Ejective Typology: The Case of Lushootseed*

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Abstract: This study investigates ejectives in Lushootseed. The goal of this study is to address whether Lushootseed ejectives can be classified as stiff or slack, using Lindau's (1984) and Kingston's (1985, 2005) typology for ejectives. A study was performed on one speaker to analyze acoustic properties (i.e., VOT, f0 perturbation, jitter perturbation, and rise time) of Lushootseed ejectives. The results reveal that Lushootseed ejectives showed properties of both stiff and slack ejectives. These findings suggest that there is no need for a typological distinction among ejectives in Lushootseed.

Keywords: Lushootseed, stiff ejectives, slack ejectives, VOT, f0 perturbation, jitter perturbation

1 Introduction

The research question for this paper is whether ejectives can be classified as stiff or slack. According to Lindau (1984) and Kingston (1985, 2005), there are cross-linguistic differences in the realization of ejectives. These cross-linguistic features differ in several acoustic properties. According to Kingston (2005), stiff ejectives are characterized by a silent period between the consonant release and voice onset. This results in a long VOT. Moreover, stiff ejectives are achieved with increased longitudinal tension and medial compression of the vocal folds, resulting in a raised f0 at voice onset and a tense or modal voice quality. Other characteristics of stiff ejectives include a sharp rise in the amplitude of the vowel and relatively intense burst. Stiff ejectives apparently occur in Tigrinya (Kingston 1985), Nez Perce (Aoki 1970), Montana Salish (Flemming et al. 2008), K'ekchi (Ladefoged & Maddieson 1996), and Navajo (Lindau 1984).

On the other hand, slack ejectives are characterized by a short VOT and little longitudinal tension, resulting in a depressed f0 at voice onset. The voice quality at voice onset is creaky. Other characteristics of slack ejectives include a slow rise time in the amplitude of the vowel and normal burst. Slack ejectives apparently occur in Hausa (Lindau 1984, Lindsay et al. 1992), Quiche (Kingston 1985), and Gitksan (Ingram & Rigsby 1987). Table 1 provides a summary of the Lindau/Kingston classification of stiff and slack ejectives.

Table 1: Proposed ejective typology following Lindau (1984) and Kingston (1985, 2005)

	Stiff ejective	Slack ejective
VOT	long	short
f0	raised	depressed
voice quality	modal or tense	creaky
burst	intense	normal
rise time	fast	slow

However, Warner (1996), Kingston (1985), and Wright et al. (2002) report language-dependent and speaker-dependent variation in these acoustic features for ejectives. Although a relatively short

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Papers for the International Conference on Salish and Neighboring Languages 56.
D. K. E. Reisinger, Hannah Green, Laura Griffin, Marianne Huijsmans, Gloria Mellesmoen, and Bailey Trotter (eds.). Vancouver, BC: UBCWPL, 2021.

VOT, irregular voicing at voice onset, weak burst and slow rise times are observed for ejective stops in Ingush (like slack ejectives), there is a raised pitch at voice onset (like stiff ejectives) (Warner 1996). Kingston (1985) reports speaker variation in f0 following ejectives in Tigrinya. Contrary to the predictions of ejective typology proposed by Lindau (1984) and Kingston (1985, 2005), Wright et al. (2002) found considerable variation across speakers in Witsuwit'en. Some speakers showed properties of stiff and slack ejectives, such as short VOT (like slack ejectives) and modal/tense voice quality at voice onset (like stiff ejectives). Other speakers showed depressed f0 (like slack ejectives) and long VOT (like stiff ejectives).

Little research has explored within-speaker variability for ejective consonants. In this study, I examine the acoustic properties of Lushootseed ejectives. I compare these properties with unaspirated stops in Lushootseed. This study predicts that Lushootseed ejectives show acoustic properties that are observed in both stiff and slack ejectives. This suggests that there is no need to classify ejectives as either stiff or slack in Lushootseed. Thus, there is no need for a typological distinction among ejectives.

2 Background

Lushootseed (ISO 639-3: lut) is a Coast Salish language that is spoken in the Puget Sound region of the Pacific Northwest (PNW). According to Lonsdale (2001), Lushootseed is classified as a polysynthetic language — that is, a language where words are made up of many morphemes creating sentence-like structures. There are two regional dialects that are known in Lushootseed: Northern Lushootseed and Southern Lushootseed (see Figure 1 for a map of the distributions). According to Ethnologue (Eberhard, Simons & Fennig 2021), there are no first language (L1) speakers remaining for either dialect. Phonological differences are not understood well between these dialects. According to Hess (1977), the dialects differ by their placement of stress. For example, the first syllable that does not contain a schwa in a stem is the location of primary stress in the northern dialect, while the primary stress is always on the first syllable of a stem in the southern dialect. Lushootseed has 37 contrastive consonants. Nine of these are ejectives. In this paper, only one of these (i.e., the ejective alveolar stop /t'/) is examined.

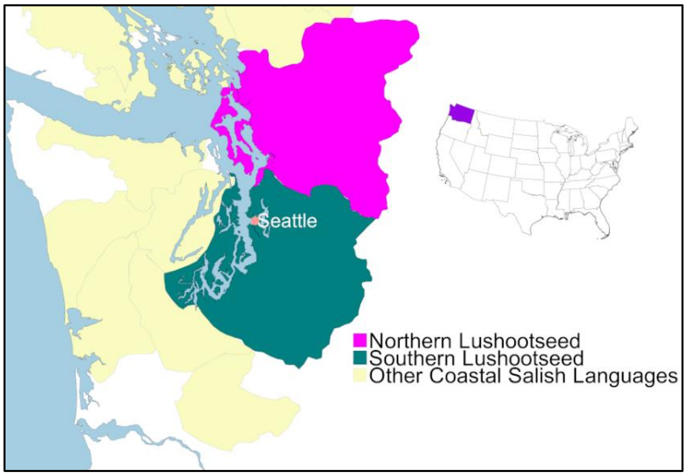

Figure 1: Regional dialects of Lushootseed. Adapted from Thom (2011).

3 Methods

3.1 Recordings

As there are no remaining L1 speaker of Lushootseed, acoustic properties of recordings dating back to the early 1950's were examined. Several recordings were recovered from the University of Washington's Ethnomusicology Archives (Burke Museum 2015) and were digitized at 44.1kHz with 16-bit depth. These recordings were resampled at 22.05kHz to increase precision and attenuate for high-frequency noise. The recordings that were examined come from the Metcalf collection. From this collection, two of these recordings (Daniels 1952, 1954) were examined. These recordings have a combined length of approximately 40 minutes and were made by a single speaker. These were recordings of traditional Salish myths.

3.2 Speaker

In this study, a female native elder speaker (abbreviated AD) who spoke Lushootseed as her primary language was examined. AD was born near the Green River in the early 1870s. She spoke the Southern dialect of Lushootseed and lived in the Muckleshoot tribal reservation.

3.3 Measurements

In this study, four of the major acoustic components for ejectives were examined. These were (i) Voice Onset Time (VOT), (ii) f0 perturbation, (iii) jitter perturbation, and (iv) rise time. The software that was used to analyze these recordings was Praat (Boersma & Weenink 2021). Ejectives were qualitatively examined by using visual inspection of a wide-band spectrogram and a waveform. VOT has been used to measure aspiration contrast in stops (Lisker & Abramson 1964). Moreover, it has been used to compare ejectives with other laryngeal settings. VOT measurements were taken from the waveform. Spectrograms accompanied the waveforms for reference. VOT was measured by taking the interval between the initial burst release to the first positive or negative movement of periodicity (i.e., voice onset).

Average f0 and jitter was obtained from a 46.5ms window at voice onset and vowel midpoint. Voiced period marks were generated by Praat. These marks were inspected for errors and corrected by hand if necessary for jitter and f0 measurements. Average f0 was calculated by taking the inverse of the time between each voiced pulse that were marked in the window. Jitter is the variation in the duration of successive fundamental frequency cycles (Gordon & Ladefoged 2001). The mean percent jitter ratio was calculated by taking the average absolute difference between consecutive pulses divided by the average period and multiplied by 100 (Koike 1973). Energy was obtained at the vowel onset and the vowels peak amplitude. RMS energy was calculated from the absolute amplitude values in a frame and was divided by the duration of the frame. Decibels of Sound Pressure (dB SPL) was calculated from 10 times the log (base 10) of RMS energy values. F0 and jitter were normalized, as shown in Table 2. F0 perturbation was calculated by subtracting the mean f0 at vowel onset from the mean f0 at vowel midpoint. Jitter perturbation was calculated in a similar way. Rise time was calculated by subtracting the RMS energy (in dB) at the vowel's peak amplitude from the RMS energy (in dB) at the vowel onset.

Table 2: Formulas for normalized measures

Measurement	Formula
f0 perturbation	(mean f0 at onset) – (mean f0 at midpoint)
jitter perturbation	(mean jitter at onset) – (mean jitter at midpoint)
rise time	(RMS energy at vowel peak) – (RMS energy at vowel onset)

3.4 Data analysis

This study examined voiceless unaspirated alveolar stops /t/ and ejective alveolar stops /t'/ in root-initial position. The first syllable of a root is always stressed in the Southern dialect. Root-initial ejectives were studied to control for possible variations due to differences in stress. The laryngeal types (unaspirated vs. ejective) and voice onset quality (creaky vs. modal) were examined. 36 ejectives and 41 unaspirated stops were examined.

Jitter values tend to be higher during creaky phonation than other phonation types (Belotel-Grenié & Grenié 2004, Gordon & Ladefoged 2001, Javkin & Maddieson 1983, Kirk et al. 1993). The average jitter at voice onset for unaspirated stops (which always had a modal voice onset quality) was close to zero (*M*=1.81, *SD*=1.08). Any values that were considered a significant departure from the average jitter (at voice onset) of unaspirated stops were above 4.5%, which was observed as values that approximates closer to irregular glottal pulses (as in creaky phonation). For ejectives, when the mean percent jitter ratio was greater than 4.5% at voice onset, the voice onset quality of the ejective was labeled "creaky". Moreover, based on impressionistic observations, sounds with a mean percent jitter ratio greater than 4.5% sounded creaky in the 46.5ms window. Values below 4.5% were labeled "modal". The voice onset qualities ("creaky" vs. "modal") of ejectives were compared with unaspirated stops (see Section 4.2).

Some ejectives showed patterns of relatively short VOT, while others showed long VOT. This is shown in the waveforms in Figure 2 and Figure 3. Based on waveform analysis, ejectives were labelled according to their VOT type. Ejectives were labelled "long" when there was a silent period between the consonant release and voice onset (as characterized by Lindau's and Kingston's model). If there was no evidence of silence between the consonant release and voice onset or if the VOT was less than 40ms, the ejective was labelled "short". Unaspirated stops were labelled as "unaspirated stops", regardless of the VOT duration. VOT types were compared.

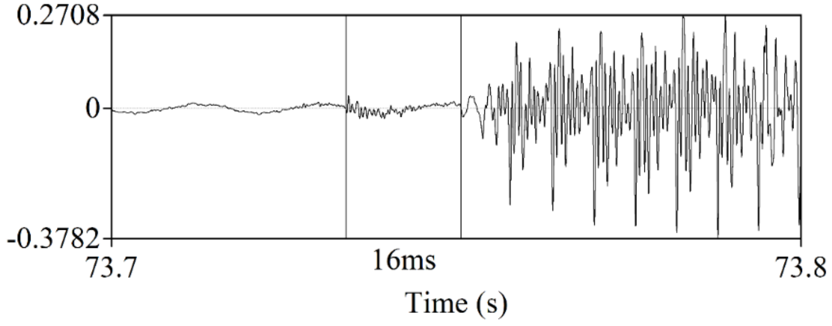

Figure 2: Waveform of /t'/ with short VOT

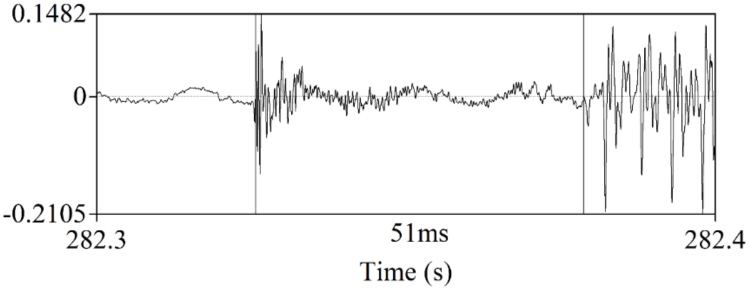

Figure 3: Waveform of /t'/ with long VOT

The dependent measures (VOT, f0 perturbation, jitter perturbation, and rise time) were submitted to two tests. For VOT measures, VOT types ("long", "short", and "unaspirated stops") were analyzed in an ANOVA. Post hoc comparisons using Tukey's HSD test were used to compare the levels of VOT types. To investigate the effect of laryngeal types (ejective vs. voiceless unaspirated) and voice onset quality (creaky vs. modal) on f0 perturbation and jitter perturbation, an ANOVA was used. The Lindau and Kingston model would predict that f0 perturbation varies with VOT. To test this, these acoustic measures were fitted into a linear model to test for any correlation between f0 perturbation and VOT.

3.5 Hypotheses

Based on the data analysis, the following predictions are made: (i) average VOT for ejectives will be greater than unaspirated stops; (ii) jitter perturbation will be greater for ejectives with creaky voiced onset than unaspirated stops; (iii) f0 perturbation will be depressed for ejectives with creaky voiced onset, normal (or raised) for ejectives with modal voiced onset and normal (or raised) for unaspirated stops; (iv) amplitude rise time will be slower for ejectives with creaky voiced onset but normal for ejectives with modal voiced onset and unaspirated stops; and (v) f0 will not correlate with VOT.

4 Results

4.1 Voice onset time (VOT)

17 of the 48 ejectives showed short VOT, whereas 31 of the 48 ejectives showed long VOT. These data were compared with the VOT of unaspirated stops, summarized in Table 3. Figure 4 illustrates the VOT (in ms) of each VOT type.

Table 3: Means and standard deviations for VOT (in ms) for each VOT type

VOT type	*n*	*M (SD)*	95% CI
Long ejective	31	69.57 (21.33)	[61.75, 77.4]
Short ejective	17	29.69 (6.47)	[26.37, 33.02]
Unaspirated stops	41	25.07 (8.07)	[22.52, 27.62]

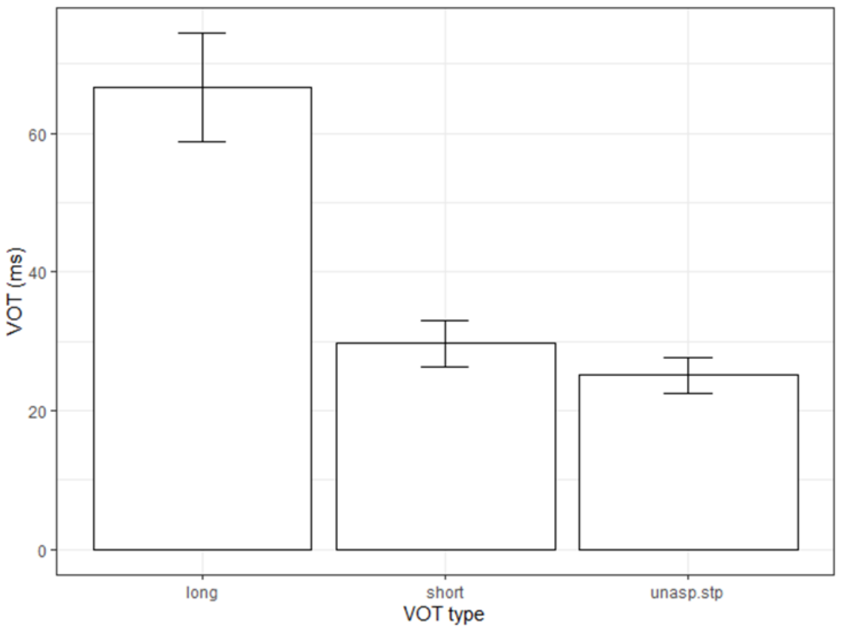

Figure 4: VOT (in ms) for each VOT type

For this speaker, statistically significant differences were found for VOT types, $F(2, 86) = 83.38$, $^{***}p<.001$, $\hat{\eta}^2 = .66$. Post hoc analysis showed that long ejectives had a significantly greater VOT than short ejectives, $t(46) = 8.71$, $^{***}p<.001$, 95% CI = [26.81, 46.96]. Moreover, long ejectives had a significantly greater VOT than unaspirated stops, $t(70) = 12.43$, $^{***}p<.001$, 95% CI = [33.56, 49.45]. However, short ejectives did not significantly differ from unaspirated stops $t(56) = 1.14$, $p = .129$, 95% CI = [-5.0, 14.25]. The ANOVA showed that laryngeal type (ejective vs. unaspirated stop) had a significant effect on VOT, $F(1, 85) = 70.14$, $^{***}p<.001$, $\hat{\eta}^2 = .45$. However, voice onset quality (creaky vs. modal) did not have a significant effect on VOT, $F(1, 85) = 1.81$, $p = .182$, $\hat{\eta}^2 =.021$.

4.2 Jitter perturbation

29 of the 48 ejectives showed creaky voiced onset, whereas 19 of the 48 ejectives showed modal voiced onset. Table 4 summarizes the data. Figure 5 illustrates the jitter perturbation of laryngeal type and voice onset quality.

Table 4: Means and standard deviations of jitter perturbation for laryngeal type and voice quality

Laryngeal type-quality	*n*	*M (SD)*	95% CI
Ejective-creaky	29	8.91 (7.8)	[5.94, 11.88]
Ejective-modal	19	1.98 (1.13)	[1.44, 2.53]
Unaspirated Stops	41	1.17 (1.06)	[0.83, 1.5]

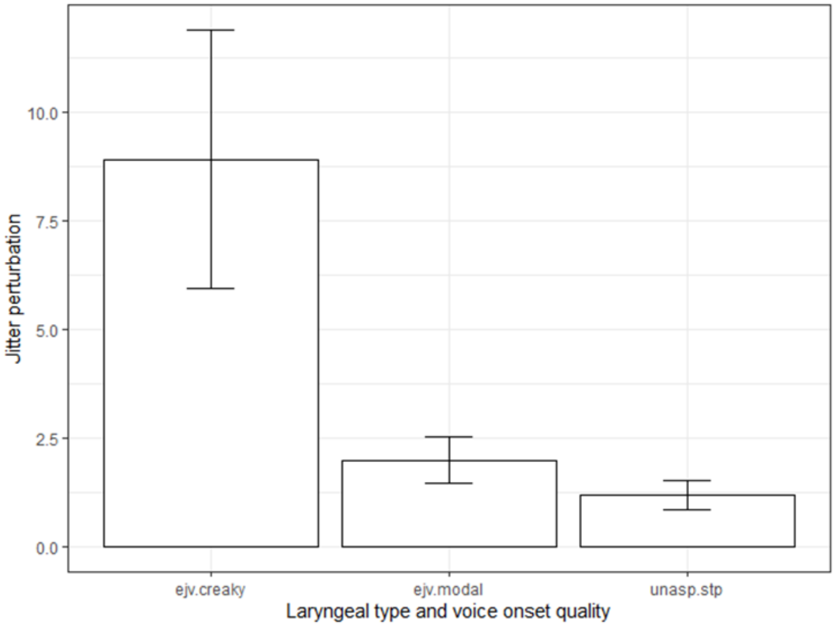

Figure 5: Jitter perturbation for laryngeal type and voice onset quality

Laryngeal type (ejective vs. unaspirated stop) was labelled together with voice onset quality (creaky vs. modal). Three levels were compared: ejective-creaky, ejective-modal, and unaspirated stops (which always had a voice onset quality that was modal). A one-way ANOVA was used to test the effects of laryngeal type and voice onset quality on jitter perturbation. The effect of laryngeal type (ejective vs. unaspirated stop) and voice quality (creaky vs. modal) on jitter perturbation was statistically significant, *F*(2, 86) = 26.78, ****p*<.001, $\hat{\eta}^2$ =.384. Post hoc analysis showed that ejective-creaky had a significantly greater jitter perturbation than ejective-modal, *t*(46) = 5.17, ****p*<.001, 95% CI = [3.74, 10.12]. The jitter perturbation for ejective-creaky was also significantly greater than unaspirated stops (which was always modal), *t*(68) = 7.03, ****p*<.001, 95% CI = [5.12, 10.37]. However, ejective-modal did not significantly differ from unaspirated stops, *t*(58) = 0.65, *p* = .26, 95% CI = [-2.18, 3.82].

4.3 F0 perturbation

Table 5 summarizes the data for f0 perturbation of laryngeal type and voice quality. Figure 6 illustrates the f0 perturbation of laryngeal type and voice quality at voice onset.

Table 5: Means and standard deviations of f0 perturbation for laryngeal type and voice quality.

Laryngeal type-quality	*n*	*M (SD)*	95% CI
Ejective-creaky	29	-34.67 (30.68)	[-45.84, -23.51]
Ejective-modal	19	-9.24 (10.98)	[-14.18, -4.3]
Unaspirated Stops	41	-0.52 (10.88)	[-3.96, 2.91]

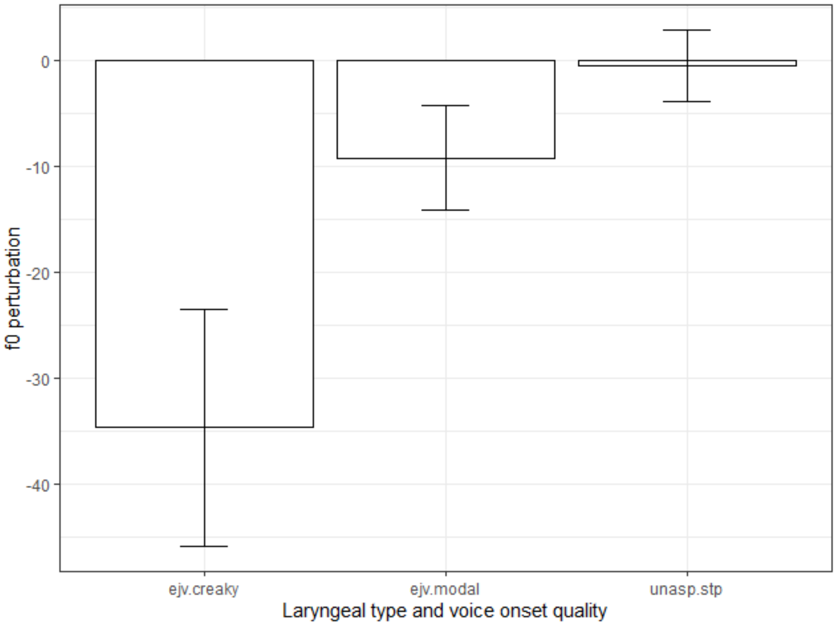

Figure 6: F0 perturbation for laryngeal type and voice quality

As before, laryngeal type (ejective vs. unaspirated stop) was labelled together with voice onset quality (creaky vs. modal). Three levels were compared: ejective-creaky, ejective-modal, and unaspirated stops (which always had a voice onset quality that was modal). A one-way ANOVA was used to test the effects of laryngeal type and voice onset quality on f0 perturbation. As Figure 6 shows, ejectives showed depressed f0 perturbation for both creaky voiced onset and modal voiced onset. The effects of laryngeal type (ejective vs. unaspirated stop) and voice quality (creaky vs. modal) on f0 perturbation was statistically significant, *F*(2, 86) = 26.17, ****p*<.001, $\hat{\eta}^2$ = .378. The one-degree-of-freedom contrast of primary interest (the mean difference between ejective-creaky and ejective-modal) was also statistically significant at the specified *p* = .05 level, *t*(46) = -3.56, ***p* = .001, 95% CI = [-40.23, -10.64], *d* = -1.02. The mean difference between ejective-creaky and unaspirated stops (which was always modal) was also statistically significant, *t*(68) = -6.58, ****p*<.001, 95% CI = [-44.5, -23.79], *d* = -1.6. Moreover, the mean difference between ejective-modal and unaspirated stops was statistically significant, *t*(58) = -2.88, ***p* = .006, 95% CI = [-14.78, -2.65], *d* = -0.8. This suggests that although f0 perturbation was depressed for ejectives with creaky voiced onset and modal voiced onset, the f0 perturbation for ejectives with creaky voiced onset was significantly more depressed than ejectives with modal voiced onset.

4.4 Rise time

Table 6 summarizes the data for rise time. Figure 7 illustrates the rise time for laryngeal type and voice onset quality.

Table 6: Means and standard deviations of rise time (RMS energy difference in dB) for laryngeal type and voice quality.

Laryngeal type-quality	*n*	*M (SD)*	95% CI
Ejective-creaky	29	10.94 (2.8)	[9.93, 11.96]
Ejective-modal	19	8.29 (1.63)	[7.56, 9.02]
Unaspirated Stops	41	8.74 (2.09)	[8.1, 9.38]

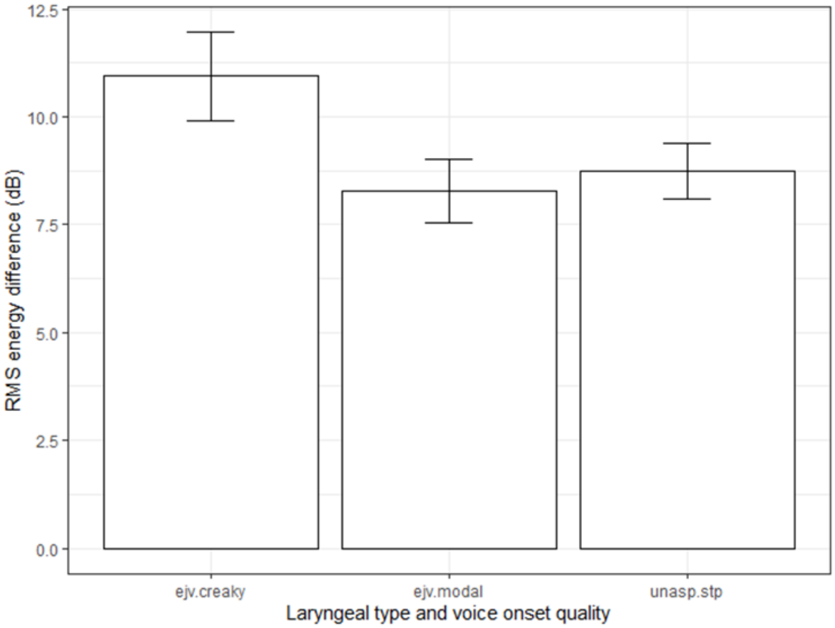

Figure 7: Rise time for laryngeal type and voice quality

The effect of laryngeal type (ejective vs. unaspirated stop) and voice quality (creaky vs. modal) on rise time was statistically significant, $F(2, 86) = 10.76$, $***p<.001$, $\hat{\eta}^2 = .2$. Post hoc analysis showed that ejective-creaky had a significantly greater rise time than ejective-modal, $t(46) = 3.97$, $***p<.001$, 95% CI = [1.06, 4.25]. The rise time for ejective-creaky was also significantly greater than unaspirated stops (which was always modal), $t(68) = 4.01$, $***p<.001$, 95% CI = [0.9, 3.51]. However, ejective-modal did not significantly differ from unaspirated stops, $t(58) = 0.71$, $p = .239$, 95% CI = [-1.05, 1.95]. This suggests that the rise time for ejectives with creaky voiced onset is slower than ejectives with modal voiced onset.

4.5 Correlations

The Lindau and Kingston model would predict that ejectives with relatively long VOT has a raised or static f0, whereas those with relatively short VOT have depressed f0. However, there was no correlation ($R^2 = .057$) between f0 perturbation and VOT. As the scatter plot and regression line in Figure 8 show, long VOT and short VOT can vary independently of f0.

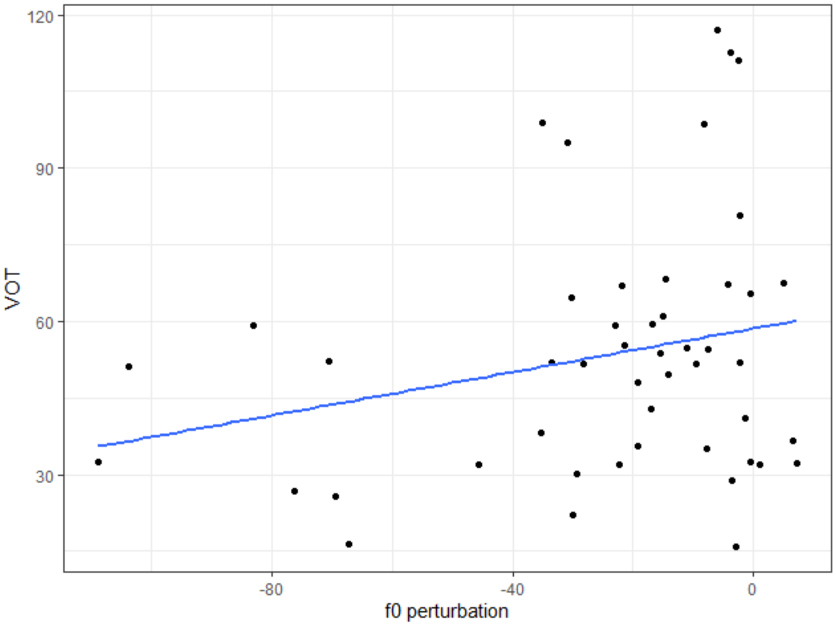

Figure 8: Scatter plot with a simple regression line showing the relationship between VOT and f0 perturbation for ejectives.

5 Conclusion

The speaker in this study showed the following patterns: (i) (majority) long VOT (like stiff ejectives), (ii) depressed f0 perturbation (like slack ejectives), and (iii) variable voice onset quality (slightly more instances of creaky voiced onset than modal voiced onset). As predicted, ejectives with creaky voiced onset had a slower rise time than ejectives with modal voiced onset. Given this variability, the Lindau and Kingston model doesn't seem to work for Lushootseed. However, some aspects of the Lindau and Kingston model are supported by the data. Some of the characteristics of Lushootseed /t'/ (such as depressed f0 perturbation) suggest that this sound is a slack ejective. Moreover, approximately 60% of the ejectives showed creaky voiced onset, which patterns with slack ejectives. However, the prediction that short VOT correlates with lowered f0 does not seem to hold. This suggests that the typology cannot predict the variation observed in Lushootseed ejectives.

The typology is based on widely held assumptions about vocal fold tension and compression. As Wright et al. (2002:70–71) states, these assumptions may underestimate the complexities of laryngeal muscular adjustments, as well as timing relationships in the production of ejectives. An increase in f0 is primarily manipulated by the stiffness of the vocal folds (Stevens 2000). Stiffness is achieved mainly by stretching the vocal folds. The vocal folds are stretched (via longitudinal tension) through contraction of the cricothyroid (CT) muscle, which is responsible for the rocking and horizontal translation of the thyroid cartilage in relation to the cricoid cartilage. The rocking and translation motion of the thyroid cartilage lengthens and stretches the vocal folds. An increase in medial compression accompanies the stiffness of the vocal folds. The muscles that cause adduction to the vocal folds and applies medial compression are the interarytenoid (IA) and lateral cricoarytenoid (LCA) muscles.

Contrary to the assumptions in Lindau's and Kingston's model, there may be strong medial compression due to constriction of the adductor muscles (IA and LCA) in the absence of longitudinal tension. This would inhibit voicing, which results in a long VOT that is accompanied by depressed f0 and creaky voiced onset (Wright et al. 2002:71). Because f0 perturbation was depressed, the longitudinal tension (CT) of the vocal folds must have decreased prior to the relaxation of medial compression (IA and LCA). However, because f0 perturbation was depressed for ejectives with creaky voiced onset and modal voiced onset (and because f0 perturbation for ejectives with creaky voiced onset was more depressed than ejectives with modal voiced onset), the decrease in longitudinal tension (CT) may vary at differing degrees in the production of ejectives. Moreover, there may have been differing degrees of larynx raising and medial compression. These would account for the variability observed in the data. The rise time for ejectives with creaky voiced onset was slower than modal voiced onset. The reduced amplitude at voice onset occurs because a constricted glottis (when generating creaky voicing) generally reduces the amplitude itself (Keating et al. 2015). This is because the pressure within the lower portion of the glottis decreases in response to the decrease in abducting forces (Stevens 1999). There is also a reduced intraoral pressure during creaky phonation (Ingram & Rigsby 1987). Because creaky phonation is generated with reduced longitudinal tension and increased medial compression (a result of this is a lower f0), the spectral peak (peak amplitude) is much smaller at lower frequencies than modal phonation. The slower rise time is likely to be a consequence of manipulating the adductor muscles (IA and LCA) to produce creaky voicing.

It is possible that stiff and slack ejectives are two extreme endpoints that fall along a continuum of varying realizations for ejectives. Due to the variability in the data, the ejectives observed in this study can fall anywhere along this continuum from most stiff to least stiff and from most slack to least slack. Because Lushootseed ejectives showed short VOT and long VOT, this suggests that VOT types are not strictly exclusive features that distinguishes ejectives in Lushootseed. This also holds for voice onset quality.

The variability observed in the data pose interesting problems to theories of sound change. Ohala (1981) states that contrasts that are variable and confusable tend to be lost over time. Although most ejectives showed long VOT, approximately 35% of ejectives showed short VOT. Ejectives with short VOT did not significantly differ from unaspirated stops. There is evidence in the Salish literature showing that glottalized (i.e., glottalic egressive) consonants dissimilated to non-glottalized (i.e., pulmonic egressive) consonants (Kuipers 2002, Van Eijk & Nater 2020). Kuipers (2002:8) observed the deglottalization of some ejective stops in root-initial position in Shuswap, as in **k'ip'* 'squeeze' (Proto-Salish) > *kip'* 'squeeze' (Shuswap). This change occurs in syllables with two ejectives (root initially and root finally). Kuipers states that "Grassmann's law" takes place, where the first ejective becomes deglottalized in these syllables (2002:8). Moreover, Kuipers observed this in reduplicated stems with more than one ejective, which suggests that Grassmann's Law has a wider application than just root-initial position. It is possible that root-initial ejectives show a greater frequency of short VOT in roots with two ejectives. This may also be true in words with more than one ejective such as reduplicated stems. A future study that examines roots with two ejectives needs to be done to test this prediction.

This study worked with only one speaker, which is a severe limitation. The results are questionable because the effects that were observed come from only one speaker. It is possible that these patterns reflect the idiolect of the speaker. Whether this effect was unique to the Southern dialect cannot be addressed by examining only one speaker. More speakers need to be examined to test whether these effects are observable for more than one speaker. Another limitation is that a single place of articulation (i.e., alveolars) was examined for ejectives and unaspirated stops. More stops with different place of articulations need to be examined to observe these effects on ejectives and unaspirated stops.

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