PHONETIC CUES TO STRESS IN A TONAL LANGUAGE: PROSODIC PROMINENCE IN SAN LUCAS QUIAVINÍ ZAPOTEC*

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San Lucas Quiaviní Zapotec (SLQZ), an Otomanguean language spoken in southern Mexico, displays the following prosodic patterns: Tone, Phonation types and Stress. This is exceptional from a typological viewpoint, as most languages have at most two of these properties (e.g. tone and stress in Ayutla Mixtec (Pankratz & Pike 1967; de Lacy 2002)). The exceptional prosodic properties of Zapotec prompt questions, such as, what are the formal properties of each pattern? How do they interact? What are the acoustic correlates of each pattern? This study focuses on one aspect: stress. The goal of this study is to determine the phonetic cues to stress in SLQZ with the objective of contributing to the phonetic description of the prosodic prominence in this language as well as to the dichotomy between the linguistic function of prosodic systems and their phonetic realization.

In section 1, I will describe the basic prosodic properties of SLQZ. Section 2 offers a general background of how stress, tone and phonation types are manifested at the phonetic level in the languages of the world. The subsequent section, number 3, presents the hypothesis and predictions with respect to the spectral correlates of stress in SLQZ. The acoustic analysis is presented in section 4, followed by the discussion and the conclusions.

1. San Lucas Quiaviní Zapotec Prosodic Properties

Munro, Lopez et al 1999 (hereafter ML) identified four tones for SQLZ: high (1), low (2), rising (3) and falling (4):

(1)	*gyix:tiilly*	/ gjiʂ̥.ˈtiːllj /	˥	‘bamboo’
(2)	*lohnihih*	/ lo̤.ˈni̤ /	˩	‘fiesta’
(3)	*da'ad*	/ daʔad /	/|	‘father’
(4)	*bargàa'*	/ baɾ.ˈga̰aʔ /	\\|	‘grasshopper’

* Thanks to my consultants Lia Tory, Lia Chel, Tiu Rogel & Tiu Tan from San Lucas Quiaviní, Oaxaca. *X:tyoozënn yùad.* Zapotec data comes from personal fieldwork unless indicated otherwise. This paper has greatly benefited from comments and discussion with Francisco Arellanes, Bryan Gick, Calisto Mudzingwa, Pam Munro, Doug Pulleyblank & Joe Stemberger. All the mistakes are mine. This research was funded by a SSHRC grant, to Joe Stemberger, and by a Ph.D. CONACYT fellowship granted to the author.

Actes du congrès annuel de l'Association canadienne de linguistique 2008.
Proceedings of the 2008 annual conference of the Canadian Linguistic Association.

Moreover, this language also presents contrastive phonation types (ML; Gordon & Ladefoged 2001 for the first three types):

(5)	Modal	/ e /	(example 1)
(6)	Breathy	/ e̤ /	(example 2)
(7)	Creaky	/ ḛ /	(example 4)
(8)	Checked	/ eʔ /	(examples 3, 4)

Particular tones are closely associated with phonation types[1]: modal and checked vowels have high tone, whereas breathy and creaky vowels have low tone. In addition, the interaction of different phonation types within the same syllable nucleus creates different voice contours, and consequently, contour tones.

Finally, SLQZ also displays metrical prominence: the last syllable of uninflected words is stressed (ML). Independent evidence for this pattern comes from loanwords (Munro, Lillehaugen & Lopez, forthc.; Chávez-Peón 2006), acquisition (Stemberger & Lee 2007) and the distribution of stressed syllables: contour voices (tones), phonetic long vowels, and diphthongs only occur in stressed syllables. These distributional properties seem to be related with moraicity as it will be discussed below.

2. Phonetic Cues to Stress, Tone and Phonation Types

It is well know that stressed syllables are more prominent than unstressed syllables in languages with such distinction. The precise way to signal this prominence, however, varies from language to language. Laver (1994) defines prominence as follows:

> ...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 (p. 511).

In what follows, I present the canonical phonetic cues to stress, tone and phonation types.

Phonetic cues to stress have been shown to be pitch, intensity, duration and spectral tilt (Fry 1955; Beckman 1986; Laver 1994; Campbell & Beckman 1997, i.a.)

[1] The precise correlation between tone and phonation is still unclear (cf. ML).

(9) Stress

pitch
duration
intensity
spectral tilt
formant freq.

Pitch (measured in Hertz) is the acoustic correspondent to the fundamental frequency, "...the number of complete repetitions (cycles) of variations in air pressure occurring in a second" (Ladefoged 1996: 114). Duration (miliseconds) is the amount of time in which the articulation of a sound is maintained. Intensity (deciBells) or loudness, is the "...proportional to the average size, or amplitude, of variations in air pressure" (Ladefoged 1996: 115). These three correlates have been the most commonly used ones in explaining the characteristics of stress in a language.

Spectral tilt is the measurement "of the slope of the spectrum indicating how much of the energy is in the fundamental frequency as compared with higher frequencies" (Ladefoged 2003: 179); stressed vowels "will have a more positive slope (greater intensity in the higher frequencies)" (Ladefoged 2003: 181). And finally, some languages also use formant frequencies, in other words vowel quality, to determine stress (e.g. schwa is never stressed in English).

Pitch, as defined above, is the intrinsic correlate of tone.

(10) Tone

pitch

The spectral correlates of phonation types or voice qualities have been found to be all of the above, plus periodicity.

(11) Phonation types (Gordon & Ladefoged 2001, i.a.)

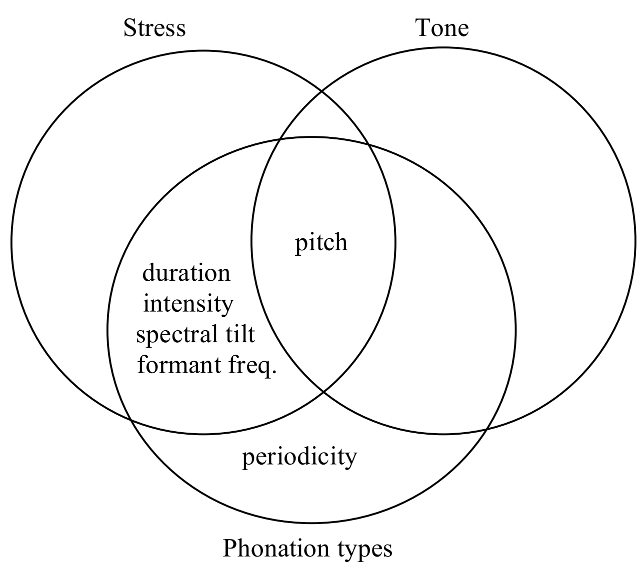
pitch
duration
intensity
spectral tilt
formant frequencies
periodicity

With respect to pitch, non-modal phonation types are commonly associated with lowering of fundamental frequency (F0), although "this lowering effect is not universal, as certain languages have developed high tone as a reflex of glottal constriction" (Gordon 1998; Gordon & Ladefoged 2001: 17). As for duration, non-modal vowels are in some languages longer compared to modal vowels (Gordon & Ladefoged 2001: 18). Many languages show a decrease in overall acoustic intensity in both breathy & creaky phonations (breathiness: Gujarati (Fischer-Jørgensen 1967), Kui and Chong (Thongkum 1988); creakiness: Chong (Thongkum 1988) and Hupa (Gordon 1998).

Gordon & Ladefoged (2001: 15) explain the effect of spectral tilt with respect to different voice qualities as follows "breathy vowels have the greatest drop off [...] in energy as frequency increases, while creaky vowels display the largest boost in energy as frequency is increased" (Gordon & Ladefoged 2001: 17). The peaks of resonance in the vocal tract, i.e. formant frequencies, may also vary as a function of phonation type. In Jalapa Mazatec (Kirk et al 1993) frequency values for the first formant are higher during creaky phonation than either breathy or modal phonation; whereas in Chong (Thongkum 1988), breathiness is associated with a lowering of the first formant. Finally, periodicity, or the regularity of the vocal folds vibration also varies depending on phonation. While vocal folds vibration is regular in modal voice, creaky phonation is characteristically associated with aperiodic glottal pulses; breathiness is characterized by increased spectral noise, particularly at higher frequencies.

The Venn diagram below illustrates a general comparison of the different phonetics cues that may correlate with stress, tone and phonation types.

(12) General comparison of phonetic cues to stress, tone and phonation types:



As the diagram shows, the phonetic correlates of each pattern may interact or overlap. The question is how do these patterns interact in languages with two or the three of them. How are these acoustic properties distributed and mapped to the phonology of a given language? The next section presents language specific examples of possible interactions and set the predictions for SLQZ.

3. Typological Considerations and Hypothesis

Although a considerable amount of research is still necessary to deeply understand the phenomena, there are some analyses of a number of languages with different combinations of prosodic patterns. Ayutla Mixtec (Pankratz & Pike 1967; de Lacy 2002) has been analyzed as a tone-driven stress system. Tone and stress interact, with a clear preference for high tone to be stressed. Lamba (Bickmore 1995; de Lacy 2002), on the other hand, has been described as a stress-driven tone system; stressed syllables have high tone. The interaction between tone and phonation types is common in the Otomanguean family (to which SLQZ is a member of). According to Silverman (1997), in Jalapa Mazatec, tone and non-modal phonation are sequenced with respect to one another, so that tonal differences may be realized in modal voice. In other words, phonation types and tone avoid their co-ocurrence. In Munduruku (Picanco 2006), a language with tone and phonation types, non-modal vowels also show a restricted distribution of tone (e.g. creaky vowels only bear low tone). What is, then, the phonetic and phonological correlation between tone, phonation types and stress in SLQZ? Gordon & Ladefoged (2001) found that particularly periodicity and spectral tilt were useful measurements to detect voice qualities in SLQZ.

Assuming that languages distribute phonetic cues systematically (including prosodic patterns) and that this distribution is language specific, the following hypothesis will be tested:

(13) SLQZ Hypothesis Prosodic patterns in SLQZ (stress, tone, phonation types) are distributed such that each can be differentiated (by speakers and in the learning process)

From the above, specific predictions for spectral correlates of stress in SLQZ are proposed:

(14) Prediction 1 **Pitch** is not used as a phonetic cue to stress (Interference with tone)

(15) Prediction 2 **Duration** is a phonetic cue to stress

(16) Prediction 3 **Intensity** is a phonetic cue to stress

In other words: Prominent (stressed) syllables would be longer and with higher intensity values than non-prominent ones (unstressed), while values for pitch would not be statistically significant.

4. Acoustic Analysis

A phonetic experiment was conducted to test the hypothesis and predictions above. The experiment consisted of a comparison of unstressed versus stressed vowels (modal and non-modal).

4.1 Methods

Subjects: Four native speakers of SLQZ participated in the experiment; two female, 22 and 18 years old, and two male speakers, 46 and 61.

Stimuli: The stimuli consisted of words containing unstressed and stressed syllables in modal and non-modal voice (breathy)[2] in the middle of real sentence. Unstressed vowels were in open syllables and stressed vowels followed by a lenis (voiced) consonant, this being the more perceptually salient contrast along the dimension of stress.[3] Below I list the words used in the stimuli followed by the actual phrases.

(17) Words in the stimuli

Four disyllabic words with unstressed and stressed modal vowels

1. *garaad*	[ga.ˈɾaːd]	'plow'
2. *sabaad*	[sa.ˈbaːd]	'shoe'
3. *montoony*	[mon.ˈtoːnj]	'a lot of '
4. *paleteer*	[pa.le.ˈteːɾ]	'ice cream'

Four stressed breathy vowels[4]

5. *(dìi'zh) nahah*	[na̤ː]	'curse'
6. *wgya'a xguehehg*	[ʷgjaˀa ʃge̤ːg]	'dancer'
7. *xguehehg*	[ʃge̤ːg]	'type of gourd'
8. *zihihny*	[zi̤ːɲ]	'palm'

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[2] Creaky vowels were not taken into account because they mostly occur in stressed syllables and the phonological status of checked vowels is still under consideration.

[3] In other Zapotec variants (Smith-Stark 2003; Arellanes 2008), it has been observed that the type of coda consonant determines the duration of the vowel in stressed syllables. The fortis/lenis contrast is pervasive in Zapotec languages (roughly voiceless/voiced). I avoided this potential conflict by excluding fortis consonants from the stimuli.

[4] As shown with the stimuli with modal vowels, the preferred word was a disyllabic one that contains both unstressed and stressed vowels. For the non-modal vowels, however, it was much more difficult to find these kind of stimuli. Instead, stressed (long) breathy vowels in monosyllables were used (words 5-8) and other items with unstressed (short) breathy vowels (9-12), regardless of the phonation in the stressed syllables for the latter.

Four unstressed breathy vowels

9. *(gyìa') bdahg zh:uhnng* [bda̤g ʒṳŋŋ] ‘medicinal plant’[5]

10. *behtx:tiilly* [be̤tʂtiːllj] ‘mint’

11. *lohcwàa'* [lo̤.ˈkwa̰ʔ] ‘my forehead’

12. *bahlcwe'uh* [ba̤l.ˈkweʔu] ‘moss’

(18) Actual stimuli:

Four disyllabic words with unstressed and stressed modal vowels

1. *Jwany ruhnye* ***garaad*** *zèi'ny* "John works with the plow"
2. *Rnia* ***sabaad*** *cuan Dìi'zh Sah* "I say shoe in Zapotec"
3. *Càa teihby* ***montoony*** *mùully* "There is/I have a lot of money"
4. *Mnizh* ***paleteer*** *gei nàa* "The salesman gave me ice cream"

Four unstressed non-prominent breathy vowels

5. *gyìa'* ***bdahg*** *zh:uhnng* "medicinal plant"
6. *Rcà'za'* ***behtx****:tiilly* "I want mint"
7. ***lohcwàa'*** *nàa bi'chi'ih* "My forehead is small"
8. *rapa'* ***bahlcwe'uh*** *liaza'* "I have moss in my house"

Four stressed breathy vowels

9. *Re'ipyih dìi'zh* ***nahah*** *Biedoy* "He cursed the Mrs."
10. *Wgya'a* ***xguehehg*** *cayia'a loh gi'a* "The dancer dances in the plaza"
11. *Mnìi'zh xnàana'* ***xguehehg*** *nàa'* "My mother gave me the gourd"
12. *Chiecw bdeidy* ***zihihny*** *zhyap* "Francisco gave a palm to the girl"

Data collection and analysis: Four repetitions of each phrase were collected based on a randomized list. In the cases where the speaker was unable to read, the phrase was given in Spanish by the facilitator (the author). Recordings were made with a Marantz 660 solid-state recorder and a wired lapel countryman microphone (phantom power).

In total, 256 vowels were measured in Praat for Mac (4 unstressed modal vowels + 4 stressed modal vowels + 4 unstressed breathy vowels + 4 stressed breathy vowels x 4 repetitions each token x 4 speakers = 256 vowels). Each vowel was measured for: duration (ms; total timing of vowel), intensity (dB; average within vowel duration) and pitch (Hz; average within vowel duration). Results were compiled in Excel 2004 for Mac and the statistics were run in JMP IN 5.1 for Mac (two tailed paired T-test).

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[5] The word *bdahg* on its own means "leaf", but it's used in different compounds as well, such as *bdahg mùuully* "type of leaf used in tanning leather" or *gyibdahgweh* "type of plant whose leaves (*dahgweh*) cause an itchy rash". In these compounds, as it is the case of the word in the stimuli, *bdahg* is unstressed; stress falls on the last syllable.

Just before presenting the results of the experiment, it might be important to have a point of comparison with respect to the values for duration, intensity and pitch in a prototypical stress language. According to Ortega & Prieto (2006), in Spanish, the averages for duration in unstressed is 110ms versus 125ms for stressed. In terms of intensity, unstressed reported 72dB and stressed 75dB. Pitch was hard to compare, there are many variables to take into account and there is considerable variation depending on the type of sentence (cf. Ortega & Prieto 2006). (See also Quilis 1988 and references therein.)

4.2 Results

In what follows, I present the results of the experiment. Table 1 illustrates the results for the four speakers with respect to modal vowels, whereas table 2 includes the breathy vowels.

Table 1. Modal vowels (16 tokens per subject per category)

	Duration (ms)		Intensity (dB)		Pitch (Hz)	
Female 1	Unstressed	Stressed	Unstressed	Stressed	Unstressed	Stressed
Average	55.88	168.88	75.38	79.67	232.31	236.06
Stdev	19.26	18.74	3.25	3.19	8.46	10.90
T-test	p < 0.0001		p = 0.0007		p = 0.2855	
Female 2						
Average	67.00	174.75	77.71	80.32	228.50	227.38
Stdev	18.26	40.34	3.47	3.22	12.76	10.40
T-test	p < 0.0001*		p = 0.0358*		p = 1.0	
Male 1						
Average	65.85	203.00	80.75	85.16	132.70	149.40
Stdev	17.29	38.37	2.37	2.08	7.51	13.93
T-test	p < 0.0001		p < 0.0001		p = 0.0002	
Male 2						
Average	61.19	179.63	80.33	84.78	127.06	134.38
Stdev	11.73	29.70	2.01	2.16	5.26	14.06
T-test	p = 0.0001*		p = 0.0001*		p = 0.0662	

(< 0.05 = statistically significant)

We observe that both duration and intensity were statistically different in modal vowels for all the subjects. Pitch, however, was not significantly different for female speakers. For male speakers, pitch resulted significantly different for male 1, but marginally significant for Male 2.

Table 2. Breathy vowels (16 tokens per subject per category)

	Duration (ms)		Intensity (dB)		Pitch (Hz)	
Female 1	Unstressed	Stressed	Unstressed	Stressed	Unstressed	Stressed
Average	87.25	202.25	77.37	78.14	222.56	229.93
Stdev	27.06	46.66	4.58	3.48	42.10	20.88
T-test	p < 0.0001		p = 0.597		p = 0.5352	
Female 2						
Average	66.19	184.69	78.81	76.89	224.44	226.38
Stdev	17.10	38.88	4.60	3.29	11.45	15.31
T-test	p < 0.0001*		p = 0.1864		p = 0.6882	
Male 1						
Average	98.22	230.25	83.61	82.32	131.19	133.25
Stdev	32.23	56.79	3.28	4.81	12.02	22.89
T-test	p < 0.0001		p = 0.3795		p = 0.7531	
Male 2						
Average	71.00	193.38	82.49	81.26	133.88	116.90
Stdev	15.68	24.79	2.97	4.48	22.03	19.69
T-test	p < 0.0001*		p = 0.3679		p = 0.0566	

As for breathy vowels, duration was also statistically different. On the other hand, neither intensity nor pitch were significantly different (marginally significant for Male 2).

5. Discussion

From the results above the hypothesis was confirmed, repeated below.

(19) SLQZ Hypothesis √

> Prosodic pattern in SLQZ (stress, tone, phonation types) are distributed such that each can be differentiated (by speakers and in the learning process)

Tone and phonation types in SLQZ have been described phonetically. As in any other language pitch is the direct correlate of tone (Chávez-Peón in prep.), whereas phonation types can be identified by a number of phonetic cues, such as intensity, periodicity and spectral tilt (Gordon & Ladefoged 2001), as well as formant frequencies (Chávez-Peón, ms.). This study also showed that non-modal vowels are longer than modal ones (cf. Gordon & Ladefoged 2001: 18). It was unclear, as stayed in the introduction, which phonetic cues signal stress in SLQZ. The findings show that the main correlate of stress is duration. This was particularly interesting in the light of the potential conflict due to the interaction of the same phonetic cues for different prosodic patterns.

In more detail, the table below illustrates the particular predictions and results of this study.

(20) Predictions for spectral correlates of stress in SLQZ:

Phonetic cue	Prediction	Voice	Female	Male	Summary
		Modal	yes	yes	
Duration	yes	Breathy	yes	yes	√
		Modal	yes	yes	
Intensity	yes	Breathy	no	no	√ / X
		Modal	no	yes	
Pitch	no	Breathy	no	no	√ / X

Again, we clearly observe that duration is the most robust spectral correlate of stress in SLQZ as it was significant for both modal and no modal vowels and regardless of the gender. Moreover, according to the results of the experiment, phonation and gender may also intervene in terms of how stress is signaled. When stressed vowels are modal, intensity was also significant to distinguish unstressed versus stressed syllables; however, it was not the case for breathy vowels. In terms of gender, the male speakers show significant (marginal significance for one of them) in terms of pitch in modal vowels. Gender differences have been also noticed on how phonation is realized in SLQZ. Creaky voice is more noticeable for male speakers, whereas breathy voice is more salient for female speakers (Munro, Lillehaugen & Lopez, forthc.: Unit 1; Gordon & Ladefoged 2001: 10)

Let us now complete the schema of how the different phonetic cues of stress, tone and phonation types are distributed in SLQZ with a Venn diagram. Figure (21) below, corresponds to modal vowels, in the set of stress, duration and intensity are included as they were found to be relevant.[6] Pitch, against the prediction, was also distinctive, but only for male speakers. All these spectral correlates are also indicators of phonation types and, therefore, intersect in the diagram below. In comparison, (22) shows that duration and not intensity was relevant to signal stress for breathy vowels. Here, pitch is shared as a spectral correlated by both tone and phonation types.

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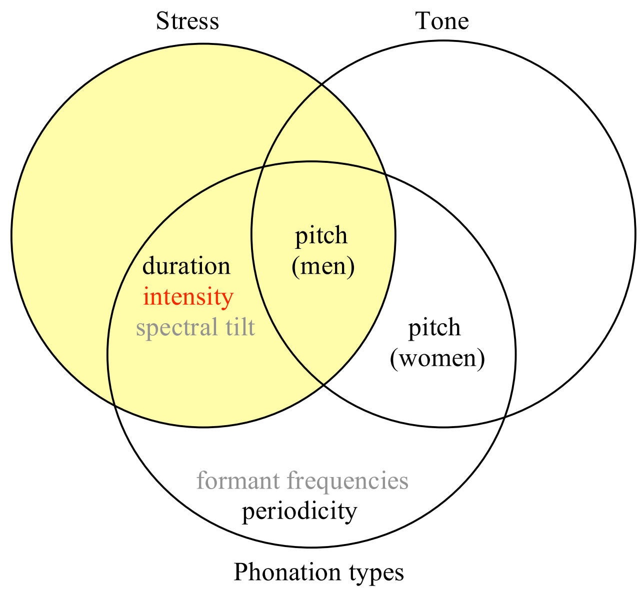
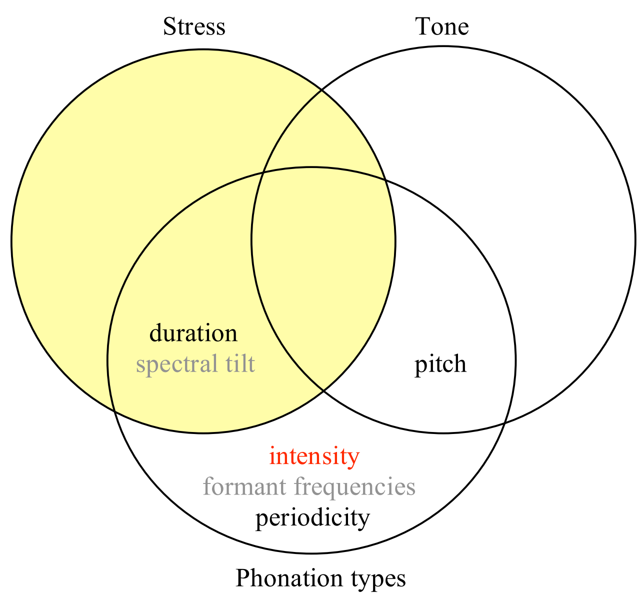
[6] Preliminary analysis within this experiment show that spectral tilt is also relevant in distinguishing unstressed versus stressed vowels. The proper account for spectral tilt, however, is pendant on future research.

(21) SLQZ interaction of stress with tone & phonation types for modal vowels



(22) SLQZ interaction of stress with tone & phonation types for breathy vowels



Taking into account the previous facts, it is important to consider in some more detail SLQZ metrical prominence at the phonological level. As mentioned in section 2, the last syllable of uninflected words is stressed; distributionally, contour voices (tones), phonetic long vowels, and diphthongs only occur in stressed syllables. In sum, a good amount of the complexity of SLQZ phonology is restricted to prominent (stressed) syllables. This type of distribution is common in the languages of the word; clusters of information or crucial data occupy salient positions (e.g. Beckman 1998). Now, related to the duration of stressed syllables, it is likely that if they are carrying a considerable amount of information, they are forced to be longer.

In terms of moraicity, it is well know that many languages establish a clear relationship between duration and syllable weight (e.g. Cohn 2003). Gordon (2001), for instance, establishes for a number of languages that the durational rhyme ratio of 1 to 2 in unstressed versus stressed syllables corresponds to monomoraic versus bimoraic structure, respectively. Based on the results presented in this paper (1 to 3 ratio for vowel duration in unstressed versus stressed syllables) and the typological accounts for syllable weight, I propose to analyze unstressed syllables as monomoraic and stressed syllables as bimoraic in SLQZ.

6. Conclusions

The general question pursued by this paper was to find out the phonetic cues to stress in a tonal language, namely SLQZ. If tone and stress are not in a particular interaction (e.g. high tone = stressed), then it is expected that pitch will not be a primary cue to stress. Accordingly, pitch does not have a primary role as an indicator of stress in SLQZ, instead, duration is the main cue.

With respect to the phonetics-phonology mapping, the considerable amount of phonetic duration suggests that it can be translated into syllable weight. As stated above, stressed syllables are considerably longer than unstressed and, therefore, they are to be considered bimoraic. A more precise account, however, which takes into account different syllable shapes and coda consonants, is necessary to accurately establish this correlation.

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