different inventories of postvelar consonants, which could clarify which patterns of perceptual confusions reflect language-specific biases and which reflect intrinsic perceptual possibilities of the sounds being investigated.

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