Title: Oral-laryngeal timing in glottalised resonants

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Abstract

Although previous studies of intergestural timing in multi-gesture segments have identified some consistent patterns, fundamental questions remain about the underlying causes of these patterns. Hypotheses based on universal perceptual or biomechanical restrictions (Gick, Campbell, Oh & Tamburri-Watt, 2006) have proven difficult to test because of confounding factors, e.g. anatomical coupling (Sproat & Fujimura, 1993) and aerodynamic necessity (Kingston, 1990). The cross-linguistically rare class of glottalised resonants (GRs) involves oral and laryngeal gestures, which are neither anatomically nor aerodynamically interdependent, thereby providing a revealing test case for these hypotheses. If intergestural timing is determined by universal perceptual factors, GR timing patterns should be consistent across languages. This comparative study of GRs in three endangered British Columbian languages reveals distinct patterns: the timing of GRs is consistently pre-glottalised in Nuu-chah-nulth, post-glottalised in Nɬeʔkepmxcin, and dependent upon syllable position in St'át'imcets. These findings indicate that a strong hypothesis based on perceptual recovery (e.g. Silverman, 1997) must be rejected, and suggest instead that intergestural timing must be specified on a language-specific basis.

Keywords: glottalised resonants; intergestural timing; laryngeal; endangered languages; Nɬeʔkepmxcin; Thompson; Nuu-chah-nulth; St'át'imcets; Lillooet

1. Introduction

Recurring patterns in intergestural timing have been observed in multi-gesture segments both within and across languages. Researchers have proposed different universal causes for these timing patterns: perceptual recoverability (Mattingly 1981; Silverman & Jun 1994; Byrd 1994, 1996a, b; Wright 1996; Silverman 1997; Chitoran et al. 2002; Kochetov 2002, 2006), mechanical (biomechanical or aerodynamic) restrictions (Krakow 1989, 1993, 1999; Browman & Goldstein 1992, 1995; Sproat & Fujimura 1993; Gick 2003; Gick et al. 2006), or a combination of mechanical restrictions and perceptual recoverability (Kingston 1985, 1990).

Existing proposals have been difficult to evaluate because of confounding effects of biomechanical and/or aerodynamic interdependencies between gestures involved in the majority of segments tested, and also because of the limited data, often based only on auditory descriptions, on which many of the perceptual recoverability theories are based. The present paper aims to overcome both difficulties by examining glottalised resonants in three languages of the Pacific Northwest. The glottalised resonants (hereafter GRs) considered in this study involve minimal if any anatomical and aerodynamic coupling, so potential interference from mechanical factors is avoided. By conducting instrumental analysis of GRs in three different languages and across syllable and word positions and stress conditions, the present paper broadens the empirical basis upon which claims of universal factors underlying intergestural timing are made.

1.1. Background

Several studies have explored intergestural timing in segments comprising multiple gestures, many of them focusing on oral gestures. Within American English, studies of /m/ (Krakow 1989, 1993), /l/ (Browman & Goldstein 1992, 1995; Sproat & Fujimura 1993) and /w/ (Gick 2003) have revealed timing asynchronies that appear to be sensitive to syllable position. These studies, which focus on timing between two or more oral gestures, have observed that more anterior gestures (such as those involving the lips or tongue tip) tend to occur temporally farther from the syllable peak while less anterior gestures (such as those involving the velum or tongue dorsum) occur nearer the syllable peak, an effect most apparent in postvocalic allophones. In a cross-language study of intergestural timing in liquid allophones, Gick et al. (2006) found that four of the six languages and dialects studied exhibit similarities to the pattern described above for American English, at least in postvocalic position. A small number of studies have focused on timing between oral and glottal/laryngeal gestures. For example, Kingston (1985, 1990) shows that the relative timing of the glottal closure and the oral release burst are tightly bound in stop consonants.

A number of researchers have argued that at least some of these recurrent timing patterns may be governed by a single, overriding phonetic factor - that of "perceptual

recoverability" (Mattingly 1981; Silverman & Jun 1994; Silverman 1997; Byrd 1994, 1996a, b; Wright 1996; Kochetov 2002, 2006; Chitoran et al. 2002). Under a strong hypothesis based on perceptual recoverability, temporal asynchronies in intergestural timing should generally result from a tendency of speakers to attempt to enhance the perceptibility of each gesture. For example, Kochetov (2006) finds that in the production of Russian /p^{j}/, the tongue body gesture (palatalisation) lags behind the lip closure, even though these two gestures are mechanically independent from one another. He attributes this temporal offset to perceptual recoverability: the delay between the lip and tongue body gestures allows the tongue body gesture to be more easily recovered by the listener.

Another possible explanation for these recurring timing patterns is that they are determined by relatively mechanical factors. The two such factors most likely to play such a role are anatomical coupling (generally affecting timing between oral gestures) and aerodynamic coupling (generally affecting timing between oral and laryngeal gestures). As an example of anatomical coupling, English liquids - the consonant type most frequently studied for timing generalisations - comprise multiple lingual constrictions involving complex anatomical interdependencies; likewise, the component gestures of both liquids and /w/ share the jaw as a coupling factor. As an example of aerodynamic coupling, the oral-laryngeal sounds investigated in previous studies (as in Kingston (1985, 1990) mentioned above) rely on tightly constrained relative timing between gestures to produce a requisite increase in oral pressure (whether using a pulmonic source combined with laryngeal opening for voiceless stops, or a glottalic source for ejective stops). Kingston (1985, 1990) in fact argues for a combination of both mechanical (aerodynamic) and perceptual restrictions. In this view, intergestural timing maximizes intra-oral pressure so as to maximize in turn the perceptual salience of place cues.

In order to tease apart mechanical and perceptual explanations, it would be desirable to identify segments comprising gestures that share neither anatomical nor aerodynamic coupling. Both Kingston (1985, 1990) and Silverman (1997) recognise GRs as an example of such segments, based on the assumption (following the traditional model of the vocal tract, c.f. Laver, 1980) that the gestures responsible for the place and manner properties of the resonant are independent from the laryngeal/glottal gestures responsible for its glottalisation. While this is not in fact the case for all GRs, it is the case with the most common ones, and with the ones considered in this study.[1]

Independent of the larger question of mechanics vs. perception, at least two different perceptual recoverability-based predictions have been forwarded regarding gestural timing within GRs. Silverman (1997) proposes that the canonical timing for GRs should be pre-glottalised ([$^{?}$RV]), at least in onset position. His proposal is based upon the universal drive for perceptual recoverability: GRs are pre-glottalised because the formant transitions into the following vowel, which provide acoustic cues to resonants, could be obscured by cues to glottalisation if they were to overlap. Kingston (1985, 1990), on the other hand, argues for variable oral-laryngeal timing. Since continuants do not need to rely on a short release burst to transmit cues (unlike obstruents), there is no need to strongly anchor the two articulatory gestures, and timing should be variable. In

[1] In pharyngeal GRs, laryngeal sphinctering occurs both to realise the place/manner features of the resonant and to realise phonological glottalisation (Esling, 2005; in press). In order to minimize any anatomical coupling effects, this study does not include pharyngeal GRs.

other words, according to Kingston's view, while perceptual recoverability is an important factor in determining intergestural timing for some oral-laryngeal sounds, this is not the case for GRs.

The present paper describes a systematic cross-linguistic acoustic study of GRs in three languages. It is hoped that this study, by focusing on a segment type that minimizes the possible confounding mechanical factors described above, will distinguish between previous mechanical and perceptual hypotheses, and between Silverman's (1997) and Kingston's (1985, 1990) proposals on the universality of timing patterns as a function of perceptual recoverability. Specific predictions will be discussed at the end of Section 1.

1.2. Glottalised Resonants

Glottalised resonants[2] are a relatively rare set of sounds, found in 20 of the 317 languages sampled by Maddieson (1984). They are however frequent in the Salish and Wakashan languages of the Pacific Northwest, in which they contrast with non-glottalised resonants. The Salish family consists of two main language branches: Central Salish and Interior Salish. Central Salish is spoken on the West Coast of British Columbia and Washington State. Interior Salish can be further split into Northern and Southern branches. Northern Interior Salish languages are spoken in the interior of British Columbia and across the border in Washington State. Southern Interior Salish languages are spoken in the interior of Washington, Oregon, Montana, and Idaho. Two of the languages considered in this study, St'át'imcets (Lillooet) and Nɬeʔkepmxcin (Thompson) belong to the Northern Interior branch of the Salish family.

The Wakashan family also comprises two main language branches: Northern and Southern. Northern Wakashan languages are spoken on Northern Vancouver Island and on the Northern West Coast of British Columbia. Southern Wakashan languages are spoken on the Southern West Coast of Vancouver Island and on the Olympic Peninsula in Washington. The third language considered in this study, Nuu-chah-nulth (Nootka) belongs to the Southern Wakashan group.

Figure 1 provides an example from St'át'imcets contrasting a word-initial plain /m/ with a word-medial (coda) /m̰/. In this case /m̰/ is mid-glottalised, as can be seen by the spreading out of the pitch pulses in the middle of the segment[3].

[2] "Glottalised" will be used throughout this paper to refer to resonants that are phonemically glottalised. This will cover both resonants that have accompanying creaky phonation (and thus more accurately described as laryngealised) and those with a full glottal stop.

[3] Note the additional duration of /m̰/ compared to /m/. Although duration was not considered in the current study, it has been found to cue glottalisation in some languages, e.g. Nuu-chah-nulth (Esling, et al., 2005).

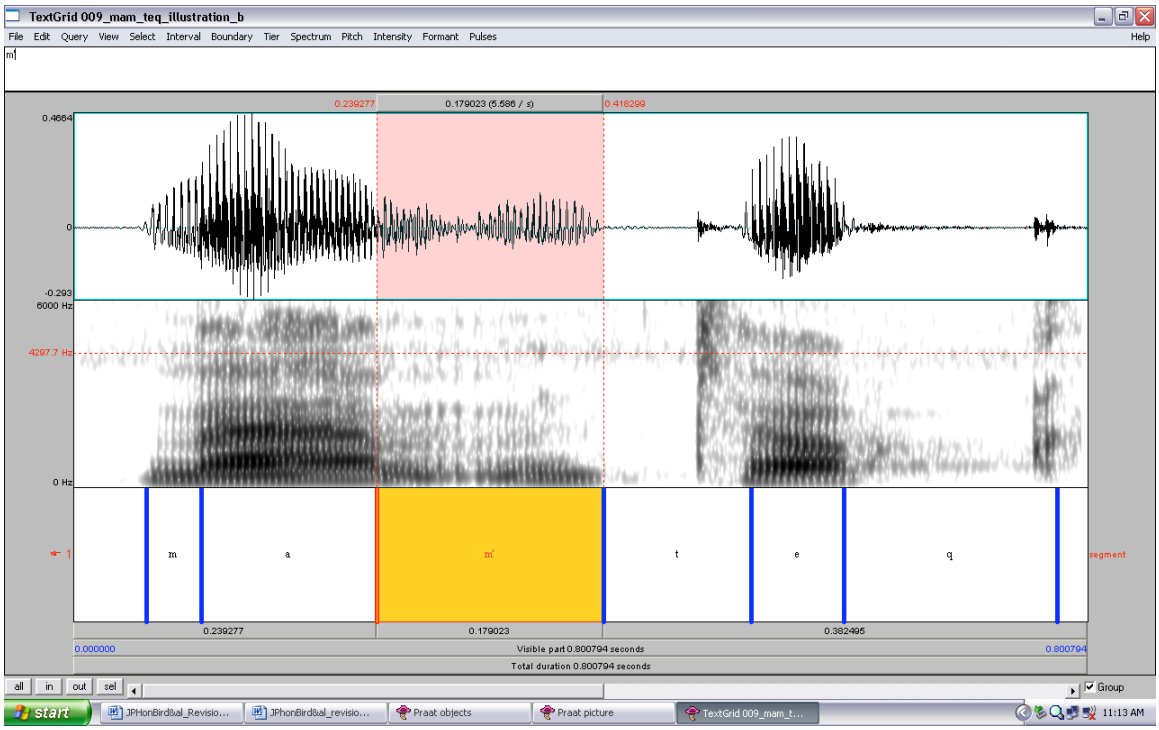

Figure 1. Plain word-initial /m/ vs. medial mid-glottalised medial /m̓/ in *mám̓təq*[4] (St'át'imcets: 'to go for a walk')

Existing descriptions of timing in GRs that might support one or another of the proposals described above are rare; in particular, very few comprehensive instrumental analyses of these sounds have been conducted (see below). Gordon and Ladefoged (2001), based on a review of published work on GRs, note that in general pre-glottalisation is most common, but mention a number of languages in which post-vocalic resonants are post-glottalised, or variable dependent on stress or vowel length. Following Silverman (1997), they hypothesize that these timing patterns exist to enhance perceptual salience. Similarly, Howe & Pulleyblank (2001) observe that documented cases of GRs in onset position are all pre-glottalised, and conclude that, at least in onset position, "[t]here is a correlation between syllabic position and the patterns of glottal timing" (2001:76). However, a review of the literature on the Pacific Northwest languages indicates that three timing patterns are in fact attested: consistently pre-glottalised, consistently post-glottalised, and variable depending on prosodic position.

Nuu-chah-nulth (Nootka; Southern Wakashan) allows GRs only in onset position. Kim (2003) and Esling et al. (2005) show instrumentally that this language exhibits pre-glottalisation, though neither study compares GRs across different stress (stressed; unstressed) and word (initial; medial) positions. Similarly, Flemming et al. (1994) show instrumentally that in Seliš (Montana Salish; Southern Interior Salish), which allows GRs

[4] In this example and elsewhere, broad transcription is used and stress (primary) is marked with an acute accent.

in coda position as well as onset, GRs are also typically pre-glottalised, "even in final position or before a voiceless consonant" (1994:16).

Nɬeʔkepmxcin (Thompson Salish; Northern Interior Salish) however, seems to exhibit the opposite pattern: post-glottalisation. In this language GRs can occur in onset and coda position. On the basis of laryngoscopic and acoustic evidence, Carlson et al. (2004) shows that GRs are consistently post-glottalised in coda positions. Shaw et al. (2005) present acoustic evidence that GRs are post-glottalised in onset positions as well. The Nɬeʔkepmxcin data thus support the hypothesis that no absolutely fixed timing relationship exists between oral and glottal/laryngeal gestures.

Finally, some Salish languages have been described as exhibiting a third timing pattern: variable, dependent on the prosodic position of the GR. For example, according to Montler's (1986) description of Sencoten (Saanich; Central Salish) GRs, the glottal gesture is attracted to stress such that GRs are post-glottalised preceding a stressed vowel ([R^{ʔ}V]) and pre-glottalised following a stressed vowel ([V^{ʔ}R]). Leslie (1979) describes the same pattern (glottal gesture attracted to stress) for the Cowichan dialect of Halkomelem (Central Salish). In contrast, van Eijk (1997) notes that in Lower St'át'imcets the glottal gesture is repelled by stress such that GRs are pre-glottalised preceding a stressed vowel ([^{ʔ}RV]) but post-glottalised elsewhere. None of Montler, Leslie or van Eijk provides phonetic data to accompany their descriptions. Caldecott (1999) investigates glottalisation in Sencoten acoustically; her findings on intervocalic GRs support Montler's description; her findings on GRs in other positions are less conclusive. To the extent that this third timing pattern is confirmed through phonetic analysis, it also supports the hypothesis that timing between oral and glottal/laryngeal gestures are not universally fixed in GRs.

In summary, previous studies have come a long way in increasing our understanding of GRs. However, many of these studies have been limited in scope and/or have lacked instrumental substantiation. Further, cross-study comparison has been compromised by the variety of methods employed. Thus, to distinguish effects of mechanical factors vs. perceptual factors, and to distinguish between previous perceptual recoverability proposals, a systematic instrumental study of timing across various positions in different languages is needed. The following section outlines such a study, in which a unified methodology was used to study GRs in three separate languages. As other studies, it has limitations: only three languages are considered; only a preliminary acoustic analysis on a subset of GRs is included. Despite these limitations, this study provides important evidence bearing directly on the questions and issues introduced above.

Because the present study minimizes mechanical dependencies between gestures, it is assumed that any broad similarities observed between intergestural timing in GRs and other segment types (see discussion above) are attributable to perceptual factors. Predictions for this study are as follows: Based on the existing evidence, we expect that different languages will exhibit different intergestural timing patterns. If this expectation is correct, it will indicate that perceptual recoverability is not the sole factor in determining intergestural timing (at least in GRs), supporting the view of Kingston (1985, 1990). If, on the other hand, a single common pattern of intergestural timing in GRs is found to obtain across languages, then this pattern will be taken as resulting from perceptual recoverability; furthermore, if this common pattern is one in which

glottalisation is timed away from transition into vowels, it will support Silverman's (1997) theory of perceptual recoverability.

2. Methodology

The three languages considered in this study are Nuu-chah-nulth (Southern Wakashan), Nɬeʔkepmxcin (Northern Interior Salish), and St'át'imcets (Northern Interior Salish). In all three languages, the factors considered and the coding system used are the same; they are therefore outlined in section 2.1. Methodological details specific to each language are described in sections 2.2.-2.4.

2.1. General Methodology

In all three languages, data were collected to test for the role of (a) syllable structure, (b) word position and (c) stress in accounting for observed timing patterns. Syllable position is a known factor affecting timing in other kinds of multi-gesture segments (see section 1.1. above). Word position was included to rule it out as a confounding factor in any observed syllable-position effects. Stress is a factor that has been discussed specifically with respect to timing of GRs in languages of the Pacific Northwest (see section 1.2. above). In total, 13 positions were considered reflecting the range of *syllable x stress* interactions (Table I). Because of restrictions on the distribution of GRs in different languages, not all 13 conditions were testable for each language. In addition, as evident in sections 2.2.-2.4. below, the distribution of GRs across positions differs in terms of frequency, such that the number of tokens elicited across conditions varies somewhat from language to language. However, within these constraints, every effort was made to employ consistent methods across languages.

Table I provides a summary of the conditions tested, along with the languages for which each position was tested. Examples from each language are given in sections 2.2. – 2.4. Four syllabic positions are distinguished: onset, coda, intervocalic, and syllabic. Intervocalic consonants were placed in a separate category to avoid confounding effects of syllable position and segmental context (only GRs in intervocalic position are surrounded by vowels). Syllable boundaries are not included because consonant clusters surrounding the GRs may be treated differently across languages; the exact syllabification of these consonant clusters does not affect the syllabic position of the GR. The three word positions considered are initial (at the beginning of the word), final (at the end of the word) and medial (word-internal). Pre-stress is used for GRs immediately preceding the stressed vowel; post-stress for GRs immediately following the stressed vowel; and non-stress-adjacent for GRs separated from the primary-stressed vowel[5] by at least one segment.

Table I. Positions considered (# = word boundary; C = consonant; ( ) = optional; V = stressed vowel; v = unstressed vowel; _= GR; *Nɬe* = Nɬeʔkepmxcin; *Nuu* = Nuu-chah-nulth; *St'á* = St'át'imcets)[6]

Condition	*Context*	*Nuu*	*Nɬe*	*St'á*

[5] Only primary stress was considered as a factor in this study.
[6] This legend applies to tables II-IV as well.

pre-stress				
initial onset	#(C)_V	√	√	√
medial onset	vC(C)_V	√	√	√
intervocalic	v_V	√	√	√
post-stress				
medial coda	V_C(C)v		√	√
final coda	V_(C)#		√	√
intervocalic	V_v	√	√	√
non-stress-adjacent				
initial syllabic	#_CV		√	
initial onset	#(C)_v	√	√	
medial onset	VC(C)_v	√	√	√
medial coda	v_C(C)V		√	√
final coda	v_(C)#		√	√
final syllabic	C_#		√	
intervocalic	v_v	√		

In a preceding study of St'át'imcets (Bird & Caldecott, 2004) it was found that consonant sonorancy affected timing: [-son] GRs (ż,ʕ̓) were consistently pre-glottalised whereas [+son] GRs (ṁ, ṅ, l̓, l̓, ẏ, ẇ, ʕ̓ʷ) were much more variable in their timing. In order to avoid this confounding effect, only [+son] GRs were considered here. Also, pharyngeal GRs do *not* involve independent articulations: the laryngeal articulator is responsible for both place of articulation and phonation (Esling et al., 2005). Pharyngeal GRs were therefore excluded from this study. The subset of GRs examined, in all three languages being studied, was: / ṁ, ṅ, ẏ, ẇ/[7].

Data were elicited in different ways across studies, to accommodate the speakers of each language (see sections 2.2-2.4 for details): for Nuu-chah-nulth, the speaker was asked orally to translate English words and pronounce them in a frame sentence; for Nɬeʔkepmxcin, words were also elicited orally as translations, but were pronounced in isolation. In St'át'imcets, speakers read words in frame sentences from a computer screen. While none of these elicitation methods are ideal to gain natural speech, they are relatively consistent in that target words are elicited in citation form[8]. Previous research has shown that the effects of different elicitation methods on speech patterns are minimal

[7] North American Phonetic Alphabet (NAPA) symbols are used throughout this paper rather than IPA symbols for two reasons: 1) They are conventional in scholarly documentation of these languages and 2) the speakers of these languages are more familiar with them than IPA symbols. The differences between the IPA and NAPA evident in this paper are 1) the use of /ẏ/ to represent IPA /j'/ and 2) the position of the glottalisation marker with respect to the segment. The representation of glottalised resonants with the diacritic above the segment, rather than preceding or following, allows for a neutral representation of the timing of these segments.

[8] Frame sentences were held constant and as a result speakers could easily work out which word was targeted, leading to citation forms in production; this is a flaw of using consistent frame sentences.

(Klatt, 1976).

Data were analysed through visual inspection of the spectrogram and waveform. Cues to glottalisation included the presence of a glottal stop[9] which does not act as a separate phoneme (as evident from phonological alternation or morphophonemic processes); duration (in the case of Nuu-chah-nulth); a sharp fall or rise in pitch, or a fall in intensity, which could not be attributed to other factors; or the presence of laryngealisation or creak on resonants or the adjacent edges of vowels, as evidenced by aperiodicity in the waveform. Any one of these acoustic properties was taken as indicating glottalisation, though sometimes they occurred in combination. More sophisticated analyses – e.g. laryngoscopic, electro-glottalographic (EGG), aerodynamic, or spectral – would certainly increase our understanding of the characteristics of GRs. The analyses conducted here serve as an easily accessible, preliminary look at these sounds.

The following definitions were used with respect to timing:

- **pre-glottalised**: glottalisation preceded or occurred simultaneously with the resonant onset and diminished prior to resonant offset.
- **post-glottalised**: glottalisation followed the resonant onset, and extended until or beyond the resonant offset (resonant was modal at onset).
- **mid-glottalised**: glottalisation occurred in the middle of the resonant, surrounded by modal voicing[10] in both resonant onset and offset.
- **pre and post glottalised**: glottalisation occurred at onset and offset, but was interrupted by modal voicing in between.
- **throughout**: glottalisation occurred throughout the resonant.

Because not all of the data were analysed by the same person across all three languages, blind validation tests were done in which selected sets of tokens were coded by each of two people (one consistent across all three languages) and compared for consistency. For St'át'imcets, two researchers each coded approximately two thirds of the 235 elicited tokens independently (157 tokens each), with one third overlap (78 tokens). Coding was consistent across researchers for approximately 90% of the 78 tokens they both coded. In cases of disagreement, researchers re-examined the tokens together and settled on a single coding. For Nɬeʔkepmxcin, a single researcher coded all the data. A second researcher cross-checked 140 tokens of the total 324 elicited tokens (43%). Coding was consistent across researchers for 118 (84%) of these 140 tokens. In cases of disagreement, the primary coder's judgement was used. Similarly for Nuu-chah-nulth, a single researcher coded all data. A second researcher cross-checked 68 of the total 206 elicited tokens (33%). Coding was consistent across researchers for 67 (99%) of the data. As for Nɬeʔkepmxcin, in cases of disagreement the primary coder's judgment was used.

[9] Based on Esling et al. (2005), we assume that, in the GRs considered here, a full stop is glottal rather than epiglottal; acoustic analysis cannot be used to distinguish between the two.

[10] In some intervocalic cases, formant transitions were visible in the vowel preceding the GR. Unless the transitions were followed by a modal voiced consonantal interval preceding glottalisation, the GR was coded as pre-glottalised.

2.2. Nuu-chah-nulth

Nuu-chah-nulth is a Southern Wakashan language spoken along the West Coast of Vancouver Island from Barkley Sound to Quatsino Sound. There are an estimated 200-300 speakers remaining (Kim 2003). Unlike the other languages in this study, Nuu-chah-nulth has only four glottalised resonants -- /m̓, n̓, y̓, w̓/-- which occur only in onset position (Sapir 1938; Rose 1976; Stonham 1994, 1999).

2.2.1. Speaker

The subject is a fluent 59-year old female speaker of the Ahousaht dialect of Nuu-chah-nulth. She grew up on Flores Island and currently lives in Victoria, B.C. She uses the language daily to communicate with her elderly mother.

2.2.2. Stimuli

Tokens were selected from Kim (2003), an unpublished word list and volunteered by the speaker. The speaker's familiarity with each token was confirmed. For each token, the speaker was then prompted with the English translation and asked orally to pronounce it in the frame sentence "wa mitsish X 7am'iimit7i" ("I said X yesterday") or "wa mitsish X wa" (I said X, PART). Each sentence was repeated three times in a row.

2.2.3. Procedure

Data were recorded in two sessions in a quiet project room at the Inter-disciplinary Speech Research Laboratory at the University of British Columbia (UBC). The first session was recorded using an Audio-technica AT-831b cardioid condenser lavalier microphone to record to a Marantz PMD 430 tape recorder and digitised using Sound Studio 2.07 on an Apple iMac running OSX. The second session used the same microphone to record directly to a Toshiba Satellite PC using Praat 4.1.1. (Boersma & Weenink, 2004). Data from session 1 were analysed using Praat v. 4.1.13 on a PC running Windows XP. Data from session 2 were analysed using Praat v. 4.3.11 (Boersma & Weenink, 2006) on a PC running Linux.

2.2.4. Analysis

In total, 62 sentences were used, each one repeated three times. Some target words contained multiple GRs, resulting in a total of 206 GRs considered. All orthographic GRs were produced as phonetically glottalised. Twenty-four tokens were discarded due to clipping or mispronunciation, resulting in a total of 182 GRs analysed. As mentioned above, GRs occur only in onset position in Nuu-chah-nulth. For this reason a relatively small subset of the positions in Table I above are included. Table II provides the distribution of GRs across positions:

Table II. Distribution of GRs across stress and syllable positions in Nuu-chah-nulth

Condition	*Context*	*Example*	*Total*
Pre-stress			
initial onset	#_V	**m̓**áa (to bite)	**27**
medial onset	vC_V	ƛ̓at**w̓**áa (to paddle a canoe)	**15**

intervocalic	v_V	tum̓áqx̌ (dark as night)	**46**
Post-stress			
intervocalic	V_v	t̓án̓a (child)	**34**
Non-stress-adjacent			
initial onset	#_v	m̓aɬáa (cold)	**36**
medial onset	VC_v	t̓áatn̓aʔis (children)	**17**
intervocalic	v_v	qʷiqʷɬaam̓inhíi (what their names are)	**7**
Total			**182**

2.3. Nɬeʔkepmxcin

Nɬeʔkepmxcin, also known as Thompson River Salish, is a Northern Interior Salish language spoken in south central British Columbia and across the Canada-US border into Washington State. Nɬeʔkepmx communities extend along the Fraser River from Yale to Lillooet, the Thompson River from Lytton to Ashcroft, the Nicola River from Spences Bridge to Nicola Lake, and the Coldwater River from Merritt extending about 14 miles south (Jimmie, 1994). It is estimated that across 15 Nɬeʔkepmx bands, there are between 350-500 fluent speakers (p.c. M. Jimmie).

The phonological inventory of Nɬeʔkepmxcin includes 9 contrastive glottalised resonants: m̓, n̓, l̓, w̓, y̓, z̓, ɣ̓, ʕ̓, ʕ̓ʷ. GRs occur in a wide range of positions: word-initial, word-final, and word-medial as onset or coda. Like plain resonants, GRs are most commonly adjacent to a vowel, but they also occur as syllabic.

2.3.1. Speakers

Two female native speakers of Nɬeʔkepmxcin, aged 59 and 67, participated in the study. Both speakers grew up in the Lytton area, and share dialectal features of this region. As adults each has spent considerable time in the city, but they continue to speak the language regularly with relatives and friends.

2.3.2. Stimuli

Words containing GRs were selected from Thompson and Thompson's (1996) dictionary, from M. Jimmie's (2002-2004) UBC First Nations Languages Program teaching materials, and from a general database of fieldwork with these two speakers. Each target word was elicited orally as a translation from English; if the consultant did not readily produce the word, she was prompted with the Nɬeʔkepmxcin target pronounced by one of the authors. Several repetitions of each response were recorded. Because of differences in dialect between certain dictionary entries and the speakers, not all targeted words contributed to our data for analysis. Only words that had a clear instance of a GR, as perceived by two trained transcribers, were included.

2.3.3. Procedure

Data were recorded to a Marantz 670 PMB solid-state digital recorder with two Audio-technica AT-831b cardioid condenser lavalier microphones at various locations on the UBC campus. The data were then transferred to a Macintosh Powerbook G4 for analysis in Praat v.4.3.02 (Boersma & Weenink, 2006).

2.3.4. Analysis

A total of 324 tokens were elicited for this analysis. Of these, 39 were excluded, 9 due to background noise interference, 22 where glottalisation was expected but not apparent, and 8 due to other various mispronunciations. Table III provides the distribution of GRs across positions.

Table III. Distribution of GRs across stress and syllable positions in Nɬeʔkepmxcin

Description	*Context*	*Example*	***Total***
Pre-stress			
initial onset	#_V #C_V	ẏ́ɛ́ (good) pẏ́ím (squeeze)	**27**
medial onset	vC_V	ḵʷɛtṅ́íy (mouse)	**9**
intervocalic	v_V	ẇɛẇ́íkm̓ (seeing things)	**25**
Post-stress			
medial coda	V_Cv V_CCv	šχáẏ́wi (husband) q̓əpéẅštn̓ (belt)	**40**
final coda	V_# V_C#	ḵɛtníṁ (fishing with a rod) šwéẅɬ (trout)	**69**
intervocalic	V_v	húṁɛɬ (good-bye)	**35**
Non-stress-adjacent			
initial syllabic	#_CV	n̓̀tɛ́š (give (food))	**14**
initial onset	#_v	ẏ́ɛɬẏ́ɛɬiʔt (cough)	**11**
medial onset	C_v	šqozépẏ́ɛ (cheek)	**3**
medial coda	v_CV v_CCV	n̓ʕʷoẏ́télq̓š (nightgown) qʷəṅqʷṅóχ (very sick)	**28**
final coda	v_# v_C#	nɛ́xʷəṁ (it's true) ʔíṁnəṁš (animal makes a noise)	**22**
final syllabic	C_#	ẇɛtúšn̓̀ (meet someone)	**2**
Total			**285**

2.4. St'át'imcets

St'át'imcets is also a Northern Interior Salish language, comprising two main dialects: Upper and Lower. It is spoken in 11 bands: Upper St'át'imcets is spoken in Pavilion, Fountain, Lillooet, Bridge River, Seton Portage/Shalalth, and Cayoose Creek; Lower St'át'imcets is spoken in Mount Currie and D'Arcy; Douglas (possibly a branch of Lower) is spoken in Samahquam, Sqatin and Port Douglas. In total, there are approximately 100 fluent speakers over the age of 60 (http://www.uslces.org/uslces.html)

Like other Salish languages, St'át'imcets has an extremely rich consonant inventory, including the following GRs: /ṁ, ṅ, l̓, l̓̀, ẇ, ẏ, ż, ɣ̇, ʕ̓, ʕ̓ʷ[11] /, all of which have

[11] As with glottalised pharyngeals in other Interior Salish languages, glottalised pharyngeals in St'át'imcets are often realised acoustically as a stop (Bird & Caldecott 2004). Whether they are in fact epi-glottal stops such as those in Nɬeʔkepmxcin cannot be ascertained through acoustic data alone.

non-glottalised counterparts. The sounds are relatively unrestricted in terms of the word and syllable positions in which they occur; the only position in which they are rare is word-initially[12]. To the extent that phonological GRs do occur in this position, they are often not glottalised phonetically (see below). In addition, syllabic GRs do not occur.

2.4.1. Speakers

Three fluent speakers of Upper St'át'imcets participated in this study: CA: mid 60s, brother of AP, Upper St'át'imcets; AP: early 60s, sister of CA, Upper St'át'imcets; LR: mid 50s, Upper St'át'imcets with some Lower St'át'imcets influence (from mother). All three speakers use the language to communicate with family and elders in the community.

2.4.2. Stimuli

Words containing GRs were selected from van Eijk's (1987) *A Dictionary of the Lillooet Language*. Each speaker's familiarity with these words was checked before the words were framed in the sentence: Tsut sDaryn X inátcwas ("Daryn said X yesterday"). Speakers were then asked to read each sentence off a computer screen; the sentences were spelled in the St'át'imcets practical orthography, with which all three speakers are familiar.

2.4.3. Procedure

Recording sessions were held in the kitchen of a private home in Lillooet, British Columbia. Subjects were asked to read sentences from a computer screen and were recorded using a Sony MZ-B10 portable mini-disc recorder and a Sony ECM-T115 lapel microphone. Data were then uploaded to an iMac OSX using Sound Studio 2.07. Data were analysed on two Toshiba Satellite PCs using Praat v. 4.1.13 (Boersma & Weenink, 2006).

2.4.4. Analysis

In total, 225 words were recorded. Some words contained multiple GRs, leading to a total of 235 GRs. All of these words were either mono- or disyllabic, which meant that intervocalic consonants were either pre- or post-stress. Twenty-one tokens were discarded for various reasons (mispronunciations, recording errors, etc.). Of the 214 remaining GRs, only 172 were actually phonetically glottalised, based on auditory judgment and a visual inspection of the spectrogram. This fact reflects a change in progress in St'át'imcets, whereby glottalisation is becoming neutralised, particularly in onset position (H. Davis, p.c.). In total then, 172 GRs were analysed: 92 /m̓/, 29 /n̓/, 30 /y̓/, and 21 /w̓/. As can be seen in Table IV below, most of these are in coda and intervocalic position.

Table IV. Distribution of GRs across stress and syllable positions in St'át'imcets

Condition	*Context*	*Example*	***Total***
Pre-stress			
initial onset	#_V	**m̓**ə́m̓šməš (little cow)	**2**

[12] Word-initial GRs are more frequent in other Interior Salish languages, e.g. Nɬeʔkepmxcin (considered here) and Nxa'amxcín (Moses Columbian; Southern Interior Salish; E. Czaykowska-Higgins, p.c.).

	#C_V	kn̓úšaż (kinnikinnick bush)	
medial onset	vC_V vCC_V	lulm̓úɬ (always jealous) təqtw̓áxʷ (to wrestle)	**4**
intervocalic	v_V	xim̓ín (to put something out of sight)	**16**
Post-stress			
medial coda	V_Cv V_CCv	mím̓ša? (flat; thin) mək'iláw̓šxən (bannock)	**21**
final coda	V_# V_C#	təxʷčám̓ (to raise the price of something) q̓əm̓p (ten)	**44**
intervocalic	V_v	kaxím̓a (to disappear temporarily)	**25**
Not-stress-adjacent			
medial onset	VC_v	pə́qm̓əqʷ (to have white (or grey) hair)	**4**
medial coda	v_CV	šəm̓xál (to cut a hide into strips of things)	**9**
final coda	v_#	píχəm̓ (to hunt)	**47**
Total			**172**

3. Results

3.1. Nuu-chah-nulth

GRs in Nuu-chah-nulth are overwhelmingly pre-glottalised across all resonants and all positions: 98% of GRs examined were pre-glottalised. The remaining 2% were glottalised throughout or mid-glottalised. No GRs were post-glottalised. As Table V illustrates, neither syllable position nor stress affected the realisation of glottalisation.

Table V. Distribution of timing patterns across conditions in Nuu-chah-nulth (numbers in parentheses = percentages; shaded cells indicate the 'majority' case for each condition)

Condition	*pre-*	*post-*	*mid-*	*pre&post-*	*thru-*	***Total***
pre-stress						
initial onset	25 (92)		1 (4)		1 (4)	**27**
medial onset	15 (100)					**15**
intervocalic	45 (98)				1 (2)	**46**
post-stress						
intervocalic	33 (97)				1 (3)	**34**
non-stress-adjacent						
initial onset	36 (100)					**36**
medial onset	17 (100)					**17**
intervocalic	7 (100)					**7**
Total	**178 (97.8)**		**1(0.6)**		**3(1.6)**	**182**

3.2. Nɬeʔkepmxcin

The prevalent timing pattern for GRs in Nɬeʔkepmxcin is post-glottalisation (81%). Intervocalic position displays greater variance in this timing than other contexts. However, instances of post-glottalisation significantly outnumber those with other timing patterns, and are found in all of the syllable positions examined in this study. Table VI provides the distribution of timing patterns across conditions. Despite the variability in these data, neither stress nor syllable position has a major effect on the timing of glottalisation for resonants, with the exception of those occurring intervocalically. In this position the timing is less stable, particularly pre-stress, with cues to glottalisation tending to be farther from the stressed vowel.

Table VI. Distribution of timing patterns across conditions in Nɬeʔkepmxcin (numbers in parentheses = percentages; shaded cells indicate the 'majority' case for each condition)

Condition	*pre-*	*post-*	*mid-*	*pre&post-*	*thru-*	***Total***
pre-stress						
initial onset		25 (93)		2 (7)		**27**
medial onset		6 (67)			3 (33)	**9**
intervocalic	7 (28)	5 (20)	6 (24)		7 (28)	**25**
post-stress						
medial coda	1 (2.5)	34 (85)	1 (2.5)	2 (5)	2 (5)	**40**
final coda		68 (99)			1 (1)	**69**
intervocalic		23 (65.7)	9 (25.7)		3 (8.6)	**35**
non-stress-adjacent						
initial syllabic		12 (86)		1 (7)	1 (7)	**14**
initial onset		8 (73)			3 (27)	**11**
medial onset		3 (100)				**3**
medial coda		26 (93)			2 (7)	**28**
final coda		20 (91)			2 (9)	**22**
final syllabic		2 (100)				**2**
Total	**8 (3)**	**232 (81)**	**16 (6)**	**5 (2)**	**24 (8)**	**285**

3.3. St'át'imcets

The overall generalisation exhibited by the St'át'imcets data (Table VII) is that timing depends on syllable position, but not on stress. GRs are most often pre-glottalised in onset position, post-glottalised in coda position, and mid-glottalised intervocalically, regardless of stress position. This pattern indicates that glottalisation tends to occur as far away from the adjacent vowel as possible. It is worth pointing out here that although timing patterns are largely predictable based on syllable position, there is a substantial amount of variability within each position. This may indicate that other factors are at play here as well (c.f. Bird & Caldecott, 2004), or simply that the effect of syllable position on timing is stochastic rather than categorical. Interestingly, the highest degree of variability is found in St'át'imcets, in which glottalisation often seems to be undergoing neutralisation. Both variability and neutralisation could stem from the fact that glottalisation carries an extremely low functional load in St'át'imcets (H. Davis, p.c.).

Table VII. Distribution of timing patterns across conditions in St'át'imcets. (numbers in parentheses = percentages; shaded cells indicate the 'majority' case for each condition)

Condition	*pre-*	*post-*	*mid-*	*pre&post-*	*thru-*	***Total***
pre-stress						
initial onset	2 (100)					**2**
medial onset	2 (50)	1 (25)	1 (25)			**4**
intervocalic	3 (19)	1 (6)	12 (75)			**16**
post-stress						
medial coda		11 (52)	9 (43)	1 (5)		**21**
final coda	1 (2)	35 (80)	3 (7)		5 (11)	**44**
intervocalic	7 (28)	3 (12)	14 (56)		1 (4)	**25**
non-stress-adjacent						
medial onset	4 (100)					**4**
medial coda	2 (22)	4 (44)	3 (33)			**9**
final coda	1 (2)	37 (79)	3 (6)	2 (4)	4 (9)	**47**
Total	**22 (13)**	**92[a] (33)**	**45 (26)**	**3 (2)**	**10 (6)**	**172**

[a] Note: this number is disproportionately high because of the frequency of coda GRs, most of which are post-glottalised.

4. Discussion

The above results show three distinct but consistent patterns of intergestural timing. No single factor, such as stress or syllable or word position could account for all three languages. Results confirmed that Nuu-chah-nulth GRs, which occur only in onset position, are consistently pre-glottalised, regardless of word position or stress. Nɬeʔkepmxcin, where the distribution of GRs is much more varied, shows the opposite pattern, with the majority of conditions realised as post-glottalised. In St'át'imcets, glottalisation tends to occur as far from the adjacent vowel(s) as possible, leading to variable timing: pre-glottalisation in onset position; post-glottalisation in coda position; and mid-glottalisation intervocalically.

The observed cross-linguistic variability in GR timing is not indicative of a universal pattern such as that found by Gick et al. (2006) for liquids. This confirms that there is no mechanical dependency between the oral and glottal/laryngeal articulators that would force cross-linguistic similarities[13]. It also suggests that there are no universal perceptual salience restrictions that govern intergestural timing in these segments. Rather, timing is determined on a language-specific basis. That stress also plays no obvious role in intergestural timing in any of these languages is interesting and perhaps somewhat unexpected, given that it has been claimed to be a major factor in the description of

[13] Based on Esling's (in press) Laryngeal Articulator model, it is expected that pharyngeal GRs will exhibit less variability than other GRs because the articulators involved are much less independent: the tongue root is engaged in articulating the place and manner of the resonant (Namdaran, 2005) in addition to being passively engaged in the glottal/laryngeal articulation (as a result of laryngeal sphinctering).

timing in other Pacific Northwest languages, such as Halkomelem and SENCOTEN (see section 1.3 above). Note that stress may affect the mode of *realisation* of glottalisation (full glottal stop vs. laryngealisation) rather than the timing (c.f. Pierrehumbert & Talkin (1992) on glottalisation in English). It is hoped that future research will address this question.

The St'át'imcets results taken alone might support the position of Silverman (1997), in the sense that glottalisation is timed as far away from the vowel as possible, perhaps to satisfy perceptual restrictions. However, the results taken as a whole clearly fail to reflect a single, universal pattern of pre-glottalisation in resonants, even in onset position. As such, the results do not support Silverman's hypothesis that a single universal factor – perceptual recoverability – is responsible for intergestural timing. However, the results do show considerable within-language systematicity, more so than might be expected based on Kingston (1985, 1990). If there were no constraint whatsoever on intergestural timing, we would not have predicted the three distinct and consistent patterns of intergestural timing that emerge from these data. Two possible explanations could account for these patterns: (1) they result from factors other than perceptual recoverability; (2) they result from the *interaction* between perceptual recoverability and other language-specific factors.

Under the first explanation, perceptual recoverability plays no role in determining intergestural timing; other, language-specific factors account for attested patterns. If neither mechanical nor perceptual constraints on timing exist, languages are free to manipulate timing for language-specific linguistic and indexical purposes (e.g. to reinforce stress cues or to signal dialectal differences), allowing for a wider range of timing patterns than has previously been observed in studies of other types of segments. It is interesting to note that St'át'imcets, with its variable timing, shows language change in the direction of glottalisation loss. In Nuu-chah-nulth, on the other hand, glottal timing is consistent, and the language shows no such loss. The question of how the possibility of variability in GR production may lead to language-specific choices in phonetic form and to changes from one phonetic form to another awaits further research.

Under the second explanation, perceptual recoverability does play a role, but it is mitigated by other language-specific factors. Competition for saliency among incompatible cues may mean that the perceptually optimal timing configuration of segments could differ systematically across languages, depending on which cue the language chooses to optimise. This weaker version of perceptual recoverability is compatible in principle with the notion that languages avoid circumstances that might compromise perceptual cues to consonants and vowels, but do so in a language-specific manner. With respect to GRs, while a peripheral placement of glottalisation may enhance the perceptibility of consonant-vowel transitions, this same placement may decrease the perceptibility of the glottalisation itself. Thus, it remains possible that a perceptual recoverability-based account could explain a variety of distinct timing patterns (contra Silverman 1997), depending on the relative importance of each of the physical events in each language.

Under either explanation, language-specific requirements play an important role in determining timing. Given that, in this study, three languages exhibited three distinct timing patterns, the prediction is that other patterns may arise when more languages are considered, e.g. glottalisation timed adjacent to the syllable nucleus (the opposite pattern

from that found in St'át'imcets) to enhance the perceptual salience of glottalisation. Testing this prediction will further our understanding of the factors contributing to variable timing.

The St'át'imcets pattern observed here may be taken as support for an explanation in which perceptual salience plays at least some role. Its vowel-avoidant timing is reminiscent of the syllable-based asymmetry observed in previous studies of intergestural timing in other segment types (see section 1.1 above). This similarity in timing governed by syllable-position across such dramatically different segment types alludes to a common factor, which could very well be perceptual salience. At the very least, we must consider the possibility that there is a universal underlying factor that plays a role in syllable position dependent timing, even if we do not yet fully understand the extent of its influence.

In summary, these results support the view that, while perceptual recoverability is clearly not the sole factor in determining intergestural timing patterns, it may still play a role in intergestural timing across languages, and across a wide variety of segment types. Evaluating this role requires a better understanding of perceptual recoverability, something that will hopefully come with continued research in this area.

5. Conclusion

This paper presents results from a cohesive, systematic study of three languages spoken in the Pacific Northwest – Nuu-chah-nulth, Nɬeʔkepmxcin, and St'át'imcets – and has shown that no single timing pattern holds of glottalised resonants across languages. No single factor, such as stress, syllable or word position could account for the three distinct but consistent timing patterns in these three languages. Nor can assumptions about timing be extended within language families, as St'át'imcets and Nɬeʔkepmxcin, areally adjacent Interior Salish languages, have distinct patterns. Given this result, and assuming no mechanical dependencies exist between articulators, a strong perceptual recoverability hypothesis must be rejected. While GRs do not show a universal timing pattern, neither is the timing completely random, which we might expect given a broad interpretation of Kingston (1985). A weaker version of the perceptual salience hypothesis may still be possible, in which perceptual recoverability interacts with other factors in the language to lead to certain tendencies in timing.

The present study allowed intergestural timing to be observed essentially unconstrained by the mechanical factors that have confounded previous findings in this area. Although it is possible that the variety of patterns found in this study could be considered the result of perceptual factors (interplaying with the perceptual "priority" of each event in each language – mentioned above), these findings also leave open the possibility that timing *per se* may be manipulated within a language in order to achieve higher linguistic goals (i.e., those beyond achieving efficient production and perceptibility). Future research into the within-language functions of the language-specific timing patterns observed in this study would help to distinguish between these possibilities.

This study highlights the importance of conducting instrumental research on endangered languages. Glottalised resonants are rare cross-linguistically, but abundant in the languages of the Pacific Northwest. The fact that three languages, two of which are closely related, exhibit such distinct timing patterns demonstrates the need to broaden the empirical basis upon which claims of universality are made (both in terms of the types and number of languages considered, and the use of instrumental analysis as compared to auditory impressions). Languages such as those of the Pacific Northwest are essential to consider when evaluating models and theories of linguistic structure. Because these languages are critically endangered, it is crucial to continue researching them while we still have the opportunity to do so.

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