Vowel quality and duration in Yukon Deg Xinag*

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1 Background

Deg Xinag is an Athabaskan language spoken in the western interior of Alaska. The Yukon dialect is the traditional language of the villages of Anvik, Shageluk and Holy Cross, although as of 2009 there are no longer any speakers living in Anvik and Holy Cross.¹ The language has also been known as Ingalik (e.g. Osgood 1940) and more recently as Deg Hit’an (Krauss 1974).²

1.1 Consonant inventory

The inventory of consonants found in Yukon Deg Xinag is given in (1)-(3) in both IPA (in //) and orthographic representations (in <>). (1) contains consonants which can occur in syllable-initial position.³ The Deg Xinag inventory is ‘large’ from a cross-linguistic point of view (Maddieson 2005), even when two of the 44 consonants in (1) (/p pʰ/), found only in loan words) are removed. Compared to other languages of the family, Deg Xinag also has ‘a rather full Athapaskan consonant system’ (Krauss 1962). The large number of places of articulation in the Yukon Deg Xinag consonant inventory is due to the fact that the Proto-Athabaskan *g⁷*-series has not merged with any other sibilant series in Deg Xinag (Yukon dialect),⁴ and the *k⁷*-series has developed into both /k/ and /ʧ/ in an apparently unconditioned split.⁵

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²I am deeply grateful to Yukon Deg Xinag native speakers James Dementi, Raymond Dutchman, Lucy Hamilton, Edna Deacon, Phillip Arrow, the late Alta Jerue, the late Katherine Hamilton, and the late Hannah Maillelle for their willingness to work with me on this and other projects.

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⁴A very small amount of data from the Kuskokwim (K) dialect is cited in this paper. However, unless accompanied by ‘(K)’, all data in this paper are from the Yukon dialect.

⁵“Deg Hit’an” rather than “Deg Xit’an” is a somewhat unfortunate spelling choice. Xit’an is the orthographic representation of /χot’an/ ‘people of (area)’, a nominalized verb form. There is no contrast between /ʧ/ and /h/ in the verb prefixes of Deg Xinag, and acoustic evidence indicates that the normative pronunciation in that context is [χ] rather than [h] (Wright et al. 2008).

⁶I use two transcription systems in this paper to make the information accessible to non-Athabaskanists (who would presumably prefer IPA) as well as Athabaskanists, who are used to viewing the syllable-initial voiceless unaspirated stops and affricates with “voiced” symbols. Throughout this paper IPA is given in [] or //; orthography is italicized or placed in <>. The Deg Xinag practical orthography was designed by Krauss 1962 and further modified by Kari 1974.

⁷The basic contrasts of the Proto-Athabaskan consonant and vowel inventories were worked out by Krauss 1964, but see Leer 2005 for the latest version of the Proto-Athabaskan segment inventories. This paper generally uses Leer’s

Krauss 1962 notes that the Deg Xinag palato-alveolar affricates ‘correspond with those in other languages which show front or unrounded vowels’, whereas the velar stops correspond ‘with forms in other languages which show back or rounded vowels or PAstructurally labialized consonants in final position.’ However, he also notes that ‘more work will have to be done before the differentiation can be explained completely.’

Most reconstructions cited in this paper are taken from the Comparative Athabaskan Lexicon (Leer 2006-2010), although in place of Leer’s ‘O’P’- (indicating possessive prefix to noun required) I simply have a hyphen in front of reconstructed nouns, and in place of ‘O’P’- to indicate object of postposition prefix required, I simply use ‘P’, as in Kari 1990. I retain Leer’s ‘O’- to represent a verbal object prefix (standard in Athabaskan linguistics), and his ‘=’-, representing a clitic (or disjunct verb prefix) boundary.

The Comparative Athabaskan Lexicon was compiled over a period of years, and in the first chapters completed, reconstructions are not flagged in the usual way, with ‘PA’ *. Instead, we find entries like B P O-...=za-
synchronously /dl/ also occurs word-internally in the verb prefixes (< *hə- + s- conjugation + h- "classifier" Leer 2000) when a coronal stop or affricate follows (Hargus 2008).

Syllable-finally there are additional contrasts in glottalization and voicing among nasals and glides.

(3) Nasal and glide contrasts (syllable-final position)

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The glottalized sounds in (3) appear restricted to word-final position, where they may be analyzed as clusters (/m’/ etc.). The voiceless sonorants in (3) are mostly restricted to word-final position with the exception of [ŋ], which is also synchronically attested word-internally. 8 Historically, glides and nasals were devoiced in word-final position unless a vowel followed (Krauss 1962, Leer 2008), the vowel preserving the original voicing of the sonorant. This is the same process that resulted in innovative voicing contrasts among stops and affricates in that position, as seen in (2).

1.2 Vowel inventory

Krauss 1962:25b noted that Deg Xinag has the set of vowel phonemes in (4), a ‘rather peculiar system of full vowels, characterized by a complete lack of close vowel phonemes’:

\[ t-a: \text{‘mistrat, abuse O’}, \text{where the ‘B P’ in front of the reconstructed form indicates that reflexes are attested in the B (= British Columbian) and P (Pacific Coast) subbranches of the family. I have nonetheless treated such forms in this paper as PA reconstructions, even when not explicitly labeled as such by Leer.} \]

\[ ^7\text{When reflexes of PA words are given in this paper, the DX gloss of the lexical item is omitted if the PA word has not undergone any semantic change.} \]

\[ ^8\text{Word-internal [ŋ] nh occurs in denhch’i ‘four’, vanhgiq ‘Indian ice cream’, venhdi(da’) ‘tomorrow’, ganhdliit ‘cooked berries’, xonhdzoghdl ‘green-winged teal (honhdzighudl, Kari 1978), -anhecin ‘wrist, forearm’, -anhtse ‘nose’, and -anhc’it ‘nostril’. In vanhdong ‘this morning (past)’ and niṅgidinghdi ‘here and there’, -dong ‘past (time)’ and -di ‘(place) where, (time) when’ were originally suffixes.} \]
Deg Xinag vowel phonemes

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Deg Xinag is thus one of the few Athabaskan languages which lack both vowel phonemes /i u/. Another such language is Hupa (Golla 1970, Gordon 1995), with three basic quality distinctions whose realization depends on whether the vowel is short or long:

Hupa vowel phonemes

- e: ɪ
- o: o
- a: a

Vowel systems like those of Deg Xinag and Hupa run counter to those of the majority of the spoken languages of the world, which tend to have vowels which are evenly and widely dispersed, as noted by Liljencrants and Lindblom 1972 and much subsequent work. To consider just how unusual Deg Xinag is, in a typological study of the vowel systems in the UCLA Phonological Symbol Inventory Database (UPSID), a genetically controlled sample of 317 of the world’s languages designed by Ian Maddieson, Disner 1984 noted only four languages in the database that lacked high vowels: Tagalog with /ɪ ø ʊ/, and Squamish, Alabama, and Amuesha with Deg Xinag-like /e a o/.

The Deg Xinag lower-high vowel /ʊ/ is restricted in distribution, mainly occurring next to uvulars (e.g. /qʰʊn'/ (qun') 'fire'; /ðuq/ (dluq) 'laughter'). Krauss 1962 noted that ‘the Ingalik /ʊ/ appears only in context with back velars, so far as the somewhat limited data indicate…’ Krauss and Golla 1981: 73, also thinking that Deg Xinag /ʊ/ occurs only next to uvulars, stated that ‘[Ingalik] also distinguishes PA *qʰ from *q next to a reduced vowel,’ interpreting (e.g.) [qʰʊn'] as [qʰwʊn'] and [thʊq] as [thœqʰ]. However, as noted by Krauss 1962, the [qu]-as-[qʰ] analysis essentially trades one limited distribution for another, as putative /qʰ/ would only occur next to /w/. A more serious problem for this analysis is the existence of some instances of [ʊ] next to consonants of places of articulation other than uvular. An exhaustive list of lexical items containing [ʊ] not adjacent to uvulars in Deg Xinag is given in (6):

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9 Orthographic equivalents of the vowels, where different from phonetic symbols, are /i/ = <i> and /u/ = <u>.
Deg Xinag [ʊ] not adjacent to uvular\textsuperscript{10}

/\textipa{k}ul\textipa{a}/ (\textit{kula}) \quad \text{‘poor thing’}
/\textipa{t}\textipa{od}ul/ (\textit{dikul}) \quad \text{‘gratitude’ (?)}
/\textipa{th}\textipa{ok}\textipa{u}/- (\textit{thik} ‘u-’) \quad \text{‘uphill, into woods’}
/\textipa{x-k}\textipa{u}\textipa{O-l\-}\textipa{ʔaŋ}/ (\textit{x-k\textipa{u}O-l\-\textipa{ʔanh})} \quad \text{‘medically assist O’}
/juk/ (\textit{yuk}) \quad \text{(listener’s expression at end of story)}
/p\textipa{b}u\textipa{s}\textipa{ɬ}/ (\textit{pusiy}) \quad \text{‘cat’}

Possible etymologies of the words in (6) are discussed in 3.2.

One point of investigation in the vowel system is the quality of the vowel transcribed [Y]. Impressionistically, this vowel is [Y] unless adjacent to uvulars, where the auditory impression is [ö]. [Y ö] are thus in complementary distribution, and since [ö] has the more limited distribution, the basic phone in this set is considered /Y/. While the uvular-adjacent allophone is investigated in the acoustic experiment described in §2, in this section I present qualitative evidence concerning /Y/e. In (7), a spectrogram of [juk], note the relatively high F1 of [ʊ], 543 Hz at the point where F1 and F2 are closest (reaching the target for [ʊ]), considerably higher than the 356 Hz F1 of the preceding glide [j].

\begin{figure}
\centering
\includegraphics[width=0.5\textwidth]{spectrogram.png}
\caption{Spectrogram and lowest three formants of [juk] (\textit{yuk}) (listener’s expression at end of story) (female speaker LH)}
\end{figure}

In (8), F1 is also not particularly low, 553 Hz (for comparison, F1 of [a] in the same token is 740 Hz).

\textsuperscript{10}See also 1.3, where I raise the possibility that [ʊ] can also occur next to laryngeal consonants, although there predicted by rule.
In neither (7) nor (8) are F1 and F2 particularly close (in general, the closer F1 and F2, the more back the vowel quality, e.g. Ladefoged 1996), indicating centralization of [ʊ] (at least in these tokens, for this speaker).

As mentioned above, the Deg Xinag vowel phonemes were worked out by Krauss 1962, who noted that the ‘system has proven a bit tricky to analyze, because of the relatively wide allophonic range of the vowels (both in quality and length)’. Krauss 1962:25c noted a particularly large set of allophones for /ə/: ‘[i], unless /t t’/ precedes, then it is [ə], unless back velars precede or follow or /m/ follows; then it is [ʌ], unless /dʒ, tʃ, lʃ, y, ʃ, ɫ/ precedes or /ŋ, g, y/ follows; then it is [i] or [ɪ^].’ Impressionistically, the [ɪ^] allophone of /ə/ noted by Krauss 1962 can be even closer, even as close as [i]. In (9), note the very close F2 and F3 in the final syllable, characteristic of /ɪ/. F2 and F3 become ever closer, even overlapping as the vowel proceeds:

(9) Spectrogram and lowest five formants of /ʔələj/ [ʔɪli] (iliy) ‘devil’; expression of fright (female speaker ED)

[Diagram of spectrogram and lowest five formants]

[Caption: Spectrogram and lowest five formants of /ʔələj/ [ʔɪli] (iliy) ‘devil’; expression of fright (female speaker ED)]

[Note: [ʔ] is predictable in word-initial position in Deg Xinag, hence omitted from phonemic representations.]
1.3 Rounding Assimilation

I posit that Deg Xinag also has a phenomenon of Rounding Assimilation, whereby /ə/ and /o/ are neutralized as [ʊ] when a round vowel (/i/ or /o/) occurs in the following syllable and a uvular consonant intervenes:

(10) Rounding Assimilation

\[ \alpha \rightarrow o / \_ \_ \ C_{uvular} \{ o, o \} \]

Rounding Assimilation appears to be obligatory across an intervening uvular. The extent to which Rounding Assimilation also takes place across an intervening laryngeal is a topic of current research (Hargus in preparation). Jeff Leer (p.c.) reports that Koyukon has something like Rounding Assimilation as well, but its effects are not transcribed in the Koyukon dictionary (Jetté and Jones 2000), nor commented on in essays on Koyukon phonology (Marlow 2000, Krauss 2000).

Rounding Assimilation holds morpheme internally as well as across morpheme boundaries. In the data in (11), both vowels on either side of the uvular are round, and localization of the rounding to one or the other vowel cannot really be justified: 12

(11) Morpheme-internal Rounding Assimilation

\[
\begin{align*}
[\text{juxunh}] & \text{ (yuxunh)} & \text{‘you (pl.)’} \\
[\text{yuxudz}] & \text{ (yuxudz)} & \text{‘all’} \\
[\text{uxudinity}] & \text{ (uxudinity)} & \text{‘fast, quickly, early’} \\
[\text{tuq} \# (\delta, \delta) & (\text{duq} \# (\text{dh, dh})) & \text{‘ashore, up from water’} \\
[\text{xuxo}{’}in] & \text{ (Yuxo’in)} & \text{‘Flat’ (no known literal meaning)} \\
[\text{uxt}, [\text{xot}] & \text{ (xodit, uxodit)} & \text{‘they (themselves’)}
\end{align*}
\]

Some alternations induced by Rounding Assimilation are given in (12)-(13). The words in (12) all contain the progressive prefix /ʁə/:

(12) Rounding Assimilation examples: progressive prefix

a. [ʁə]- before round V, intervening uvular C

\[
\begin{align*}
[\text{te ghuqo} \#] & \text{ (te ghuqo)} & \text{‘he’s carrying water’} \\
[\text{xutl ghughu}] & \text{ (xutl ghughu)} & \text{‘a sled is moving’}
\end{align*}
\]

b. [ʁə]- before non-round V

\[
[\text{xal dhith ghigha}] & \text{ (xal dhith ghigha)} & \text{‘he’s packing a pack’}
\]

c. [ʁə]- before round V, intervening non-uvular or non-laryngeal C

\[
[\text{ghisolo}] & \text{ (ghisolo)} & \text{‘I’m walking’}
\]

\[\text{Previous transcriptions of some of the words in (11) from Kari 1978 are: yixunh ‘you (pl.)’, yixudz ‘all’. Stress generally occurs on the final syllable in Deg Xinag polysyllables ending in a consonant (see Hargus 2005), and perhaps the source of rounding in such words was attributed to the stressed vowel.}\]
The consonant preceding the reduced vowel of the progressive prefix is a uvular. Rounding Assimilation also occurs when the consonant before the vowel undergoing Rounding Assimilation is non-uvular. Alternations involving the unspecified object/possessive prefix /kə-/ (gi-) are given in (13). In all forms in (13), the vowel of the second syllable is round:

(13) Rounding Assimilation examples: unspecified object/possessive prefix

a. [ku]- (gu-) before round V, intervening uvular C
   [kuqʰul] (guqul)  ‘there’s nothing’
   [kuqʼuy] (quqʼux)  ‘(something’s) fat’
   [kuqodz] (gughudz)  ‘boat rib’
   [kuqʰod]-[kuqʰodl] (guqod–quqodl)  ‘small deadfall’

b. [kə]- (gi) before round V, intervening coronal C
   [kədɔy] (gidhux)  ‘she’s scraping something’
   [kəson] (gisonh)  ‘I’m eating something’

If it turns out that Rounding Assimilation also takes place across a laryngeal consonant, then the phenomenon is significant for discussion of the distribution of [ʊ]: the surface distribution of [ʊ] would not be limited to adjacent uvular consonant.

2 An acoustic study of Deg Xinag vowel quality and quantity

2.1 Research questions

Because of the odd position of /ʌ/ in the Deg Xinag inventory, an acoustic study was undertaken to determine whether or not the uvular-adjacent allophone is truly a short version of /o/, as auditory impressions suggest. In order to understand the position of /ʌ/ relative to the other vowels of Deg Xinag, a set of narrower research questions was devised:

(14) Research questions for acoustic study

a. What are the spectral properties of the Deg Xinag vowels?
   i. Which vowels are significantly different in normalized F1 and F2?
   ii. How does an adjacent uvular consonant affect the vowel formants?
   iii. How does an adjacent retroflex consonant affect the vowel formants?

b. Which vowels are significantly different in duration?

Disner 1984:141, in discussing the three languages in UPSID which lack /i u/ (Squamish, Alabama and Amuesha) (see 1.2), stated that ‘for these languages, and for Cheremis, which are compressed along one edge of the vowel space only, acoustic measurements are needed to determine whether near-maximal, or only adequate, dispersion is in effect.’ Thus research question (14)a.i. is designed to confirm what all previous Deg Xinag field researchers’ ears have heard: namely, that in place of /i u/ Deg Xinag has /e o/.

Justification for research question (14)a.ii. (effect of adjacent uvular consonant) is that /ʊ/ mainly occurs adjacent to a uvular consonant in DX, as discussed above, and uvulars have well-known cross-linguistic lowering and/or backing effects on vowel quality. For example, in the
evolution of Witsuwit’en-Babine from Proto-Athabaskan, high vowels \(*i:\) and \(*u:\) lowered to [e] and [o] before a uvular (Story 1984, Hargus 2007).

Justification for research question (14)a.iii. (effect of adjacent retroflex consonant) is more complex. As noted by Minoura 1993, Minoura 1994, the Proto-Athabaskan full vowels underwent a process of ‘sibilant-loss-related vowel modification’ in their development in Upper Tanana. In that language \(*i:\) and \(*e:\ > /eal/, \(*a:\ > /u:/, and \(*u:\ > /iu/; and full nasal vowels \(*\dot{i}:\ > /\dot{i}a/\) and \(*\dot{q}:\ > /\dot{q}o/).^{13}\) The change happened before sibilants, described by Minoura 1994:163-164 as the class consisting of ‘\(\dot{\theta}, \dot{\delta}, \dot{\theta}\), as well as s-, ts-, š-, tš-type sounds.’ The sibilants were then deleted, or neutralized to /h/ or /t/. Tuttle and Lovick 2008 proposed that ‘UT vowel retraction is a generalization of retraction preceding stem-final retroflexes.’ According to their historical scenario, the sibilants were all neutralized to retroflex in stem-final position in pre-Upper Tanana, with the retroflexion then responsible for the distinctive patterns of vowel modification seen in modern Upper Tanana before becoming lost. Thus, for Deg Xinag, research question (14)a.iii. investigates to what extent retroflex consonants affect vowel quality synchronically.

2.2 Method

2.2.1 Participants and recordings

Acoustic recordings were made in the field with eight adult native speakers of Deg Xinag, three male and five female. The speakers varied in age from approximately 68-80 at the time of recording. All were bilingual in English, with varying degrees of proficiency in English.

Recordings were made using either a professional CD recorder or compact flash recorder, with an AT 4041 microphone externally attached. The sampling rate at the time of recording was 44,100 Hz, later downsampled to 11,025 for analysis. Four repetitions of each token were elicited from each speaker. Sets of repetitions were recorded in random order (the same random order for each speaker).

Each target word on the vowel duration word list was embedded in a sentence context, presented to speakers using the symbols of the practical writing system. The English translation of the sentence was also included.

\[\text{(15) Sentence context for vowel duration word list (in DX orthography)}\]
\[\text{chenh \underline{_____} didaghsne’} \quad \text{“I said \underline{_____} again”}\]
\[\text{again I said}\]

Although there are some Deg Xinag publications that utilize the writing system (e.g. Kari 1978, Kari 1981, Deacon 1985, Jerue et al. 1993), only three speakers had minimal proficiency in written Deg Xinag. Some speakers could sometimes recognize the target word from the English

\[^{13}\text{Proto-Athabaskan is generally reconstructed without nasal vowels; see Leer 1979:14 for more discussion. There Leer notes that “alternatively, perhaps nasalization was a common feature of PAE” [Proto-Athabaskan-Eyak]. Note also the following PA reconstructions with nasal vowels (transcribed with subscript nasal hook); e.g. “O-q’i:ts’ “stretch O, out, limber up O” (Leer 2006-2010: q’/54), “\(d\dot{a}-q’i:ts’ “be sour” (Leer 2006-2010: q’/162), “(\(D\)-wq:ts’ “roll” (Leer 2006-2010: w/4), “O-u:- \(\dot{\imath}\) (male) copulates with O” (Leer 2006-2010: \(\dot{\imath}/25), “\(\dot{v}\dot{i}:\dot{\imath}\) “snare, net” (Leer 2006-2010: w/17).}\]
translation, but others did not have strong English literacy skills. Often it was necessary to orally prompt speakers in order for them to recognize the target word.

Preceding and following consonant place and manner of articulation was controlled for in the vowel duration word list. Vowels were recorded in two consonantal contexts: (a) voiceless unaspirated alveolar stop ___ voiceless unaspirated alveolar stop or affricate, and (b) voiceless unaspirated uvular stop ___ voiceless unaspirated alveolar stop or affricate. One or two lexical items were selected for each context. The word lists for each context are given in the respective results sections below.

The words on the vowel quality word list were recorded in isolation, except for some words taken from the vowel duration word list. Vowels were recorded in five consonantal contexts: alveolar ___ alveolar, alveolar ___retroflex, retroflex ___alveolar, uvular ___ alveolar, alveolar ___ uvular. Like the vowel duration study, the words on the vowel quality word list were presented to speakers in written form along with their English translations. Oral prompting was utilized as needed.

2.2.2 Acoustic analysis
Measures of the lowest four formants of vowels were made using Praat (version 4.3.27). Maximum Formant settings were 5000 Hz for men and 5500 Hz for women. Vowels were measured at the steady-state point of the vowel (if there was one), where F1 and F2 had reached their points of maximal displacement (if they did), often but not always at the vowel’s midpoint. In (16), the measurement point of the vowel in this token is indicated by the arrow. This is the point where F1 is at its highest. In this token, F2, on the other hand, does not have such a clear target but rises steadily across the vowel:

(16) Sample spectrogram and lowest three formants of /χθʃɔt/ (xathdrit) ‘they’re lying down’, showing measurement point in [ə] (HM, a female speaker)

In this token, measured F1 is 452 Hz and F2 1708.
Vowel duration measures were made using Multi-Speech 2.5. First tags were placed at the onset and offset of F2, and saved with each sound file. Tags helped ensure consistency of measurement points across the data set. After tags were placed in all tokens for a particular speaker, duration was then measured between the tags.

2.2.3 Statistical analysis

Two inferential statistical tests were used. The first was repeated measures ANOVA. In the vowel duration studies, the independent variable was Vowel (phoneme), and the dependent variable was each speaker’s mean vowel duration. In the vowel quality studies, the independent variable was also Vowel (phoneme), and the dependent variable was each speaker’s mean log-normalized F1 and F2 (Nearey 1978, Nearey 1989). Post hoc analysis was performed with the Bonferroni/Dunn test, with alpha level set to .05.

2.3 Results: Spectral properties of vowels

In this section, sample vowel plots, not log-normalized, were generated with PlotFormants. These graphs show Bark-scaled F2 on the horizontal axis and F1 on the vertical axis. The large symbol represents the mean F2 and F1 for that vowel, and the ovals represent two standard deviations. These vowel plots are included here for illustrative purposes only, as they approximate the look of traditional vowel charts. They are all from the same female speaker. Vowel plots for the other speakers measured are given in the appendix (§6).

2.3.1 Alveolar __ alveolar

The word list for the vowels measured in this context are given in (17):

(17) Vowels in alveolar____alveolar context

a /ntataʔ/ (ndada’) ‘when (in the future)?’
   /ntadz/ (ndadz) ‘how’

e /ReGated/ (Reqgided) ‘eel’
   /kokatg/ (gogidet) (listener’s response to ade ‘hello’)

ə /taRtadõ/ (daRididdh) ‘red-necked grebe’
   /vataRtﬁts/ (vidaghtldits) ‘I bit it’

ɔ /ŋatot/ (ngidot) ‘downriver there’
   /ŋotodz/ (ngidodz) ‘from downriver’

In the sample vowel plot in (18), note the relatively low F1 and high F2 for /ə/, which gives the auditory impression of an [ɪ]-like vowel in this context, due to the high F2 of the surrounding coronal consonants. Also note the relatively front position of /a/ relative to /o/ for this speaker.

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(18) Plot of F2 (horizontal axis) x F1 (vertical axis) / alveolar___alveolar (HM)

For vowel plots of other speakers in this context, see 6.1.

The male speakers’ mean F1 and F2 in this context are given in (19). Corresponding values for female speakers are shown in (20).

(19) Mean F1 and F2 (male speakers)

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(20) Mean F1 and F2 (female speakers)

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<thead>
<tr>
<th></th>
<th>F1</th>
<th></th>
<th>F2</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>a</td>
<td>e</td>
<td>ã</td>
<td>o</td>
</tr>
<tr>
<td>AJ</td>
<td>851</td>
<td>421</td>
<td>386</td>
<td>543</td>
</tr>
<tr>
<td>ED</td>
<td>788</td>
<td>509</td>
<td>440</td>
<td>594</td>
</tr>
<tr>
<td>HM</td>
<td>626</td>
<td>459</td>
<td>391</td>
<td>478</td>
</tr>
<tr>
<td>KH</td>
<td>796</td>
<td>541</td>
<td>471</td>
<td>459</td>
</tr>
<tr>
<td>LH</td>
<td>829</td>
<td>564</td>
<td>443</td>
<td>529</td>
</tr>
</tbody>
</table>

Repeated measures ANOVA indicated significant differences in both normalized F1 ($F[3,21] = 56.397$, $p < .0001$) and normalized F2 ($F[3,21] = 208.493$, $p < .0001$). Post hoc analysis revealed that all vowel pairs except [e o] were significantly different in normalized F1. All vowel pairs except [e ã] were significantly different in normalized F2. Post hoc analysis thus indicates that the vowels divide into three vowel heights (low, [a]; mid, [e o]; lower-high, [ã])
and three degrees of backness (front, [e ə]; central, [a]; back, [o]) in this context, more or less as expected from auditory impressions.

2.3.2 Retroflex___alveolar

The word list for the vowels measured in this context is given in (21):

(21) Vowels in retroflex___alveolar context

<table>
<thead>
<tr>
<th>Vowel</th>
<th>Alveolar Vowel</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>/ʈʂʰaʈʰʔe't/ (traŋθʰet)</td>
<td>‘kashim’</td>
</tr>
<tr>
<td>e</td>
<td>/ʂed/ (dred)</td>
<td>‘seldom’</td>
</tr>
<tr>
<td>ə</td>
<td>/χəʈʂət/ (xathdrɨt)</td>
<td>‘they’re lying down’</td>
</tr>
<tr>
<td>o</td>
<td>/vəʈʂod/ (vidrod)</td>
<td>‘his foreleg, shin’</td>
</tr>
</tbody>
</table>

In the representative vowel plot in (22), note the absence of the fronting and raising of /ə/ for this speaker in this context, unlike (18), with preceding alveolar consonant:

(22) Plot of F2 (horizontal axis) x F1 (vertical axis) / retroflex___alveolar (HM)

Plots of the other speakers in this context are provided in 6.2.

The male speakers’ mean F1 and F2 in this context are given in (23). Corresponding values for (female speakers) are shown in (24).

---

15 Some speakers pronounced this word sraŋθʰet.
16 Nithidrok ‘they (granular objects) are’ was substituted for some speakers. This choice of lexical item was not ideal, since it ended in a velar rather than alveolar consonant.
Repeated measures ANOVA indicated significant differences in both normalized F1 ($F[3,21] = 38.38$, $p < .0001$) and normalized F2 ($F[3,21] = 109.193$, $p < .0001$). Post hoc analysis revealed that all vowel pairs were significantly different in normalized F1 except [e o], [e ə], and [o ə]. All vowel pairs were significantly different in normalized F2. Post hoc analysis thus indicates that the vowels divide into two vowel heights (low, [a]; mid, [e o ə]) and four degrees of backness (front, [e]; central-front, [ə]; central-back, [a]; back, [o]).

2.3.3 Alveolar___retroflex

The word list for the vowels measured in this context is given in (25):

(25) Vowels in alveolar___retroflex context

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>/vətadʐ/ (vidadr)</td>
<td>‘his younger sister’</td>
<td></td>
</tr>
<tr>
<td>e</td>
<td>/ɾətʂˈaʔ/ (ɾətrˈa’)</td>
<td>‘female dog’</td>
<td></td>
</tr>
<tr>
<td>o</td>
<td>/dələts/ (dhilɨr)</td>
<td>‘he urinated’</td>
<td></td>
</tr>
<tr>
<td>o</td>
<td>/vəjoŋtsˈaʔ/ (vɨyotˈa’)</td>
<td>‘his daughter-in-law’</td>
<td></td>
</tr>
</tbody>
</table>

In the representative vowel plot in (26), note the centralization of all vowels for this speaker in this context:

---

17 *gilotr’ey* ‘peeled spruce bark’ was substituted for some speakers.
Plots of the other speakers measured in this context are provided in 6.3. 

The male speakers’ mean F1 and F2 in this context are given in (27). Corresponding values for female speakers are shown in (28).

(27) Mean F1 and F2 (male speakers)

<table>
<thead>
<tr>
<th></th>
<th>F1</th>
<th>F2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>a  e  ə  o</td>
<td>a  e  ə  o</td>
</tr>
<tr>
<td>JD</td>
<td>660 365 416 463</td>
<td>1374 1809 1705 1129</td>
</tr>
<tr>
<td>PA</td>
<td>665 363 509 513</td>
<td>1249 1789 1601 972</td>
</tr>
<tr>
<td>RD</td>
<td>582 524 388 438</td>
<td>1054 1698 1599 1274</td>
</tr>
</tbody>
</table>

(28) Mean F1 and F2 (female speakers)

<table>
<thead>
<tr>
<th></th>
<th>F1</th>
<th>F2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>a  e  ə  o</td>
<td>a  e  ə  o</td>
</tr>
<tr>
<td>AJ</td>
<td>817 468 367 402</td>
<td>1109 1868 1593 1193</td>
</tr>
<tr>
<td>ED</td>
<td>791 624 504 583</td>
<td>1391 2119 2017 1296</td>
</tr>
<tr>
<td>HM</td>
<td>645 474 458 538</td>
<td>1579 1903 1728 1649</td>
</tr>
<tr>
<td>KH</td>
<td>817 511 597 561</td>
<td>1491 1863 1623 1158</td>
</tr>
<tr>
<td>LH</td>
<td>647 419 470 454</td>
<td>1321 1908 1863 1272</td>
</tr>
</tbody>
</table>

Repeated measures ANOVA indicated significant differences in both normalized F1 ($F[3,21] = 21.4937$, $p < .0001$) and normalized F2 ($F[3,21] = 39.287$, $p < .0001$). Post hoc analysis revealed that all vowel pairs were significantly different in normalized F1 except [e o], [e ə], and [o ə]. All vowel pairs were significantly different in normalized F2 except [a o] and [e
Post hoc analysis thus indicates that the vowels divide into two heights (low, [a]; mid, [e o ə]) and two degrees of backness (front-central, [e ə]; back-central, [a o]).

2.3.4 Uvular___alveolar

The word list for the vowels measured in this context is given in (29):

(29) Vowels in uvular___alveolar context

<table>
<thead>
<tr>
<th>Vowel</th>
<th>Word</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>/vəvaŋsqʰət/ (vəvaŋqšt)</td>
<td>‘I bought food’</td>
</tr>
<tr>
<td></td>
<td>/χaR dəθ/ (xaR dhiθh)</td>
<td>‘pack sack’</td>
</tr>
<tr>
<td>e</td>
<td>/jeRqəθ/ (jiRqeth)</td>
<td>‘he’s eating it (crunchy object)’</td>
</tr>
</tbody>
</table>
| ø     | /sədoŋh²ət/, /sədoŋqh²ət/ (sidsq²t,  
|       | sidiŋkɨt)                            | ‘ask me’                                          |
| ø     | /ŋəŋqísth/ (ŋiŋqísth)                | ‘club it’                                        |
| o     | /ŋəŋqísth/ (ŋiŋqísth)                | ‘(the house) collapsed’                          |
|       | /qoR jan’ tətɬən/ (ggqiR yan’ ditl’-anh) | ‘I’m walking’ (lit. ‘I’m just doing walking’)    |
| u     | /vänkəŋqəRqʰət/ (van-gəŋqəRqət)       | ‘patch it’                                       |
|       | /χʊt/ (xutl)                         | ‘sled’                                            |

In the representative vowel plot in (30), note the more compressed vowel space and greater variability for each vowel relative to the alveolar___alveolar context. Also note here the relatively high F1 for /ʊ/, resulting in an [ʌ]-like vowel, as well as the partial spectral overlap of /ʊ/ with /o/ and /a/.

(30) Plot of F2 (horizontal axis) x F1 (vertical axis) / uvular___alveolar (HM)
Plots of the other speakers are provided in 6.4, where it can be seen that all speakers have more variable realizations of the vowels in this context.

The male speakers’ mean F1 and F2 in this context are given in (31). Corresponding values for female speakers are shown in (32).

(31) Mean F1 and F2 (male speakers)

<table>
<thead>
<tr>
<th></th>
<th>a</th>
<th>e</th>
<th>ə</th>
<th>o</th>
<th>u</th>
<th></th>
<th>a</th>
<th>e</th>
<th>ə</th>
<th>o</th>
<th>u</th>
</tr>
</thead>
<tbody>
<tr>
<td>JD</td>
<td>702</td>
<td>479</td>
<td>617</td>
<td>463</td>
<td>494</td>
<td>1392</td>
<td>1831</td>
<td>1521</td>
<td>878</td>
<td>1079</td>
<td></td>
</tr>
<tr>
<td>PA</td>
<td>790</td>
<td>628</td>
<td>663</td>
<td>558</td>
<td>598</td>
<td>1314</td>
<td>1628</td>
<td>1315</td>
<td>949</td>
<td>1058</td>
<td></td>
</tr>
<tr>
<td>RD</td>
<td>724</td>
<td>518</td>
<td>609</td>
<td>502</td>
<td>514</td>
<td>1464</td>
<td>1673</td>
<td>1418</td>
<td>929</td>
<td>1065</td>
<td></td>
</tr>
</tbody>
</table>

(32) Mean F1 and F2 (female speakers)

<table>
<thead>
<tr>
<th></th>
<th>a</th>
<th>e</th>
<th>ə</th>
<th>o</th>
<th>u</th>
<th></th>
<th>a</th>
<th>e</th>
<th>ə</th>
<th>o</th>
<th>u</th>
</tr>
</thead>
<tbody>
<tr>
<td>AJ</td>
<td>687</td>
<td>618</td>
<td>512</td>
<td>498</td>
<td>555</td>
<td>1230</td>
<td>1767</td>
<td>1153</td>
<td>900</td>
<td>1086</td>
<td></td>
</tr>
<tr>
<td>ED</td>
<td>860</td>
<td>605</td>
<td>778</td>
<td>651</td>
<td>666</td>
<td>1469</td>
<td>2136</td>
<td>1579</td>
<td>1082</td>
<td>1248</td>
<td></td>
</tr>
<tr>
<td>HM</td>
<td>790</td>
<td>530</td>
<td>602</td>
<td>562</td>
<td>505</td>
<td>1508</td>
<td>1784</td>
<td>1506</td>
<td>1070</td>
<td>1250</td>
<td></td>
</tr>
<tr>
<td>KH</td>
<td>843</td>
<td>624</td>
<td>813</td>
<td>638</td>
<td>660</td>
<td>1424</td>
<td>1978</td>
<td>1406</td>
<td>1069</td>
<td>1211</td>
<td></td>
</tr>
<tr>
<td>LH</td>
<td>863</td>
<td>622</td>
<td>896</td>
<td>675</td>
<td>732</td>
<td>1438</td>
<td>2205</td>
<td>1532</td>
<td>1141</td>
<td>1360</td>
<td></td>
</tr>
</tbody>
</table>

Repeated measures ANOVA indicated significant differences in both normalized F1 (F[4,28] = 29.728, p < 0.0001) and normalized F2 (F[4,28] = 135.898, p < 0.0001). Post hoc analysis revealed that all vowel pairs were significantly different in normalized F1 except [e o], [ə Y], and [o Y] (note that [Y] had significantly lower F1 than [ə]). All vowel pairs were significantly different in normalized F2 except [a ə]. Post hoc analysis thus indicates that the vowels divide into three heights (higher-mid [Y]; lower-mid [ə]; and low, [a]) and four degrees of backness (front, [e]; central, [a ə]; central-back, [Y]; back, [o]).

2.3.5 Alveolar—uvular

The word list for the vowels measured in this context is given in (33):

(33) Vowels in alveolar—uvular context

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>/tʰag/ (tλagg)</td>
</tr>
<tr>
<td></td>
<td>/tʰoʃʰag/ (tochagg)</td>
</tr>
<tr>
<td>e</td>
<td>/REFqoj/ (REFγγγγ)</td>
</tr>
<tr>
<td></td>
<td>/REq/ (eq)</td>
</tr>
<tr>
<td>ə</td>
<td>/kəREFq/ (giriγγγγ)</td>
</tr>
<tr>
<td></td>
<td>/ŋiŋq/ (ngiyigg)</td>
</tr>
<tr>
<td>o</td>
<td>/qʰuθ tšeloq/ (quth diseloq)</td>
</tr>
<tr>
<td></td>
<td>/vəʃʰq/ (vichq)</td>
</tr>
<tr>
<td>u</td>
<td>/təʃʰuʃ/ (ditiuq)</td>
</tr>
<tr>
<td></td>
<td>/təʃ’uʃ/ (dich’uq)</td>
</tr>
</tbody>
</table>

‘no-good’
‘enclosed slough’
‘puppy’
‘fog’
‘one’
‘down, inside’
‘I have a cold’
‘his rib’
‘it’s baggy’
‘it’s sharp (quill-like)’
In the representative vowel plot in (34), note the relatively high F1 of /ə/ (again, [ʌ]-like) for HM, as well as the relatively high F1 of /o/ and spectral overlap with /ol/.

(34)  Plot of F2 (horizontal axis) x F1 (vertical axis) / alveolar uvular (HM)

Plots of the other speakers are provided in 6.5. Like the uvular alveolar context, all speakers’ vowels tend to have a relatively high degree of variability in the alveolar uvular context.

The male speakers’ mean F1 and F2 in this context are given in (35). Corresponding values for female speakers are shown in (36).

(35)  Mean F1 and F2 (male speakers)

<table>
<thead>
<tr>
<th></th>
<th>F1</th>
<th>F2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>a</td>
<td>e</td>
</tr>
<tr>
<td>JD</td>
<td>612</td>
<td>386</td>
</tr>
<tr>
<td>PA</td>
<td>734</td>
<td>622</td>
</tr>
<tr>
<td>RD</td>
<td>571</td>
<td>495</td>
</tr>
</tbody>
</table>

(36)  Mean F1 and F2 (female speakers)

<table>
<thead>
<tr>
<th></th>
<th>F1</th>
<th>F2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>a</td>
<td>e</td>
</tr>
<tr>
<td>AJ</td>
<td>842</td>
<td>612</td>
</tr>
<tr>
<td>ED</td>
<td>753</td>
<td>606</td>
</tr>
<tr>
<td>HM</td>
<td>626</td>
<td>505</td>
</tr>
<tr>
<td>KH</td>
<td>828</td>
<td>611</td>
</tr>
<tr>
<td>LH</td>
<td>821</td>
<td>612</td>
</tr>
</tbody>
</table>
Repeated measures ANOVA indicated significant differences in both normalized F1 (F[4,28] = 23.900, p < .0001) and normalized F2 (F[4,28] = 123.625, p < .0001). Post hoc analysis revealed that of the ten possible vowel pairs, all were significantly different in normalized F1 except [a ə], [e o], [e Y], and [o Y]. All vowel pairs were significantly different in normalized F2 except [o Y]. Post hoc analysis thus indicates that in this context the vowels divide into two heights (mid, [e o Y]; and low, [a ə]) and four degrees of backness (front, [e]; central, [a]; central-back, [ə]; back, [o Y]).

2.3.6 Spectral properties summary

The spectral trends in the Deg Xinag vowels measured here are summarized in (37), where ‘G1’ represents normalized F1, ‘G2’ represents normalized F2, and ‘=’ means ‘not significantly different’.\(^\text{18}\)

\[
\begin{array}{|c|c|c|c|}
\hline
& \text{__alveolar} & \text{__retroflex} & \text{__uvular} \\
\hline
\text{alveolar__} & G1: e = o & G1: e = o, e = ə, ə = o & G1: a = ə, e = o, e = Y, o = Y \\
& G2: e = ə & G2: a = o, e = ə & G2: o = Y \\
\hline
\text{retroflex__} & G1: e = o, e = ə, ə = o & & \\
\hline
\text{uvular__} & G1: e = o, e = Y, o = Y & & \\
& G2: a = ə & & \\
\hline
\end{array}
\]

The fronting and raising of /ə/ when surrounded by alveolar consonants is absent when either the preceding or following consonant is retroflex. As seen above, all vowels are more centralized when adjacent to a retroflex, particularly before. If vocalic allophones of pre-Upper Tanana were similarly centralized before a retroflex, this could have indeed paved the way for the centralized diphthongs seen in that language according to the historical scenario suggested by Tuttle and Lovick 2008.

When adjacent to a uvular, /ə/ approaches /a/ in quality in two respects. Before a uvular, /ə/ is a low vowel, in fact not differing in F1 from /a/, and after a uvular, /ə/ does not differ in F2 from /a/. /Y/ does not differ in F1 from mid vowels /e o/ when preceded or followed by a uvular consonant.\(^\text{19}\) From this phenomenon too it is easy to see the seeds of future phonemic lowering of vowels when adjacent to, especially before, uvulars in languages like Witsuwit’en.

It can also be seen from (37) that the effect of a following consonant on vowel quality is greater than that of a preceding consonant. There are fewer significant differences before

\(^{18}\)E.g. ‘G1: e = o’ means ‘/e/ and /o/ do not differ in normalized F1’.

\(^{19}\)Compare LH’s [Y] adjacent to velar [k] above in (7) and (8) at 543 and 553 Hz with her averages adjacent to a uvular: 591 Hz before a uvular and 732 Hz after uvular. For LH, [Y] actually exhibits more lowering after a uvular than before. The pre-uvular lowering of [Y] does not make this vowel much lower than her [Y] in non-uvular contexts.
retroflex consonants than after, with no significant differences in normalized F1 or F2 for /e ə/. There are also fewer significant differences before uvular consonants than after, in particular, no significant differences in normalized F1 or F2 for /o œ/, confirming auditory impressions. These vowel pairs apparently differ only in duration in these contexts.

2.4 Results: Vowel duration

In this section, duration means for each vowel are the eight-speaker average of each speaker’s mean duration for that vowel. In the tables, the number in parentheses represents one standard deviation. In bar graphs, error bars represent one standard deviation.

2.4.1 Alveolar alveolar

Recall that in this context, four vowels are attested in Deg Xinag. The word list for the vowels measured in this context is given in (38):

\[
\begin{array}{ll}
\text{a} & /\theta’\chi\ na\theta\theta\theta/ (\text{tth’ax nathdth}) \quad \text{‘she spun thread’}\\
\text{e} & /\text{kokatet} / (\text{gogidet}) \quad \text{(listener’s response to ade’ ‘hello’)}
\end{array}
\]

Duration measures for the vowels in this context are provided in numeric form in (39) and in graphic form in (40):

\[
\begin{array}{l}
\text{(39)} & \text{Mean duration in seconds of four contrasting vowels/alveolar alveolar (data averaged across 8 speakers)} \\
\end{array}
\]

\[
\begin{array}{llll}
\text{a} & \text{e} & \text{ə} & \text{o} \\
168 (.0154) & 150 (.0278) & 077 (.0080) & 176 (.0140)
\end{array}
\]

\[
\begin{array}{l}
\text{(40)} & \text{Mean duration in seconds of four contrasting vowels/alveolar alveolar (data averaged across 8 speakers)} \\
\end{array}
\]

---

\[20\text{Or genodoth ‘black hornet’, for speakers who did not know qun’ idaŋdotth.}\]
Repeated measures ANOVA revealed significant differences in length \((F[7,21] = 21.455, p < .0001)\) among the four vowels. Post hoc analysis indicated that \(/a/\) was significantly shorter than each of \(/e\ o\ a/\) \((p < .0001)\), while \(/e\ o\ a/\) did not differ significantly in length from each other. \(/a/\) thus has roughly half the duration of \(/a\ e\ o/\).

2.4.2 Uvular ___ alveolar

The word list for the five vowels measured in this context is given in (41):

(41) Uvular___alveolar vowel duration word list

\(a\) \([\text{ja}n\text{o}\text{̣}r\text{qats}]\) \([\text{yini} \text{̣}j\text{ggats}]\) ‘he stared at him’

\(e\) \([\text{va}q\text{etl}]\) \([\text{vigg}t\text{l}]\) ‘its detached skin, inner skin scrapings’

\(ə\) \([\text{ta}q\text{ə}T]\) \([\text{di}g\text{gi}t\text{h}]\) ‘it (tree) is twisted’

\(o\) \([\text{tə}l\text{qots}]\) \([\text{ti}d\text{il}g\text{gots}]\) ‘it sank’

\(Y\) \([\text{jər}h\text{o}Y\text{t}]\) \([\text{yi}t\text{og}g\text{ut}]\) ‘he’ll stab it (once)’

Duration measures for the five vowels which occur in this context are provided in numeric form in (42) and in graphic form in (43):

(42) Mean duration in seconds of four contrasting vowels/uvular___alveolar (data averaged across 8 speakers)

<table>
<thead>
<tr>
<th>Vowel</th>
<th>Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>.203 (.0169)</td>
</tr>
<tr>
<td>(e)</td>
<td>.178 (.0195)</td>
</tr>
<tr>
<td>(ə)</td>
<td>.105 (.0127)</td>
</tr>
<tr>
<td>(o)</td>
<td>.191 (.0089)</td>
</tr>
<tr>
<td>(Y)</td>
<td>.088 (.0108)</td>
</tr>
</tbody>
</table>

(43) Mean duration in seconds of five contrasting vowels/uvular___alveolar (data averaged across 8 speakers)

Repeated measures ANOVA revealed significant differences in length \((F[7,28] = 34.633, p < .0001)\) among the vowels in this context. Post hoc analysis indicated that each of \(/ə\ Y/\) is significantly shorter than each of \(/e\ o\ a/\) \((p < .0001\) for each pair of vowels), whereas \(/e\ o\ a/\) do
not differ significantly in length from each other, nor do /ə Y/ differ significantly in length from each other.

2.5 Summary of acoustic study

As confirmed by acoustic analysis, the Deg Xinag vowel system consists of two short vowels, traditionally transcribed /ə u/, and three long vowels, /e o a/. Uvulars have the most pronounced lowering and/or backing effects on the two short vowels in the system. As seen in 2.3.5, /u/ and /o/ do not differ in F1 or F2 before a uvular.

3 The evolution of the Deg Xinag vowel system

(44) contains the Proto-Athabaskan (PA) vowel system, consisting of four full vowels and three reduced vowels, as reconstructed by Krauss 1964 (and further annotated by Krauss, p.c.):

\[
\begin{array}{|c|c|c|}
\hline
\text{full} & \text{reduced} & \text{full} \\
\hline
*\text{i}: & *\text{u} & *\text{u}: \\
*\text{ɛ}/\text{æ}: ("e:" ) & *\text{æ}: & *\text{a}/\text{ɔ}: ("a:" ) \\
\hline
\end{array}
\]

Reflexes in daughter languages indicate that the PA vowel usually reconstructed as *e: varied between lower mid and low front, [ɛː]~[æː], and the PA vowel usually reconstructed as *a: was low, back and perhaps round, [aː]~[ɔː].22 Interestingly, the “square” arrangement of four full vowels found in PA is in fact the most common four-vowel inventory, as noted by Lindblom 1975 ([i a u/ plus a front vowel]). Disner 1984: 141 notes three vowel systems in UPSID which are similar to that of the PA full vowels (Shasta, Paez and Moxo).

The PA vowel reconstructed as *α was a higher and more centralized vowel than *a: (as well as shorter). The PA vowel reconstructed as *ɛ was central-front, intermediate in quality between [i] and [ɛ].

3.1 Development of PA full vowels

Leer 1979(?) notes that the PA full vowels underwent a “counter-clockwise rotation” in Deg Xinag. Apparently the first stage in this rotation was the merger of *i: and *u: as *i:,23 then

---

21This section owes much to discussions with Michael Krauss. For the most part in this section, DX is transcribed using the symbols of the practical orthography, as these differ less from the way in which PA is currently transcribed.

22Perhaps *ə/ɔ: would then be a better choice of narrow phonetic symbols for "a:"

23Krauss 1962:25c noted that ‘the most important thing in the development of this system is the forward shift and merger of */u/ with */i/.”
their subsequent lowering to /e/. These sound changes shown in (45)-(46). They have few exceptions.24

(45) PA *iː > DX /e/
\[24\]

\[25\]

In prefixes, *uː > Deg Xinag /e/ with further evolution to /ə/ within paradigms (like the perfective negative prefix listed in (45)): e.g. PA *O-uː-təmː ‘hold O’ (Leer 2006-2010: t/51) > DX yeting ‘he’s holding it’, istrying ‘I’m holding it’.

Perhaps the shift of *uː > *iː was triggered by the large numbers of coronal consonants in pre-DX (which would have increased following the split of the *kː series to /k/ and /h/). Coronal consonants have an F2-raising effect on [u], thereby fronting and increasing the similarity of [u] to [i] (Ohala 1981). *uː > iː also occurred in Dogrib (Howren 1979), but in that language there may have also been some sort of “systemic” pressure possibly due to the (prior?) shift of *ə > /ol, yielding the Dogrib vowel system /i e o/.

The result of the fronting of *uː > *iː would have been the pre-Deg Xinag vowel system in (47):

(47) Pre-Deg Xinag vowels, after PA *uː, *iː > *iː:

<table>
<thead>
<tr>
<th>full</th>
<th>reduced</th>
<th>full</th>
</tr>
</thead>
<tbody>
<tr>
<td>*iː</td>
<td></td>
<td></td>
</tr>
<tr>
<td>*ə</td>
<td>*uː</td>
<td></td>
</tr>
<tr>
<td>*aː</td>
<td>*aː (&quot;a&quot;)</td>
<td></td>
</tr>
<tr>
<td>*eː/æː (&quot;eː&quot;)</td>
<td>*aː/ɔː (&quot;aː&quot;)</td>
<td></td>
</tr>
</tbody>
</table>

Krauss 1962 and Kari 1977 note similarities in the historical development of the DX and Dena’ina vowel systems. As summarized by Krauss and Golla 1981: 73, the Deg Xinag vowel system ‘has developed essentially’ as in Dena’ina (a.k.a. Tanaina). In that language, ‘the main feature distinguishing Tanaina from Ahtna, but which Tanaina shares with Ingilik, is the reduction of the vowel system from seven to four vowels (a system resembling that of Yupik.

\[26\]
Eskimo, perhaps not by coincidence): PA *i and *u both > i [ɪ], *e > a, *a > u [ʊ], and the three PA reduced vowels *ə, *æ, *ʊ all > ə.’ The Yup’ik vowel system referred to by Krauss and Golla is given in (48):

(48) Yup’ik vowels (e.g. Jacobson 1984)

\[
\begin{array}{ccc}
\text{i:} & \text{u:} & \text{ə} \\
\text{a:} & & \\
\end{array}
\]

The merger of *u: and *i: as *i: created an asymmetry in the pre-Deg Xinag vowel system, as seen in (47), and it is tempting to view the subsequent shift of *i:, *e: and *a: to their current Deg Xinag positions as a way of resolving the asymmetry. However, Maddieson 1984: 124-125, analyzing vowel patterns in the 317 languages in UPSID, notes that:

…high front vowels are more frequent than high back vowels…The 3 vowels at the corners of the conventional vowel triangle, /i, a, u/, are the most widespread, but note that there are 24 fewer languages with /u/ than with /i/. These three vowels might be expected to be equally favored, because they each lie at an acoustic extreme. The low vowel /a/ has the highest first formant, /i/ and /u/ have the lowest first formant but /i/ has the highest second (and third) formant, whereas /u/ has the lowest second formant. However, a contributory factor to the relative disfavoring of /u/ may be the lower amplitude typical of /u/.

Athabaskan systems with /i/ but not /u/ (Dogrib, Navajo) are thus in accord with Maddieson’s typological observations. Moreover, Disner 1984: 142 notes that /u/ is even more likely to be absent from vowel systems than the mid vowels /e o/.

The rotation of *i:, *e: and *a: in the pre-Deg Xinag vowel space might not actually have involved great acoustic distance, if the pre-Deg Xinag merged *i: was lower-high, as in Dena’ina, and also given the hypothesized low to lower-mid positions of *ɛ:/æ: and *a:/ɔ: at this stage. (Recall from 2.3.1 that in the coronal___coronal context DX /a/ is not very back.)

(49) Pre-DX vowels, following hypothesized lowering of *i: to *ɪ:

<table>
<thead>
<tr>
<th>full</th>
<th>reduced</th>
<th>full</th>
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</thead>
<tbody>
<tr>
<td>*ɪ:</td>
<td>*ʊ</td>
<td>*ə</td>
</tr>
<tr>
<td>*ɛ:/æ:</td>
<td>*a:/ɔ:</td>
<td>*a:/ɔ:</td>
</tr>
</tbody>
</table>
Examples of the DX reflexes of *iː and *uː were given above in (45). Eventually *ɛː/æː ("*ɛː:"") > DX /a/ and *aː/əː ("*aː:"") > DX /o/ as shown in (50) and (51), respectively. There are few exceptions to these sound changes.  

(50)  PA *eː > DX /a/  
*P-e:(s)-don (Leer 2006-2010: 0/H 10), -eː-don (Leer 2006-2010: d/32) ‘without O’  
*(D-)leː:ŋ (meat) is fresh; (doː- stick: (tree, wood) is green)’  
(d/72) didilang ‘green wood’  
(Leer 2006-2010: ½/72)  
*-deː:tt ‘several go’ (Leer 2006-2010: d/52)  
*-šeː:-qe:-yu (also *š(ə)-qe:-yu) ‘children’ (Leer 2006-2010: q/123) sraqay  
*-l-D-yeː ‘be greasy, oily’ (Leer 2006-2010: ɬ/169) l-ghanh ‘be fat’

(51)  PA *aː > DX /o/  
PA *a  
*-aː:d-eː ‘older sister’ (Leer 2006-2010: 0/H 7)  
*-kʰaːn ‘rain’ (Leer 2006-2010: kʰ/11)  
*-O-q’a: ‘grind O, file O, sharpen O by grinding or filing’ (Leer 2006-2010: 9)    

Regardless of whether or not symmetry was a driving force or not, the result of the counter-clockwise shift of the full vowels would have been a more symmetrical vowel system than that prior to the shift. As Krauss 1962 put it, ‘unlike Tanaina...phonetic symmetry [in Ingalik] has been retained instead by the opening of /i/...’

3.2 Development of PA reduced vowels

With few exceptions, PA *o > DX /ə/, in both stems and prefixes, as noted by Krauss and Golla 1981:72.

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26 It is not at all clear, however, that phonological symmetry (as opposed to acoustic/perceptual distance) is a driving force in the evolution of vowel systems, given historically stable systems with gaps, as noted by Disnery 1984 and Blevins 2004.

27 *o > /o/ in *xɜʰ-tʃən ‘evening, dusk’ (Leer 2006-2010: tʃʰ/31, ɬ/143) > xalts’ in ‘evening,’ PA *tsəlæo ‘ground squirrel’ (Leer 2006-2010: tʃ/51) > təxalik, and possibly *tənəŋ ‘word’ (Story 1984) > xinəŋ ‘word, language’ (but cf. Leer 2006-2010: 0/h 5 *qə- (naː-)həː ‘(A-g)’ ‘speak (forcefully)’. *o > /u/ (> /lo/) in *tʃəːɡən ‘left side/hand’ (Leer 2006-2010: tʃʰ/35) > t’oɡhs-, and *gəːkəɡə ‘berry’ (Leer 2006-2010: gəː/31) > gək ‘berry’ (if the source for DX. Leer also reconstructs *gəːkəɡəl; and Krauss 1961 had noted that ‘the [a] of ‘berries’ corresponds inexplicably to [i] and [iː] in other Alaskan dialects.’) *o > /ɛ/ in *yəːɡə ‘whistle’ (Krauss and Leer 1981) > yesr, *tsəm ⟨~*səm⟩, *səm ‘star’ (Leer 2006-2010: s/43) > təhèn.’
(52) PA *ɑ > DX /ɑ/ in prefixes
   *p’ɑ- 2s possessor (Krauss and Leer 1981)  ngi-
   *tś’ɑ= pejorative with negative verb stem (Leer 2006-2010: tś’/61)

(53) PA *ɑ > DX /ɑ/ in stems
   *P-ɑɬ’ ‘together with P’ (Leer 2006-2010: 0/h 8)  -yiɬ
   *P-ɑɬ’əɬ  ‘fork, vee, gap’ (Leer 2006-2010: G/64)  ggizr
   *tś’ɑɬ’ ‘underbrush’ (Leer 1987)  tr’iɬ ‘willow’
   *yaχs ‘snow’ (Leer 2006-2010: y/31)  yith
   *xɬ’ɑ ‘scar’ (Leer 2006-2010: x/y)  sɨt
   *O-ɬ-tś’ɑs-g’, O-tś’ɑs ‘whip O, shake O (blanket-like)’  O-t-θrith (semelfactive; -troth)
   (Leer 2006-2010: tś’/61)

*ɑ compensatorily lengthens to /ɑ/ in certain environments in the verb prefixes (Hargus 2003), as well as in stems such as *tɬ’ɑɬ’ɑs ‘cottonwood’ (Leer 2006-2010: t’/30) > /t’aəθ/ (t’aghth).

*ɑ has a more complex set of reflexes in Deg Xinag than *ɑ. Krauss and Golla 1981:72 show *ɑ > DX /ɑ/, but before a uvular generally *ɑ > /o/, just like Holikachuk as listed in Table 3 of their article:28

(54) PA *ɑ > DX /o/
   *-q’ɑx ‘(animal) fat’ (Leer 2006-2010: q’/81)  -q’ux
   *P-ταx ‘among, amidst P; during P; places where, times when’  tux
   (Leer 2006-2010: t’/37)
   *O-tɬ-tɑxɬ ‘rub, anoint O with ointment, (AB also oil)’ (Leer 2006-2010: tl/3)  O-n-t-θlux ‘grease, paint O’
   *tɬ-D-tɬaxɬ ‘anim. jumps, hops, moves jerkily’ (Leer 2006-2010: tɬ/1)
   *n-ɬ-t’ɑg ‘one (bird) flies’ (Leer 2006-2010: t’/19)  n-D-’uq
   (Again, there is compensatory lengthening to /o/ rather than /u/ in certain environments within stems; e.g. *P-nɑɬ’ɑd ‘before P’s eyes, in the presence of P’ (Leer 2006-2010: x/72) > -/nɔɬ/ (-nɔgθθ).) After a uvular, sometimes *ɑ > /o/ (55), sometimes *ɑ > /o/ (56), and sometimes *ɑ > /o/ (57).

(55) PA *ɑ > DX /o/ after uvular
   *P-ɬ’ɑn ‘by, near, at, to; from; about concerning P’ (Leer 2006-2010: x/11)  -ɡhunh ‘from, before, in front of’
   in relation to P, about, concerning P’ (Leer 2006-2010: x/37)
   *xɬax-D ‘sled’ (Leer 2006-2010: x/70)  xutɬ

28 *ɡɑx ‘rabbit’ (Leer 2006-2010: G/49) may have been borrowed into Deg Xinag as ggux via Holikachuk. This form was not used in Shageluk. Shageluk (and also Anvik) speakers use noɣhniy for ‘rabbit’.
*xay ‘spruce root(s)’ (Leer 2006-2010: x/119)  xuły ‘long root’ (spruce, willow)

*D-qxay ‘long pointed object (e.g. spear, arrow, pole, boat, knife, needle, pin) jabs, pierces, rams’ (Leer 2006-2010: q/91)  D-quyh ‘scamper, poke’

(56)  PA *α > DX /ɔ/ after uvular

*-gα̃f ‘dry out, become dry, dried’ (Leer 2006-2010: G/5)  -gingh

*-n̥ɑ̃a-γα̃f ‘nail’ (Leer 2006-2010: G/2)  -logging

*-qα̃y ‘husband’ (Krauss and Leer 1981)  -qing’

*Xα̃-t ‘club’ (Leer 2006-2010: x/82)  xił (Kari 1978)

*Xay ‘winter’ (Leer 2006-2010: x/121)  xiły28

(57)  PA *α > DX /o/ after uvular30

*-q ‘øy’, -q ‘oye’ ‘pelvis, hip, crotch, fork of legs’ (Leer 2006-2010: q’/73)  -q’øy

*-t’q-ats ‘cold (air, wind, weather) extends, moves, blows’  t’q’otth ‘be cold’ (weather)

(Leer 2006-2010: q’/48)

Otherwise (when not originally adjacent to a uvular), *α > /ɔ/:

(58)  PA *α > DX /ɔ/

*-’an ‘off, away, over, beyond’ (Leer 2006-2010: ’/8)  in

*-q’e-tyt ‘heal (Leer 2006-2010: t/22, q/129)  -r̥tł

*hɔn(‘ɔ) ‘river’ (Leer 2006-2010: 0/h 6)  xìn

Turning now to *ʊ, Krauss and Golla 1981:72 list /ɔ/ as the reflex of *ʊ in Deg Xinag, possibly due to their analysis of [qY] as [q’ɔ] (1.2). In fact, *ʊ is generally maintained as /ʊ/ in Deg Xinag when adjacent to a uvular:31

(59)  PA *ʊ > DX /o/

*O-nɔ-t-d’ʊq ‘cram, stuff O; move bulky, unwieldy O’ (Leer 2006-2010: d/60)  O-n’-dʊq ‘make O into snowball’

*[D]-d’ʊq ‘laugh, smile’ (Leer 2006-2010: ṭ/111)  ni#g-duq

*t’l’ʊx, t’l’ʊy ‘grass’ (Leer 2006-2010: t’l’/54)  t’l’ux ‘lake grass, sedge, wide grass’

*k’ʊx, *k’ʊy ‘big’ (Leer 2006-2010: k’/20)  chux

28 The compound-initial/incorporated form of this stem is xey- (e.g. xeyts ‘in’, ‘autumn’, lit. “towards winter”).
30 Also note two cases of *α > /o/ before uvular: O- ‘ɔxd’ ‘move O abruptly, throw O (blanket)’ (Leer 2006-2010: ’/10) > -’oɔx and *nɔ=-n̥a-=O-k-’atłx ~ ’atłx ‘butcher O (slain animal)’ (Leer 2006-2010: ’/9) > n#O-’ɔx. /ɔ/ is expected here; cf. (54).
31 *ʊ > ʊ-o is attested with *-Gʊk’/’Gʊt’ ‘move with forceful impetus, tumble, rush, spill’ (Leer 1987) > l-ggok/ggok ‘sg./du. run’, where the progressive stem varies between -ggok and -ggok (different speakers prefer one or the other). The progressive and momentaneous future stems, however, are always -gguk.
"scrape" (Leer 2006-2010: s/71) -dhux
"fire" (Leer 2006-2010: q/177) qun’
(də-qos[X] ‘cough, cold’ (Leer 2006-2010: q/187) d-l-quth
"cloud" (Leer 2006-2010: q’/157) q’uth
-q ‘os ‘neck’ (Leer 2006-2010: q’/158) -q’uth
-xuš ‘thorn’ (Leer 2006-2010: x/243) xusr
-q-nə-yuš, *qu-yuš ‘foam’ (Leer 2006-2010: x/245) xughusr, gughusr ‘foam, bubble’
-yuš ‘thigh’ (Leer 2006-2010: x/241) -ghuth ‘thigh, hindquarter’
-kə-yułz ‘ribs of a canoe, sled’ (Leer 2006-2010: x/250) gughudz
-kə-t’u’y ‘paddle a canoe’ (Leer 2006-2010: t’/67) g-t-t’uq ‘row’

In stems with final voiced uvular fricative, *u > /o/ (also a synchronic rule of Deg Xinag):

(60) PA *u > DX /o/ before ə
-f-D-tsuv ‘be tan, yellow, etc.’ (Leer 2006-2010: ts/75) l-tthogh ‘be yellow’

Similarly, PA disyllabic stems with medial *osu > Deg Xinag /os/:

(61) PA *u > DX /o/ from compensatory lengthening
*dzəʋuIAL, *dzəy’ot ‘ball’ (Leer 2006-2010: dz’/37) dzoghdł
*tsəyəs ‘merganser’ (Leer 2006-2010: ts’/72a) troghth

The change *u > /e/ seen in (62) is thus irregular. Perhaps *u irregularly lengthened to /u:/ in this word (in which case the DX reflex /e/ is as expected).

(62) PA *u > DX /e/
*ʔəq’əl, *ʔəq ‘eddy, whirlpool, swirling water’ (Leer 2006-2010: ’/27) > /ʔeq’əl/

In the verb prefixes, *u is reconstructed in the areal prefix *qu- (Leer 2006-2010; Thompson 1993) and optative prefix *yu- (Leer 2000). The optative prefix is hardly used by current Deg Xinag speakers, although the available evidence suggests that its shape is/was /kə-/ (Hargus 2004). The areal prefix, in its CV form, is /kə/, unless preceded by the homophonous third person plural subject prefix, in which case the vowel separating the two uvular fricatives is round. Compare the forms in (63):

(63) Deg Xinag areal prefix (- 3pS prefix)
\(x\)inayh ‘he’s talking’
\(x\ux\)inayh ‘they’re talking’

The original rounding is thus preserved in some form for each of these two verb prefixes.
When not adjacent to a uvular consonant, generally PA *ᵩ > DX /ə/:\n
(64) PA *ᵩ > DX /ə/ adjacent to non-uvular
*，默认 loss of rounding
* 默认 loss of rounding
* 默认 loss of rounding
*默认 loss of rounding
*默认 loss of rounding
*默认 loss of rounding
*默认 loss of rounding
*默认 loss of rounding
*默认 loss of rounding

When not adjacent to a uvular consonant, generally PA *ᵩ > DX /ə/:\n
(65) PA *ᵩ > DX /ə/ adjacent to uvular
*默认 loss of rounding
*默认 loss of rounding
*默认 loss of rounding
*默认 loss of rounding

The similar developments of Proto-Athabaskan *ɑ* and *ᵩ* in Deg Xinag (consistent preservation of rounding before a uvular, inconsistent loss of rounding after a uvular, regular loss of rounding adjacent to a non-uvular) suggest that *ɑ* and *ᵩ* may have first merged as *ᵩ*, and then *ᵩ* merged with *ə* unless adjacent to a uvular. If this is correct, then *ɑ* may have been a round vowel, which would have facilitated the merger with *ᵩ*. Note that in closely related Koyukon, the reflex of *ɑ* is described as a ‘low back rounded reduced vowel similar to ou in English tough. It is used only in the Central and Lower dialects…’ (Marlow 2000:1xxi), the reflex of *ɑ* apparently merging with the reflex of *ᵩ* in the Upper dialect. Other languages from Krauss and Golla 1981 where *ɑ* and *ᵩ* have merged are all in Alaska: Holikachuk, Lower Tanana, and Kolchan (a.k.a. Upper Kuskokwim). Further, if *ɑ* is a shorter, more centralized version of *ᵩ*: (*ɑː:/əː;*), this supports the view of the PA vowel *ɑː* as having been round, *[ɑː] or *[ɔː].*

The number of lexical items with *ᵩ* in Deg Xinag has remained fairly stable over time compared to Proto-Athabaskan. One can then reasonably wonder what the historical sources are for the six Deg Xinag lexical items with /ə/ adjacent to a non-uvular given above in (6). Four of these appear to have been borrowed from neighboring languages. One, /pusaj/ ‘cat’, was probably borrowed from Yup’ik *puss’iq*. (Note that some speakers use /vosa/ for ‘cat’.) Three of these might be borrowings from Holikachuk, which did not undergo the *kʰ > /k/, ʃ/ /ʃ/ split found in DX. There was and still is lots of contact between Deg Xinag and Holikachuk speakers and their descendants. Similar forms are attested not only in Holikachuk but also in Koyukon:*

\[\text{Footnotes:}\]
\[\text{32 The development of *ᵩ > /ə/ in *O-ʈ-ʈ’ọg* ‘insect stings O…’ (Leer 2006-2010: t’/67) as vichi’tọg’dliṭhiy ‘bug with stinger’ (Kari 1978) is therefore unexpected.}\]
\[\text{33/ʃ/ is found in one Holikachuk word, } chux ‘big’ (Giulia Oliverio, p.c.). This is probably a borrowing from DX.}\]
\[\text{34 Data from Holikachuk (Kari et al. 1978) and Koyukon (Jetté and Jones 2000) is cited in the practical orthographies of those languages.}\]
DX velar + [ʊ] shared with Holikachuk and Koyukon

### Deg Xinag

- **kula** ‘poor thing’
- **dikul** ‘gratitude’ (?)
- **yuk** (listener’s expression at end of story)

### Holikachuk

- **kula** ‘poor one’

### Koyukon

- **kulaa** ‘how pathetic! how pitiful!’
- **dekul, -dekule** ‘poor, pitiful person’
- **yuk** ‘end (of story)’
- **yuk** ‘right! you guessed it (riddle)’

However, for two remaining Deg Xinag lexical items with velar + [ʊ], no neighboring language source is known:

### Deg Xinag lexical items not shared with any known neighboring languages

- **ttihk’u**- ‘uphill, into woods’
- **x-k’u#O-’anh** ‘medically assist O’

### Conclusion

This article has provided instrumental confirmation that the vowel inventory of Deg Xinag contains three long/full vowels and two short/reduced vowels, none of which are the typologically expected /i u/. The Deg Xinag vowel phonemes have more centralized allophones before retroflex consonants and lowered allophones before uvulars. Centralization before retroflex consonants is reminiscent of the way in which certain Upper Tanana vowels developed, as suggested by Tuttle and Lovick 2008. Lowering before uvular consonants has taken place in other Athabaskan languages, such as Witsuwit’en.

Although Krauss 1962, on the basis of the data available to him, suggested that the Deg Xinag sequence uvular + [ʊ] (and mirror image) might be analyzable as labio-uvular + /ʊ/, additional study of the language has revealed a wider distribution of Deg Xinag /ʊ/. A small number of lexical items, most likely borrowings, contain /ʊ/ next to non-uvulars. These indicate that the synchronic labio-uvular analysis is not tenable.

### References

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6 Appendix: vowel plots

In this appendix, vowel plots for all eight speakers are presented, including HM, seen above in the text. Vowel plots in this section use the following symbols: <i> = [ə], <u> = [ʊ] (which are used to spell these vowels in the practical orthography designed by Krauss 1962). Other symbols have their normal phonetic values. It can be seen that some speakers have more variability in their production of vowels than other speakers.

6.1 Alveolar–alveolar

<table>
<thead>
<tr>
<th>HM (female speaker)</th>
<th>ED (female speaker)</th>
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</table>

KH (female speaker)

LH (female speaker)
6.2 Retroflex__alveolar

HM (female speaker)

ED (female speaker)

KH (female speaker)

LH (female speaker)
### 6.3 Alveolar___retroflex

<table>
<thead>
<tr>
<th>PA (male speaker)</th>
<th>RD (male speaker)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3000 2500 2000 1500 1000</td>
<td>5000 2500 2000 1500 1000</td>
</tr>
<tr>
<td><img src="image1" alt="Diagram" /></td>
<td><img src="image2" alt="Diagram" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HM (female speaker)</th>
<th>ED (female speaker)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3000 2500 2000 1500 1000</td>
<td>5000 2500 2000 1500 1000</td>
</tr>
<tr>
<td><img src="image3" alt="Diagram" /></td>
<td><img src="image4" alt="Diagram" /></td>
</tr>
</tbody>
</table>

KH (female speaker)  
LH (female speaker)
<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>3000</th>
<th>2500</th>
<th>2000</th>
<th>1500</th>
<th>1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>JD (male speaker)</td>
<td>![JD phonemes]</td>
<td>![JD phonemes]</td>
<td>![JD phonemes]</td>
<td>![JD phonemes]</td>
<td>![JD phonemes]</td>
</tr>
</tbody>
</table>
6.4 Uvular—alveolar

HM (female speaker)  ED (female speaker)

KH (female speaker)  LH (female speaker)
<table>
<thead>
<tr>
<th></th>
<th>3000</th>
<th>2500</th>
<th>2000</th>
<th>1500</th>
<th>1000</th>
<th></th>
<th>5000</th>
<th>2500</th>
<th>2000</th>
<th>1500</th>
<th>1000</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Aj (female speaker)</td>
<td><img src="image1.png" alt="Chart" /></td>
<td><img src="image2.png" alt="Chart" /></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JD (male speaker)</td>
<td><img src="image3.png" alt="Chart" /></td>
<td><img src="image4.png" alt="Chart" /></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>
6.5 Alveolar—uvular