Acoustic Correlates of St’át’imcets /i/[1]

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1. Introduction

This paper reports the second part of a larger experiment designed to measure the F0, vowel duration and intensity of St’at’imcets (Interior Salish) vowels to assess how stress is marked.[2] This paper considers the vowel /i/ in four positions: primary stress, secondary stress, unstressed, but parsed and unstressed, unparsed, following Caldecott (2006b,c). Very little is known about the phonetic properties of prosodic words or intonational phrases in the language, so the results of this study will lay the groundwork for future research into the interaction between prosody and phonetics. Sections 1.1 and 1.2 outline the phonetic and phonological background respectively. Section 2 lays out the methodology used in the experiment. Section 3 presents the results, Section 4 the discussion and Section 5 concludes the paper.

1.1 Phonetics Background

Stressed syllables are defined in relative rather than absolute terms-- a stressed syllable is generally understood to be more perceptually ‘prominent’ than an unstressed syllable. Laver (1994) gives the following definition of stress in terms of relative prominence: “Other things being equal, one syllable is more prominent than another to the extent that its constituent segments display higher pitch, greater loudness, longer duration or greater articulatory excursion from the neutral disposition of the vocal tract”.

The factors mentioned above have been shown to affect stress to varying degrees, either independently or in conjunction with one another. Lieberman (1959) showed that stressed vowels in English had a higher F0 72% of the time, higher amplitude 90% of the time and longer duration 70% of the time when compared to unstressed vowels across words. Higher F0 and amplitude appeared to be stronger ‘cues’ than duration, in that no stressed syllable had both a lowered F0 and decreased amplitude. In addition to this, he found a ‘trading

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[2] A fourth correlate, vowel quality is not considered. See Shahin and Blake (2004) for a study on schwa in St’át’imcets. Secondary stress occurs on pre-tonic heads of feet (van Eijk(1997), Roberts and Shaw (1994) but will not be considered in this study.

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effect' where in cases of lowered F0, there was an increase in amplitude, and vice-versa. He concludes that increased F0 is a stronger 'cue' than amplitude.

The above studies were all conducted on English. Acoustic analyses of stress in the languages of North America are extremely limited. Gordon (2004) in his acoustic study of stress in Chickasaw lists only the following: Cahuilla (Seiler, 1957), Mohawk and Oneida (Michelson, 1983), Cayuga (Doherty, 1993), Piraha (Everett, 1988), Tanana (Tuttle, 1998), Witsuwit'en (Hargus, 2001) and Creek (Martin and Johnson, 2002). In keeping with the English results above, Gordon (2004) found that stressed vowels have higher F0, intensity and duration than unstressed syllables.

In terms of acoustic research on Salish languages, very little has been conducted. Benner (2006) conducted a qualitative pilot study on the stress and prosody of SENCOTEN (Straits Salish). She reports that while stressed vowels generally have higher pitch than unstressed vowels, it is not a reliable cue to stress, and may instead reflect intonation. She also found that the final syllable in tri-syllabic words differs only in length from the preceding unstressed vowel.

Watt et al. (2000) examined /a/ and /u/ in S<u>k</u>wx<u>x</u>wú7mesh (Coast Salish). This study of one male speaker, found that in general stressed /a/ and /i/ had higher F0, duration and intensity than unstressed vowels, but the speaker manipulated different correlates for the different vowels. Trisyllabic roots showed less straightforward results, which is perhaps not unexpected given their rarity. According to Dyck (2004) trisyllabic roots make up only 2% of the root inventory in the language. Results indicated that the stressed vowel had higher means for F0, duration and amplitude than both second and third vowels. No significant differences between second and third vowels were found[3].

As mentioned above, this paper reports the second part of a larger experiment examining stress in St'át'imcets. The first part of the experiment (Caldecott, 2006b,c) looked at the vowel /a/ in the same four positions considered in this study: primary stress, secondary stress, unstressed, but parsed and unstressed, unparsed. That study found that speakers were not consistent in their use of correlates to signal stress and distinguished three levels of parsing acoustically. One speaker used mainly F0, two speakers used a combination of duration and intensity and one speaker made no stressed-unstressed distinctions. Interestingly, while no speaker distinguished primary from secondary stress, two speakers made a significant duration difference between vowels in unstressed syllables and those in unparsed syllables.

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[3] Watt et al.'s results for triyllablic roots may also be complicated by other factors. First, they considered only four examples, two of which had schwa as the final vowel, and one of which had schwa as the initial vowel. There is also some disagreement about the parsing of trisyllabic roots. Dyck (2004) proposes that roots are right headed, so rather than the first vowel being stressed, the second one would be. The status of the first vowel is not clear.

1.2 Language and phonological background

St'át'imcets (Lillooet) is an Interior Salish language spoken in Southwestern Interior British Columbia. It has two principal dialects -- Upper (spoken from Nk'wwátqwa7 (D'arcy) to Ts'k'wáylacw (Pavilion) and Lower (spoken from Lillwat7úl (Mt. Currie) to Xáxtsa7 (Port Douglas) Davis (in prep): Chap. 1). Following Roberts and Shaw (1994), stress in St'át'imcets is taken to be trochaic, assigned from left to right with words being right-headed. Consider the following figure:

(1)
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             PWd                  PWd
             |                     /\
             Foot           Foot
             /\              /\
        (wá7=ɬkan)      (qlíl-min̓)-čin
               "I'm mad at you"
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Stressed syllables form trochaic feet with unstressed syllables. Secondary stress is marked on the heads of pre-tonic feet. Single syllables, such as /-čin/ above are not permitted to form feet (by a highly ranked Ftbin constraint), and so remain unparsed. Thus, four distinct levels of syllable parsing are posited: i) primary stress, ii) secondary stress, iii) unstressed but parsed, and iv) unstressed, unparsed[4]. These three levels are active in a phonological alternation in the language involving glottalised resonants. Caldecott (2006a) found that glottalised resonants in some suffixes in the transitive paradigm deglottalise in stressed and unparsed position (1a,b). Consider the transitivising suffix /-min'/ below:

(2) a. (ʔiʔwaʔ)-(mín-as) 'S/he went along with him/her
b. (ʔíʔwaʔ)-min 'Go along with him/her!'

Crucially, neutralisation does not occur in unstressed position (1c):

c. (x̌̓íq-min̓)-as 'S/he arrived for it'

This phonological difference between two unstressed syllables poses some very interesting questions: Is the parsing distinction between unstressed, but parsed and unstressed, unparsed syllables proposed by Roberts and Shaw (1994), which are active in the phonology reflected in the phonetics? Stressed vowels are acoustically different from unstressed vowels, but is there an acoustic distinction between two types of stressed vowels (primary and secondary stress) and two types of unstressed vowels (parsed vs. unparsed)?

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[4] For the sake of brevity, the three levels of parsing will be referred to as stressed (s), unstressed (us) and unparsed (up). Unparsed syllables are still parsed as part of the Prosodic Word. The language also has predictable secondary stress on the heads of pre-tonic feet. These vowels will not be considered as a part of this experiment.

The implications of these questions will affect our understanding of the phonetics-phonology interface. If the phonological differences between unstressed and unparsed vowels is realised acoustically, then this is further evidence that parsing affects the production of segments (c.f. Fougeron and Keating, 1997; etc.). If the differences are not reflected in the acoustic signal, this suggests that the alternation above is purely phonological, and that some domains in the Prosodic Hierarchy are realised acoustically while others are not.

To address the implications above, we must first begin by asking simpler questions: What are the acoustic correlates of stress in this language? How many levels of stress do speakers distinguish? The hypotheses tested in this experiment are 1) Primary stressed vowels will be significantly higher in F0, duration and intensity than secondary, unstressed and unparsed vowels and 2) There will be no significant differences between unstressed and unparsed vowels.

2. Methodology

This section lays out the methodology used in conducting this experiment.

2.1 Subjects

Four subjects, all women in their 60's and 70's participated in this study. Three participants, AP, GN and RW speak the Upper dialect of St'át'imcets, while the fourth, LT, speaks the Lower dialect. All four are fluent speakers, bilingual with English.

2.2 Tokens

Tokens were selected to control for vowel quality (only /i/ in this experiment), context and morphological class. The vowel /i/ was examined in two contexts: /iɬ/ and /in/. Bessell (1997) found that, with the exception of uvulars, preceding consonants had little effect on the quality of vowels in St'át'imcets. House (1961) also shows that following consonants have a greater influence on vowels, and so, unlike Watt et al. (2000) pre-target ejectives were included.

The design of this experiment also took into account the class and type of morpheme involved. Monosyllabic roots are by far the most common in the root inventory, comprising at least 88% (van Eijk, 1997). As a result, most roots will contain only a stressed vowel. In order to measure unstressed and unparsed vowels, suffixes and/or enclitics must be considered. One person suffix (-tsin) and one enclitic (=cwilh) were selected in order to minimize possible confounding effects of morphological class. Eight different roots were selected from (van Eijk, 1987)and (Davis, in prep):

Table I: List of Tokens

Orthography	Broad NAPA	Translation
=cwilh	=xʷiɬ	Realisation
-tsin	-čin	1sg.obj
nílh-min'	níɬ-min̓	To care for/ pay attention to s.o.
qílhil-min'	qíɬil-min̓	To run after/with s.o.
sílhts'a7	síɬc̓a7	shoe
xilh-ts	χiɬ-č	To do s.t. a certain way
k'wílh-al'-ts	k̓ʷíɬ-al'-c	(to have/leave) left-overs
ptínus-min	ptínuš-min	To worry about s.o.
q'mín-en	q̓mín-ən	To throw s.o. down
tíntin	tíntin	bell

Speakers were given the English form of the roots, and asked for the St'át'imcets translation in order to confirm their familiarity with the word in question. They were then asked to give the form in a sentence of their own, in order to maximise natural stress patterns. Variations on sentences using different modals, different enclitics/suffixes etc. were also suggested and analysed. Non-target roots with target suffixes/enclitics were also elicited, but only the suffixes/enclitics were analysed.

2.3 Procedure

Recordings were done in quiet rooms of private homes using a Marantz 670 PMB solid-state recorder and an Audiotechnica AT-831b cardioid lavaliere microphone. They were then uploaded onto an Apple iBook G4 and analysed using Praat 4.4.03 (Boersma & Weenink).

2.4 Analysis

In total, 247 tokens recorded. 17 were discarded because of pronunciation differing from the dictionary, clipping or (English) question intonation. As a result, 230 vowels were measured. Two example sentences are given below:

(3) a. (k̓wàɬan̓)(=čín=ɬkan) "I hired you"
b. (nk'yápa)=xwiɬ "It turned out to be a coyote"

In the first example, the vowel in [=čín] was considered a stressed vowel. In the second example, the /i/ in [=xwiɬ] was measured as an unparsed vowel.

With regard to measurement, duration of the vowel, rather than syllable was measured based on findings in (Crystal and House, 1990) which showed that average vowel duration is independent of the number and order of phones in a syllable, while the duration of a syllable, is function of stress and the number of phones. Vowel duration was measured based on (House, 1961) and (Gordon, 2004). Onset and offset criteria included the initiation and cessation of voicing,

and formant transitions. Using the Praat query function, mean F0 and mean intensity over the duration of the vowel were calculated.
Vowels were compared across words, not within words[5]. Statistical analysis was done in SPSS 11.0.4 in the form of Repeated Measures ANOVA and Bonferroni post-hoc tests. These results are presented in the following section.

3. Results

Descriptive statistics are given in Table II below. Results are broken down by correlate and by speaker. Significant differences and direction of difference are shown in Table III.

Table II: Descriptive Results (ps=primary stress, ss=secondary stress, us=unstressed, up=unparsed, sd=standard deviation)

	AP		GN		LT		RW	
F0 (Hz)	F(3,33)=9.37 p=.000 N=12		F(3,36)=2.95 p<.05 N=13		F(3,33)=10.0 p=.000 N=12		F(3,27)=4.08 p<.05 N=10	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
ps	192.62	13.1	201.01	11.5	212.82	19	183.52	33
ss	174.95	9	194.51	27.5	215.15	12.3	188.36	9.6
us	160.8	23.3	187.22	12.1	185.9	24.3	160.58	8.7
up	190	19.9	180.85	14.2	176.1	32	173.47	16.4
Duration (ms)	F(3,33)=1.16 p>.05 N=12		F(3,36)= 9.66 p=.00 N=13		F(3,33)=3.2 p<.05 N=12		F(3,27)=3.96 p<.05 N=10	
ps	81.6	18.5	96.44	22.3	87.67	28.6	114	38.9
ss	75.87	21.1	108.53	26.9	95.38	23.8	104.83	27.3
us	83.5	25	75.58	14.9	71.62	28.1	83.96	13.8
up	92.58	25.4	84.45	16.9	67.37	13	81.57	21.5
Intensity (Db)	F(3,33)=6.19 p<.05 N=12		F(3,36)= 4.5 p<.05 N=13		F(3,33)=14.7 p=.000 N=12		F(3,27)= 2.8 p>.05 N=10	
ps	79.67	4.6	81	2.9	80	4	74.99	8.5
ss	80.52	2.3	79.76	5.5	80.36	4.2	80.82	2.6
us	73.33	7.9	74.98	6.0	71.25	4.8	76.5	4.2
up	73.75	6.3	75.48	5.2	70.6	7.4	73.71	8.1

The table above reports the results of the experiment by speaker, correlate and position. Table 1 shows two principal effects: i) There was no consistent use of correlates across speakers, but all speakers had at least one significant difference in correlates to distinguish stressed vowels from unstressed vowels, and ii) variation for F0 and duration were similar, but considerably higher than for intensity. Intensity was the least variable within groups with standard deviation ranging from 2.3 (AP) to 8.5 (RW) as compared to a high of 38.9

[5] Thanks to Yvan Rose for suggesting relative rather than absolute measures. A quick reanalysis of the data reveals relative measurement results are not clearer than absolute measurements.

(RW) for duration and 27.5 (GN) for F0. Significant results and the direction of difference by speaker are presented in Table III below.

While statistics were not calculated across speakers, the results of all four speakers are presented together in Figures 1-3 below in order to show what trends did emerge. While the presentation order of positions is not entirely arbitrary (unparsed vowels follow unstressed vowels in words containing both), no effect of linearity should be inferred.

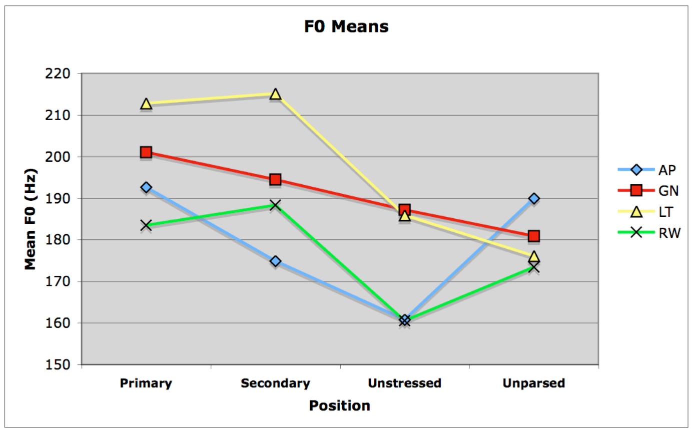

Figure 1: F0 means by speaker

Figure 1 shows four distinct patterns of F0 means across the four positions examined. It shows that stressed vowels have the highest or equal highest means for F0. It also shows that for two speakers (AP and RW), unparsed vowels have higher F0 than unstressed vowels. Duration means are shown in Figure 2 below:

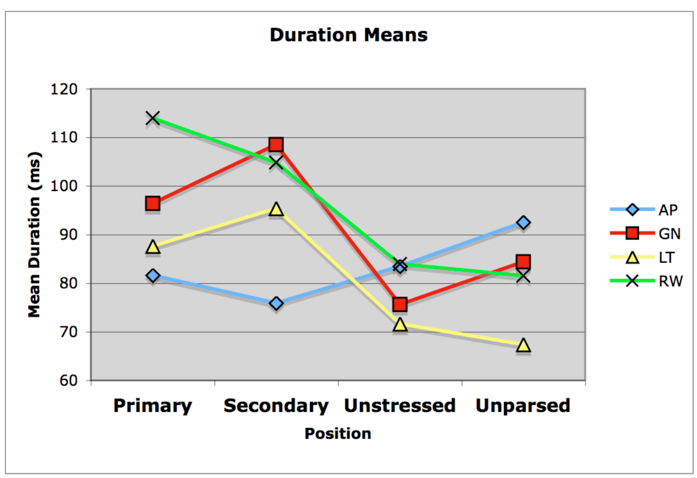

Figure 2: Duration means by speaker

Duration results show different patterns to the F0 results, and again, all four speakers pattern differently. GN and LT show longer vowels in secondary stress than primary stressed position. All speakers, except AP, have unstressed vowels that are considerably shorter than primary or secondary stressed vowels. LT was the only speaker for whom unparsed vowels were the shortest. Intensity means are shown below:

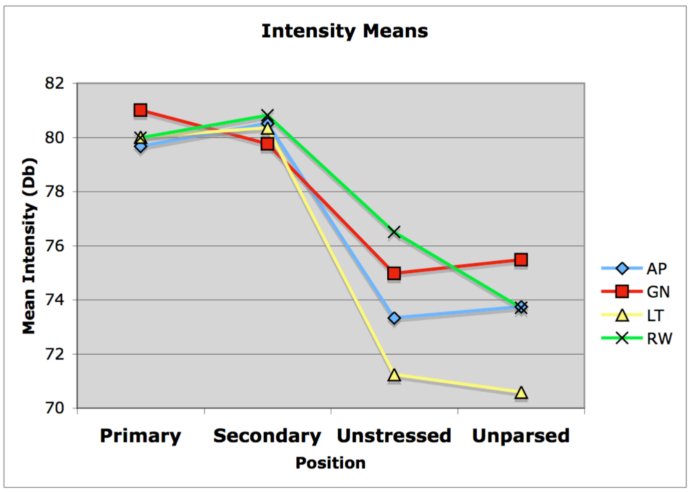

Figure 3: Intensity means by speaker

Intensity results differ from duration and F0 because all four speakers show similar patterns. For all speakers, secondary and primary stressed vowels were considerably higher than both unstressed and unparsed vowels. Significant differences and the direction of difference are given in Table III below:

Table III: Direction of significant results by speaker and position (> = *a* is significantly greater than *b*; < =*b* is significantly greater than *a*; ns=not significant)

AP	Primary-secondary	Primary-unstressed	Primary-unparsed	Secondary-unstressed	Secondary-unparsed	Unstressed-unparsed
F0	>	>	ns	ns	ns	<
Duration	ns	ns	ns	ns	ns	ns
Intensity	ns	ns	ns	>	>	ns
GN	Primary-secondary	Primary-unstressed	Primary-unparsed	Secondary-unstressed	Secondary-unparsed	Unstressed-unparsed
F0	ns	ns	>	ns	ns	ns
Duration	ns	ns	ns	>	>	ns

Intensity	ns	>	>	ns	ns	ns
LT	Primary-secondary	Primary-unstressed	Primary-unparsed	Secondary-unstressed	Secondary-unparsed	Unstressed-unparsed
F0	ns	ns	>	>	>	ns
Duration	ns	ns	ns	ns	>	ns
Intensity	ns	>	>	>	>	ns
RW	Primary-secondary	Primary-unstressed	Primary-unparsed	Secondary-unstressed	Secondary-unparsed	Unstressed-unparsed
F0	ns	ns	ns	>	ns	ns
Duration	ns	ns	ns	ns	ns	ns
Intensity	ns	ns	ns	ns	ns	ns

This table shows the direction of significant differences between vowels in all positions. All speakers has significantly higher means in stressed (primary or secondary) than unstressed and vowels. AP shows significantly higher F0 in primary stressed than secondary stressed and unstressed vowels. She shows no distinction between primary stressed and unparsed vowels. She shows significantly higher intensity in secondary stressed vowels than unstressed or unparsed vowels. She also shows a significantly higher F0 in unparsed vowels than unstressed vowels. No other speaker makes a distinction between primary and secondary stressed vowels, or between unstressed and unparsed vowels using any of the three correlates.

GN distinguishes primary stress from unstressed and unparsed vowels using higher intensity (and F0 for unparsed vowels). Like AP, she uses different correlates for secondary stress. To distinguish secondary stressed vowels from unstressed and unparsed vowel, she uses duration.

LT uses a combination of F0 and intensity to distinguish primary and secondary stress from unstressed and unparsed vowels.

RW makes only one significant difference, between secondary stressed vowels and unstressed vowels, marking the former with a higher F0. She makes no other distinctions.

4. Discussion

This experiment was designed to discover how St'át'imcets speakers mark stress, in this case, on the vowel /i/. A summary of correlate usage by speaker is given in Table IV below:

Table IV: Summary of correlates used by speakers (F=F0; D=duration; I=intensity; +=*a*>*b*;-=*b*>*a)*

	Primary vs. Secondary	Stressed vs. Not stressed	Unstressed vs. Unparsed
AP	F+	F+, I+	F-
GN		F+, I+, D+	
LT		F+, I+, D+	
RW		F+	

This table shows which correlates speakers used (had a significant difference in) to distinguish positions. The middle column combines primary and secondary stress into 'stressed' and unstressed and unparsed into 'not stressed'. By doing this, we see that speakers distinguish two levels of stress (stressed and not stressed) and are consistent in using F0 do so. AP is the only speaker to make distinctions between primary and secondary stress on the one hand, and unstressed and unparsed vowels on the other. All four speakers have a significantly higher F0 in stressed than not stressed vowels. Three speakers also have significantly louder stressed vowels than not stressed and two have significantly longer ones.

These results generally support Gordon (2004) and Watt et al. (2000) in that stressed vowels had higher values than unstressed vowels. They differ from the results for /a/ found in the first part of the experiment in that they are much more consistent. In that experiment, primary and secondary stress were not distinguished, but three of the four speakers made a distinction between unstressed and unparsed vowels. Consider Table V below:

Table V: Summary of correlates used by speakers for /a/ (F=F0; D=duration; I=intensity; +=*a*>*b*; -=*b*>*a)* (Caldecott 2006c)

	Primary vs. Secondary	Stressed vs. Not stressed	Stressed vs. Unparsed	Unstressed vs. Unparsed
AP		F+	F+, D-	
GN				I+
LT		D+, I+		D-, I-
RW		I+	F+, I+	D-

From the /a/ results we see speakers were not as consistent in using F0 to distinguish stressed from unstressed, and one speaker, though not the same speaker, made no stressed-unstressed distinction.

The finding that there is no acoustic difference between primary and secondary stress contradicts auditory impressions by van Eijk (1985, 1997), Roberts and Shaw (1994), and Davis (in prep). This raises the question of why we hear a distinction when one is not present in the acoustic signal. One possible explanation may be that the experiment is not measuring the right correlates, that speakers are marking the difference using something else.

Another might be the fact that in longer words, main stress occurs towards the end of words. In that position, the fact that they are acoustically equivalent to word initial vowels may signal prominence to a hearer expecting down drift[6].

The fact that speakers are manipulating different correlates to signal stress in different vowels is puzzling. Why are speakers more consistently using F0 for one but not the other? One possible solution may be the fact that /a/ alternates with /ə/ in the language (H. Davis, p.c.). Perhaps the more consistent the underlying vowel, the more consistent speakers are in how they manipulate them for stress.

Finally, we must consider the vowel-dependent difference in how many levels of stress/parsing speakers distinguish. Why does /a/ distinguish unstressed and unparsed while /i/ does not and why do they differ? These questions form part of a larger focus of research, namely the role of parsing on production (see Fougeron and Keating, 1997). If speakers distinguish two types of unstressed syllables in the acoustic signal, those that are parsed and those that are not, this supports that notion that the Prosodic Hierarchy (Selkirk, 1984) affects production. In particular, that legitimately parsed domains are realised differently from unparsed domains.

If they do not distinguish between parsed and unparsed syllables, then we must ask why some domains and not others are distinguished. If some vowels show a distinction between how many levels of stress/parsing they distinguish, then we must wonder what it is about the nature of those vowels that make such distinctions possible.

Future research will focus on refining methodology, considering the /u/ vowel and exploring the possibility that the distinction between unstressed and unparsed vowels is due to Prosodic Strengthening.

5. Conclusion

This experiment examined three potential correlates of stress—F0, duration and intensity—to determine how speakers mark stress in St'at'imcets. It was found that speakers distinguish two levels of stress on the /i/ vowel—stressed vs. not stressed—using mainly F0. Stressed vowels were consistently higher than not stressed vowels, supporting other research on both Salish and English.

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[6] Thanks to Adam Werle for suggesting this.

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