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Non-modal voice quality in Chichimeco

"Hablamos más con la garganta"

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Abstract

In this thesis, the phonetics and the phonology of non-modal voice quality and other glottal features in Chichimeco (Oto-Manguean, Mexico) are described. For this investigation, I analysed recordings I made in Mexico in spring 2017 as well as recordings enclosed in Lastra (2009b, 2016).

Descriptions of this language have been published since the 1930s but non-modal phonation has not received the attention it deserves. Only recently, the first proper phonetic/phonological account of breathy voice was published (Herrera 2014).

In this thesis, I corroborate Herrera's analysis of breathy voice as a phonological category /V̤/, taking into account tone. Furthermore, I propose the phonological status of creaky voice /V̰/ as distinct from a sequence of modal vowel and final glottal stop /Vʔ/. Additionally, I confirm that Chichimeco simultaneously implements phonological non-modal voice quality and tone. Therefore, this language classifies as *laryngeally complex*. Non-modal voice quality is mostly expressed towards the end of the vowel and the measures H1*-A1*, H1*-A3* and CPP seem to best characterise the three phonation categories. H1*-H2* seems to only distinguish creaky voice from non-creaky voice. No conclusive interactions with tone were found concerning these acoustic measures.

By investigating the distribution of creaky and breathy voice, I argue that these categories are related to a bigger phenomenon of glottalisation, i.e. to glottal, glottalised and aspirated consonants. These sounds generally only occur in the stressed syllable. Moreover, restrictions of their co-occurrence are related to syllable structure. Both of these facts indicate a *prosodic* governing of laryngeal features in this language.

This investigation represents new data in the growing research on the phonetics and the phonology of non-modal voice quality, as well as a further example of a laryngeally complex language. The analysis of the distribution of glottals reveals interesting connections between glottalised and aspirated vowels and consonants. Thereby, it can contribute to the theoretical phonological characterisation of laryngeal features. Finally, this investigation expands the description of Chichimeco phonology and can ultimately be used in the improvement of the orthography of the language.

Keywords: Chichimeco, non-modal phonation, non-modal voice quality, glottals, Oto-Manguean languages, laryngeal complexity

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Abbreviations

AP	Anterior Past
CDI	Comisión nacional para el desarrollo de los pueblos indígenas
CPP	Cepstral Peak Prominence
DU	Dual
EXCL	Exclusive
F0	Fundamental frequency
FOC	Focus
NA	Agent noun
NEG	Negation
OBJ	Object
PL	Plural
PRES	Present
SG	Singular
TAM	Tense-Aspect-Mode

1. Introduction

Chichimeco Jonaz[1] is a language within the Oto-Pame branch of the Oto-Manguean family, spoken by a few hundred people in Misión de Chichimecas, Guanajuato, Mexico (Lastra 1984, 1992, 2009a). Since this language is the only remaining Chichimeco language (Lastra 2014), it will henceforth be referred to as Chichimeco.

In this thesis, I investigate the phonology and the phonetics of non-modal voice quality in Chichimeco, as well as its relationship to other glottals in this language. For this purpose, I travelled to Mexico in spring 2017 to conduct a field study in which I recorded interviews and an extensive word list of nouns with native speakers.

When I listened to a recording of Chichimeco for the first time, one of the most striking features were the glottal sounds. Later, I found out that there are various kinds of them. Chichimeco implements glottal sounds in different positions in the phonology; as segments of their own and as features of other segments.

The glottal *segments* are the two consonants /ʔ/ and /h/. They occur syllable-initially, such as in *ná**ʔ**u*[2] 'my hoe' and *ta**h**ír* 'my/his/her pistol'[3]. The glottal stop also occurs syllable-finally, such as in *unhí**ʔ*** 'his/her name'. As *part of segments*, glottals can be realised as glottalisation of plosives and affricates /p' t' k' ʦ' ʧ'/ and as aspiration of plosives /pʰ tʰ kʰ/. As with the glottal stop, glottalised consonants occur syllable-initially and finally, such as in *ú**t'**u* 'his/her hoe', *ú**ʦ'**a* 'their food' and *ihé**k'*** 'you (SG)'. Analogous to the glottal fricative, aspirated consonants only occur syllable-initially, such as in *rí**kʰ**ur* 'tortilla(s)'. In syllable initial position, all these sounds can also be adjacent to a heterosyllabic sonorant, such as in *u**mʔ**á* 'sun' and *u**mh**ã́* 'lamb', *ná**nt'**a* 'one' and *ní**ntʰ**i* 'female'. In Table A1 in the Appendix, I give more examples for the distribution of these sounds for all places of articulation.

Another way in which glottal sounds can co-occur with segments is as *non-modal voice quality*[4] on vowels. Angulo (1932) already mentioned whispered vowels and transcribed them as superscript vowels or sometimes as sequences of <VhV> or a combination of both. Compare, for example, the different spellings of 'dog': *símᵃ̀n*, *símhᵃ̀n* and *símàhàn*. In comparison, Romero (1957-1958) described "complex nuclei" <VʰV> and Lastra (1984, 2009a, 2016) transcribed the same words as

1 The three-letter code of this language is *pei* (ISO 639-3).
2 Chichimeco is a tone language. I use /ˊ/ for high tone and no marking for low tone.
3 There is no grammatical gender in Chichimeco (Lastra 2011: 85). In this word, the first person form happens to be homophonous with the third person form.
4 In this thesis, I use voice quality and phonation type synonymously.

sequences of <VʔV> or <VhV>[5]. Herrera (2014) analysed *breathy voice* in Chichimeco. She proposes that Chichimeco is a *laryngeally complex* language because it contrasts tone as well as phonation types independently. In other words, any tone can co-occur with any voice quality (see also Section 2.2.). Nevertheless, all the breathy examples she lists have low tone on the syllable with the breathy vowel.

In this thesis, I test Herrera's analysis of phonological breathy voice, including the claim of laryngeal complexity, and expand the analysis to creaky voice. Additionally, I present the distribution of non-modal voice quality in relation to other glottals, i.e. glottal, glottalised and aspirated consonants.

1.1. Research questions

This thesis comprises a phonological as well as a phonetic investigation. For the actual investigation as well as for the presentation of my results, I follow the frequent practice of assuming two different disciplines in the study of the sounds of languages; phonology and phonetics. The focus of the phonological analysis in this thesis (see Chapter 4) lies on the characterisation and distribution of *distinctive phonetic features* that are considered to have phonological status. Phonetic features that are not distinctive, such as the timing of different phonation types and the exact acoustic correlates of non-modal voice quality, are only noted in this part of the investigation. The systematic study of these concomitant features is assigned to the domain of phonetics and, thus, examined and discussed in Chapter 5.

As the aim of this thesis is to examine Herrera's analysis of breathy voice, I would like to determine whether creaky voice also plays an analogous role in the phonology of Chichimeco. In other words, additionally to corroborating the phonological status of breathy voice, I want to examine whether the analysis of phonological non-modal voice quality can be expanded to creaky voice. In conjunction with the phonological analysis, I investigate the phonetic production, more specifically the acoustic realisation of the phonological categories. In order to address these issues, I try to answer several questions. These research questions can be grouped according to three themes: 1. the phonological status of non-modal voice quality, 2. the co-occurrence of non-modal phonation with other segmental and suprasegmental features, 3. the distribution of non-modal voice quality in relation to the syllable. These research questions are stated and motivated in the following:

5 In Lastra (2016), 'dog' is written as *símaʔan*, with a glottal stop instead of <h>, and in my own recordings and the recordings enclosed in Lastra (2009b), the word is consistently produced with a creaky vowel.

1. **Are breathy and creaky voice produced consistently within and between speakers? Does creaky voice constitute a phonological category distinct from that of the glottal stop?** In many languages, voice quality has paralinguistic or prosodic functions. In Swedish, Chinese and English, for example, creaky voice is used as a phrase boundary signal (Carlson, Hirschberg & Swerts 2005; Belotel-Grenié & Grenié 2004; Chavarria et al. 2004). Breathy voice also often occurs at the end of utterances when sub-glottal pressure declines (Klatt & Klatt 1990). If voice quality is indeed phonological, there should be relatively little inter- and intra-speaker variation of its pronunciation. In many languages, phonetic creaky voice is also a frequent allophone of a phonological glottal stop (Ladefoged & Maddieson 1996). If creaky voice is a phonological category of its own and not just an allophone of /ʔ/, it should have a similar distribution as /ʔ/ in at least some contexts, as well as a consistent production. Several other Oto-Manguean languages, such as Amuzgo (Herrera 2010) and San Pablo Güilá Zapotec (Arellanes 2015) make a phonological distinction between creaky voice and a final glottal stop. Thus, it might be that this contrast also occurs in Chichimeco.
2. **Do the non-modal voice qualities occur with all vowels and with both tones? If they do occur with both tones, what is the exact acoustic realisation of these combinations?** In other Oto-Manguean languages, non-modal phonation can co-occur with other suprasegmental features, such as tone and even vowel nasality (cf. Silverman 1997; Arellanes 2003, 2010, 2015; Herrera 2000, 2010). It might be that Chichimeco also allows such combinations. As mentioned before, Herrera (2014) proposed that Chichimeco is a *laryngeally complex* language (cf. Section 2.2.). To be classified as such, voice quality should be a phenomenon independent of tone. In other words, both tones should co-occur with different voice qualities. Following the patterns of *laryngeal complexity* described in Silverman (1997), it is expected that languages with tone as well as non-modal phonation contrasts *sequence* modal and non-modal voice quality (cf. Section 2.2.1.). The reason for this is that non-modal voice qualities usually have their own characteristic F0 features that might obscure the typical F0 curves for the tonal categories. Furthermore, since both creaky and breathy voice have a typical low F0, their realisation with a phonological high tone results in a different production than with a low tone in some languages (DiCanio 2012; Keating, Garellek & Kreiman 2015). For example, in San Pablo Güilá Zapotec, phonological laryngealisation in combination with a high tone is produced as tense voice or an interrupted vowel, i.e. a vowel interrupted by a very short glottal stop. With low tone, it is produced as classical creaky voice (Arellanes 2010, 2015). If we find that Chichimeco is indeed a laryngeally complex language, the exact production of non-modal voice quality and a possible sequencing of different voice qualities should be examined.

3. **Do the non-modal voice qualities only occur in the stressed syllable? Is only one non-modal voice quality allowed per syllable?** Similar to tone, glottalisation is related to stress in some Oto-Manguean languages. In San Pablo Güilá Zapotec, for example, the full degree of glottalisation contrasts only appears in the stressed syllable (Arellanes 2015). With very few exceptions, glottal consonants seem to occur only in the stressed syllable in Chichimeco. This has not explicitly been stated by any of the authors who have described Chichimeco but it becomes apparent when comparing the examples given in their publications (cf. Angulo 1932; Romero 1957-1958; Lastra 1984, 2009a, 2009b, 2011, 2016; Herrera 2014). Following this generalisation, non-modal voice qualities could also only occur in this syllable. On typological grounds (cf. Kehrein & Golston 2004), it is reasonable to assume that only one non-modal voice quality is produced per syllable, especially since the glottis is already occupied with the production of tone and the other glottals. Therefore, I investigate the distribution and the domain of non-modal voice quality in Chichimeco.

1.2. Relevance

The relevance of this thesis is twofold. To illustrate my contribution, I have to anticipate some of the results of my investigation.

First, it provides a description and analysis of an important but previously scarcely described phonological feature of the language, i.e. non-modal voice quality, and, more generally, glottalisation. Thereby, it contributes to the general description of the language which can and ultimately should be integrated in the creation of an orthography for written materials, e.g. for teaching.

The census conducted by INEGI in 2015 reports that Chichimeco has 2,134 speakers (age 3 or above). The actual number of speakers is probably much lower. According to Ethnologue (Simons & Fennig 2017), the status of the language is shifting. This means that bilingualism is the norm with Spanish being more dominant. Especially the younger generation prefers to use Spanish rather than Chichimeco or is not learning the language at all anymore, cf. also Lastra's (2009a) description.

Since the laws about basic bilingual education[6], i.e. in Spanish and the indigenous language, there have been efforts to develop teaching materials for indigenous languages. For most indigenous languages, these endeavours start with the development of an orthography. One common mistake in the creation of orthographies is that aspects of the phonology that do not have any correspondence in Spanish are often ignored or mixed up (Y. Lastra, personal communication, June 2017). For

6 Ley General de Educación (1993) and Ley General de Derechos Lingüísticos de los Pueblos Indígenas (2003).

example, in a document about the standardisation of Chichimeco orthography[7], non-modal phonation and nasalisation are transcribed quite inconsistently and unreliably. To a smaller degree, this also concerns tone. The apostrophe, for example, is consistently used for the glottal stop and glottalised consonants. In conjunction with vowels, however, it is rather inconsistently used to denote a glottal stop, creaky voice or sometimes high tone. This unreliable transcription by speakers as well as linguists indicates that neither are sufficiently meta-aware of these features that clearly play an important and systematic role in the phonology of the language. Native speakers are, of course, aware of it on an intuitive level as I experienced when I asked them to correct my speech and they were not content until I produced the correct voice quality. I also noticed similar problems in existing materials for teaching the language in primary school provided to me during my stay in Misión de Chichimecas. When I asked about the education in Chichimeco, several speakers showed me school books and expressed concerns about their correctness and suitability. More specifically, they told me that they thought that many of the transcriptions in these books were wrong. Therefore, a more comprehensive description of the phonology can help to improve the orthography which can ultimately be used in teaching the language to children.

Second, this thesis constitutes a part of linguistic fundamental research, contributing to our understanding of the phonology and the phonetics of glottalisation in general and voice quality in particular. With the analysis I propose, and with the phonetic description of non-modal voice quality, Chichimeco is a further data point in our exploration of laryngeal behaviour. The phonological analysis can give us information about the systematicity of these sounds. An acoustic description is a frequently used approximation to laryngeal behaviour proper, i.e. the actual articulations involved in the production of such sounds. Thus, this study is comparable to studies of non-modal voice quality in other languages of the world.

Non-modal voice quality is a feature that frequently occurs in other Oto-Manguean languages (e.g. Kirk, Ladefoged & Ladefoged 1993; Silverman 1997; Herrera 2000, 2010; Arellanes 2010, 2015; Keating et al. 2010; Garellek & Keating 2011). Therefore, the description of Chichimeco voice quality extends the research about this phenomenon in the language family. These other Oto-Manguean languages do not only use voice quality and other glottals but also tone. Thus, they fall into Silverman's (1997) notion of *laryngeal complexity* (see Section 2.2.). In addition to describing this phenomenon, he proposes a typology of different timing patterns of *laryngeal complexity*. In this thesis, I examine if and how Chichimeco fits into this characterisation.

7 This document was the joint effort of several speakers of Chichimeco and a general linguist.

As is discussed in Chapter 4, non-modal voice quality is part of a bigger phenomenon of glottalisation that also includes other glottal sounds. The *distribution* and *co-occurrence* of non-modal voice quality and glottal and glottalised consonants are related to syllable structure. This reference to higher prosodic structure in Chichimeco points towards a suprasegmental governing of laryngeal features. To be clear, this thesis is not a theoretical investigation but a descriptive one. Nevertheless, this description of Chichimeco phonology can contribute to the phonological theory of laryngeals.

This thesis is structured as follows. In Chapter 2, I give relevant background information concerning the phonetics of non-modal voice quality, the notion of laryngeal complexity and phonological structures in Chichimeco. In Chapter 3, I describe the data that I used in this thesis. In Chapter 4, I propose a phonological analysis of creaky and breathy voice and illustrate the relationship of these sounds to other glottal sounds. In Chapter 5, I present an acoustic study of phonological creaky and breathy voice. In Chapter 6, I give a summary of the investigation in this thesis and an outlook on possible future research topics concerning the subject of non-modal voice quality and glottalisation in Chichimeco.

2. Background

In this chapter, I present background information for my phonological and phonetic investigations of Chichimeco voice quality in Chapters 4 and 5.

In Section 2.1., I describe the phonetics of voice quality and other glottals, as well as their interaction with other features that are also present in Chichimeco phonology. This section introduces inter-relationships and potential problems in the phonetic study of voice quality and provide the necessary background for the acoustic investigation in Chapter 5.

In Section 2.2., I introduce the notion of *laryngeal complexity*. For this purpose, I describe other Oto-Manguean languages using tone and non-modal voice quality in their phonology. Furthermore, I summarise Silverman's (1997) argumentation for a typological implicational categorisation of such languages with respect to the distribution and timing of laryngeals.

In Section 2.3., I give an overview of previous phonological investigations of Chichimeco. This overview focuses on features that are essential to my own study of non-modal voice quality, i.e. word and syllable structure, phonotactics and suprasegmentals, such as tone and stress.

Certainly, there is much more to be said about these subjects than I can outline in this short chapter. Here, however, I limit my account to the issues that are immediately relevant for my own investigation of Chichimeco voice quality in Chapters 4 and 5.

2.1. The phonetic properties of voice quality and glottals

In this thesis, I conduct a phonological investigation as well as an acoustic study of voice quality in Chichimeco. For this reason, I provide an account of the phonetic properties of different voice qualities and their interactions with other phonetic features in this section.

Voice quality or *phonation type* are terms that refer to the different vibration patterns of the vocal folds. The different modes of vibration have distinct acoustic correlates. In Section 2.1.1., different kinds of phonation, i.e. the production of sound in the vocal folds, and its acoustic consequences are described.

As illustrated in more detail in Section 2.3., there are seven vowels in Chichimeco, and tone and vowel nasality occur in the phonological system. In general, F0 can interact with the source characteristics of non-modal voice quality since it is produced by the same articulator. The spectral features of different voice qualities can also be related to nasality and vowel quality. Therefore, the interaction of different voice qualities with the fundamental frequency (F0), nasality and vowel quality are presented in Section 2.1.2.

In this chapter, I use the terms F0 and harmonics in a particular way, even though they are, of course, related. Where pitch phenomena are concerned, I use the term *fundamental frequency* or *F0*. When talking about voice quality, I use the term *harmonics*. Let the reader be reminded that the first harmonic is the F0.

Furthermore, I use my own terminology concerning different glottals, see Figure 2.1. Glottalisation comprises constriction as well as aspiration. Both of them can be expressed as segments on their own or as features on consonants and vowels. The segmental realisation of constriction is the glottal stop. Constriction on consonants is produced as constricted consonants which have been called glottalised or laryngealised consonants in the literature (Herrera 2014). In the description of Chichimeco, I refrain from using the term 'glottalisation' in this sense because constriction and aspiration are connected in this language. This is a phenomenon that I term 'glottalisation'. On vowels, constriction is realised as creakiness of some kind (cf. 2.1.). Aspiration as a segment on its own is a glottal fricative. On consonants, aspiration is produced as aspirated consonants and on vowels it is realised as breathy voice.

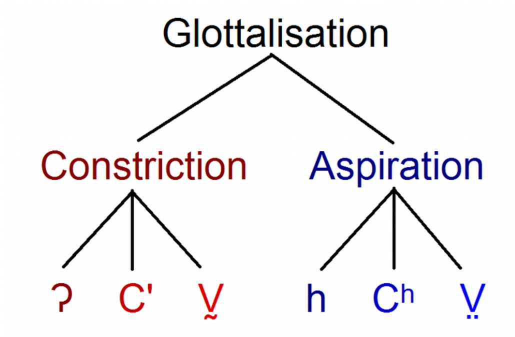


Figure 2.1. Usage of the terms 'glottalisation', 'constriction' and 'aspiration' in this thesis.

2.1.1. Non-modal voice quality

All descriptions of voice quality make reference to the articulatory and acoustic properties of modal or "normal" voice. In modal voice, the arytenoid cartilages are adducted and airflow causes the relatively relaxed vocal folds to vibrate in a quasi-periodic manner. This produces the 'normal', most effective voice quality that is usually used in vowels and voiced consonants (cf. Kreiman & Sidtis 2011: Ch. 2).

Constriction continuum. In order to describe different phonation types, Gordon & Ladefoged (2001) proposed a continuum based on laryngeal constriction. The continuum is given in (2.1).

(2.1)		Most open ◄			► Most closed
Phonation type	Voiceless	Breathy	Modal	Creaky	Glottal closure

On the extremes of this continuum are voicelessness and glottal closure. Open vocal folds result in *voiceless* sounds, such as the glottal fricative and voiceless consonants. On the other end of Gordon & Ladefoged's constriction continuum is the *glottal stop*. It is produced with complete closure of the vocal folds and enough tension in the vocalis muscle to prevent vibration. In between voiceless sounds and the glottal stop, they present breathy, modal and creaky voice quality. The continuum in (2.1) can accurately describe the relationship between, for example, glottal stops and creaky voice. However, it is an oversimplification of glottal behaviour. The glottis is quite complex and muscles can be adjusted to produce a variety of settings that cannot only be characterised by the grade of constriction. Now, I give a short account of the production and the acoustics of the most common phonation types used in languages[8].

In *breathy voice*, the arytenoids and the vocal folds are adducted enough so that airflow excites vibration, but without full contact. Since there is no full closure of the vocal folds, the rate of airflow is high. This results in a generally lower signal amplitude and in turbulent airflow and, thereby, noise in the spectrum, especially in the higher frequency regions. This mode of vibration is characterised by relatively symmetrical opening and closing phases and by the gradual closing of the vocal folds (Hillenbrand, Cleveland & Erickson 1994; Gordon & Ladefoged 2001).

In *creaky voice*, the arytenoids and vocal folds are adducted and there is a stronger tension caused by the contraction of the vocalis muscle. As a consequence, only a part of the vocal folds vibrates with a very asymmetrical vibration pattern. A relatively long closure is interrupted by a short open phase, and due to the tension the vocal folds close very abruptly (Kuang & Keating 2012). Creaky voice is also often characterised by irregular vibration. In general, breathy and creaky voice quality exhibit a lower F0 and a lower overall amplitude due to the less efficient phonation (cf. Kreiman & Sidtis 2011) compared to modal voice.

Another common phonation type that involves laryngeal constriction is *tense voice*. In creaky voice, constriction is produced by the contraction of the vocalis muscle which stiffens the vocal folds. In tense voice, however, the cricothyroid muscle, usually stretching the vocal folds, is contracted as well (Kingston 2005). These antagonistic movements result in a tension in the structure of the vocal

8 In this thesis, I do not address phonation type in the context of speech disorders.

folds that only allows vibration of the ligament part and leads to a *higher* F0, instead of a lower one as in creaky voice (Kingston 2005, Kuang & Keating 2012).

Due to its characteristics, tense voice is sometimes used in languages that combine laryngealisation with high tone, e.g. in San Pablo Güilá Zapotec (Arellanes 2015). In the literature, the term 'tense voice' has also been used to describe a phonation type in some (Southeast) Asian languages, e.g. Mpi (Silverman 1997, Gordon & Ladefoged 2001) and Yi languages (Kuang & Keating 2012). In these cases, however, it is often not clear whether the term 'tense voice' concerns the laryngeal configurations just described or simply a type of voice quality with a lesser degree of constriction than in creaky voice.

In general, glottal constriction is a rather complex phenomenon. Keating, Garellek & Kreiman (2015) cite no less than 6 different kinds of constricted voice.

Acoustic correlates. The regularity of vibration can be measured in jitter, the variation of the duration of adjacent vibration phases. In more recent literature (e.g. Keating et al. 2010, Garellek & Keating 2011, Kuang & Keating 2012, etc.), *harmonics-to-noise ratios* such as Cepstral Peak Prominence (CPP) have been used to quantify non-modal phonation types. Jitter measures of creaky voice are higher than those of modal voice and this phonation type also displays lower values of CPP due to its irregularity. CPP also has lower values for breathy voice since there is more noise in the spectrum (Keating et al. 2010).

The mode of vibration also affects *spectral tilt*. Spectral tilt denotes the energy of higher harmonics in relation to lower harmonics. One frequently used measurement (e.g. Keating & Esposito 2006, Esposito 2010, Keating et al. 2010, Garellek & Keating 2011, Kuang & Keating 2012, etc.) is the subtraction of the amplitude of the second harmonic from that of the first harmonic (H1-H2). The relationship between the amplitudes of the first and second harmonics has been connected to the open quotient (cf. Keating & Esposito 2006; Garellek & Keating 2011; Kuang & Keating 2012; Keating, Garellek & Kreiman 2015). This is the relative time of the glottal cycle of one phase in which the vocal folds are open. A relatively longer open phase of the vocal folds leads to a smaller amplitude of the second harmonic in relation to the first harmonic. In other words, the higher the measurement of H1-H2, the less constricted is voice quality. The general spectral tilt has been measured as subtracting the amplitudes of the first three formants from the first harmonic (H1-An[9]), as well as subtracting the amplitude of the fourth harmonic from the second harmonic (H2-H4) (Bishop & Keating 2012, Keating & Esposito 2006, Esposito 2006, Keating et al. 2010, etc.). These

9 I am aware that the naming of these parameters is confusing. The amplitudes of the harmonics are labelled as *Hn* while the amplitudes of the formants are labelled as *An*, instead of *Fn*. Nevertheless, I follow the tradition in the majority of previous literature and the parameter names in VoiceSauce and use these labels in this context.

measurements are related to the abruptness of vocal fold closure (Kuang & Keating 2012). The more abruptly they close, the higher are the amplitudes of the higher harmonics in the spectrum. In other words, and similar to H1-H2, higher H1-An and H2-H4 measurements indicate a less constricted voice quality. However, in the production of breathy voice, significant noise is often present in the range of the higher harmonics due to leakage in the glottis, possibly affecting the amplitudes in these frequencies (Hillenbrand, Cleveland & Erickson 1994; Wayland & Jongman 2003). Spectral tilts for modal, breathy and creaky vowels in San Lucas Quiaviní Zapotec are given in Figure 2.2. In Figure 2.2., we can see that the amplitudes of H2 and F1 in the breathy vowel (top right) are much *lower* than the amplitude of the F0, in comparison to the modal (top left) and to the creaky vowel (bottom). This means that the measurements for H1-H2 and for H1-A1 are *higher*. In contrast, in the creaky vowel, the relative amplitudes of H2 and F1 are higher than in the modal and the breathy vowel. Accordingly, the measurements for H1-H2 and H1-A1 are *lower*, in this case even negative.

How the different acoustic measurements relate to different voice qualities is summarised in Table 2.1.

In conclusion, even though Gordon & Ladefoged's constriction continuum in (2.1) seems to suffice as a model for describing glottal contrasts in most languages, actual glottal behaviour and its acoustics are not as simple and cannot be described accurately by a one-dimensional continuum.

Supralaryngeal configurations. The account of non-modal voice quality as purely glottal represents an oversimplification (cf. Edmondson & Esling 2006, Moisik & Esling 2011). It has been shown that supralaryngeal configurations, e.g. of the ventricular folds and the pharyngeal wall, also play a role in the production of non-modal voice quality in many languages, e.g. Jalapa Mazatec and !Xóõ (Gordon & Ladefoged 2001). However, in this thesis, I largely ignore this factor in the investigation of Chichimeco voice quality due to the lack of articulatory data.

Table 2.1. Acoustic correlates and measurements of different phonation types compared to modal voice.

	Speed of vibration	**Intensity of signal**	**Leakage & regularity**	**Open quotient**	**Abruptness; spectral tilt**
Acoustic Measures	**F0**	**Overall Amplitude**	**HNR/CPP**	**H1-H2**	**H1-An, H2-H4**
Breathy	lower	lower	lower	higher	higher
Creaky	lower	lower	lower	lower	lower
Tense	higher	lower?	lower	lower?	lower?

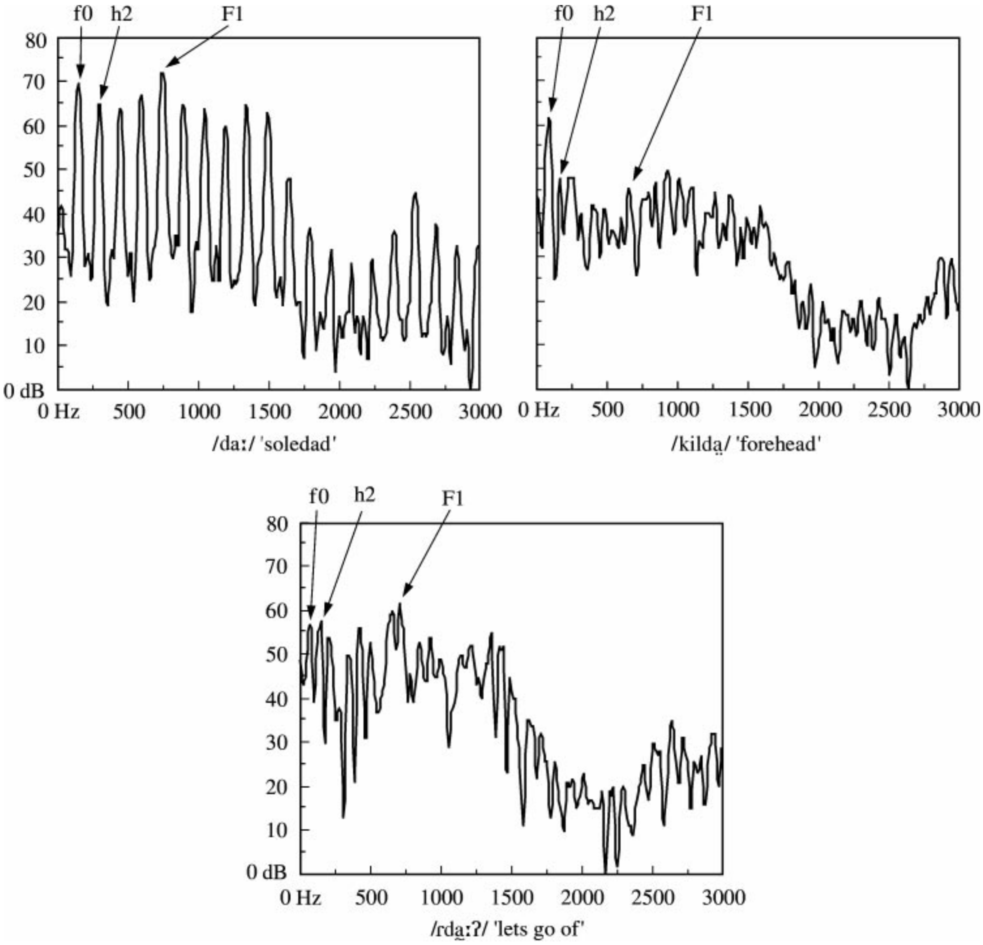


Figure 2.2. Spectra of modal (top left), breathy (top right) and creaky (bottom) vowels in San Lucas Quiaviní Zapotec (Gordon & Ladefoged 2001: 398).

2.1.2. Interaction of voice quality with other features

Voice quality and F0. Different voice qualities and F0, the main acoustic correlate of tone, are both produced by the vocal folds. This common articulator causes substantial interactions between these features. These interactions, in particular the influence of non-modal phonation on F0, have important implications for the phonological systems of languages.

Non-modal voice qualities have their own typical F0 (cf. Table 2.1.). However, this does not mean that each non-modal voice quality can only be produced with a certain F0. Rather, the *ideal* production of e.g. breathy and creaky voice lies within the lower range of a speaker.

To override this effect and produce these voice qualities with a higher F0 is possible but rather uneconomical and might even result in a different voice quality. However, the effect of constriction on F0, for example, depends on the exact production of the constriction, i.e. exactly which muscles are involved in its production. If a phonological category of laryngealisation is characterised by creaky voice and is supposed to be produced simultaneously with a high tone, the following might happen. In the production of creaky voice, the vocalis muscle is contracted to stiffen the vocal folds. At the same time, the cricothyroid is contracted to stretch the vocal folds and produce a high F0. As described in 2.1.1., this effectively results in a different voice quality; tense voice. This is exactly what happens in some languages that can combine non-modal phonation with different tones, such as San Pablo Güilá Zapotec (Arellanes 2003, 2010, 2015).

Apart from laryngeal muscle tension, vertical larynx position affects vocal fold tension and, as a consequence, F0. A lowered larynx, as in voiced plosives and breathy voice, reduces tension in the vocal folds and, consequently, lowers the fundamental frequency (Hombert, Ohala & Ewan 1979).

It is also possible that non-modal phonation masks F0 acoustically and thereby makes it imperceptible. Some kinds of creaky voice can be aperiodic, disrupting the periodicity of glottal pulses. Breathy voice can be very noisy, thus concealing information on the glottal pulses. Silverman (1997: 246) argued that "when a periodic glottal wave is either obscured or not present, the acoustic signal cannot encode a salient pitch value."

Voice quality and vowel quality. Gordon & Ladefoged (2001) describe effects that non-modal phonation can have on the formant structure of sonorants and vowels. Non-modal voice quality is often restricted to only part of the vowel, e.g. Hupa and some North American languages. The reason for this is that non-modal phonation can adversely affect formant structure. As a result, information about vowel quality and place of articulation of nasals is concealed and may not be perceived.

Another effect of phonation type on vowels is that non-modal phonation types can change the formant positions of vowels. Higher F1 values have been found in creaky vowels in Jalapa Mazatec (Kirk, Ladefoged & Ladefoged 1993) and Haoni (Maddieson & Ladefoged 1985), as well as in tense vowels in Southern Yi (Kuang & Keating 2012). Breathy voice, on the other hand, was related to a lower F1 in Chong and lower F1 and F2 in Kedang (Gordon & Ladefoged 2001). These effects on the lower formants are probably associated to larynx raising or lowering in the production of creaky and breathy voice, respectively[10]. Wayland & Jongman (2002) argue that this effect resulted in different vowel qualities for the tense and lax registers in Khmer registrogenesis.

Voice quality and nasality. Vowel nasality and breathiness have similar effects on the spectrum. Both can lower the first formant and increase formant bandwidth (Matisoff 1975). Nasal anti-formants lower the amplitude of H1 in men and of H2 in women (Simpson 2012). The relation of

10 In Kedang, however, these vowels are also produced with a wider pharynx which could be related to F1 lowering.

exactly these two measurements, i.e. H1-H2, however, is one of the most used measurements to quantify non-modal phonation types. Due to the acoustic similarity to non-modal phonation, nasality settings should not be ignored in the analysis of non-modal phonation.

2.2. Laryngeal complexity

Several languages apply relative F0 differences and different phonation types in their phonology. They might use each contrastively as tonal and voice quality categories or combine both features in a tone/register system as is common in Southeast Asia (see p. 15).

In Section 2.2.1., I explain the term *laryngeal complexity* proposed by Silverman (1997) and give a summary of his argumentation for an implicational universal concerning the distribution and timing of laryngeals in such languages. In this context, I also give a short description of languages using both features in different ways, i.e. languages that cannot be classified as *laryngeally complex*. In Section 2.2.2., I describe other Oto-Manguean languages that use tone and non-modal phonation and do fall into the category of *laryngeally complex* languages.

2.2.1. Laryngeal Complexity and typology

Silverman (1997) proposed the notion of *laryngeal complexity*. In general, this means that tone and non-modal phonation are engaged *independently* in the phonology of a given language. This excludes, for example, languages like Vietnamese and Chinese in which non-modal phonation is one of the acoustic correlates of tonal categories (Nguyen & Edmondson 1998, Gårding et al. 1986).

For languages that use both tone and non-modal phonation in their phonology, there are certain implications about the implementation of these features. The acoustic correlates of both, i.e. F0 for tone, and constriction or aspiration for non-modal phonation, are produced by the same articulator, the vocal folds (cf. 2.1.2). Due to their insufficient articulatory compatibility and their acoustic distance, tone and non-modal phonation are usually produced in sequence. This assures that enough of the vowel is produced with modal voice so that the characteristic F0 of a certain tone can be produced without too much effort. Thereby, the F0 is not obscured by other voice quality related features and can be recovered by the listener.

In terms of timing, there seems to be a certain hierarchy. Silverman (1997) gives auditory reasons for the preference of certain timing patterns over others. Auditory nerves respond more strongly to the increase in acoustic energy than to the decrease. Modal signals usually have a higher acoustic energy than non-modal signals. Accordingly, a sequence like [ha] is more perceptually salient than a sequence like [ah]. Silverman argues that a sequence like [ha] is the optimal timing pattern.

Languages that have more than one timing pattern have to make sure that the sub-optimal timing patterns are maximally distinct from the optimal one. Therefore, another common pattern is that of post-vocalic laryngeals that is maximally distinct from pre-vocalic laryngeals. A third pattern that is maximally distinct from these two is a vowel interrupted by non-modal phonation. Thus, he argues that there are certain implications about the timing patterns of modal and non-modal phonation in the languages of the world:

1. Pre-vocalic laryngeals[11] are the optimal timing pattern: ha, ʔa
2. The presence of postvocalic laryngeals implies the presence of prevocalic laryngeals: ha > ah, ʔa > aʔ
3. The presence of interrupted forms implies the presence of prevocalic and postvocalic laryngeals: ha > ah > aha, ʔa > aʔ > aʔa

Silverman described these sequencing patterns in three laryngeally complex Oto-Manguean languages (see 2.2.2.). He noted that this is, indeed, an Oto-Manguean pattern. There are other languages, like Mpi and Yi (Loloish, Sino-Tibetan), that also use these phonological categories independently without such sequencing. In these languages, however, the non-modal voice qualities are not as "extreme" as typical creaky and breathy voice. In other words, they are more modal than creaky and breathy voice in Oto-Manguean languages, not obscuring the realisation of tone to the same degree. The tonal systems are also rather simple in Mpi (2 level tones) and Yi (3 level tones). Oto-Manguean languages, on the other hand, usually have several level and contour tones in their inventories and creaky and breathy phonation are usually produced quite strongly.

In Chapters 4 and 5, I investigate to what degree Chichimeco can be classified in these terms.

In contrast to *laryngeal complexity*, tone and non-modal phonation are related in a different way in many languages. It is not surprising that the close connection between phonation type and F0 resulted in tonogenesis and in tone split in various languages, e.g. Southeast Asian languages (cf. Svantesson 2001) and Athabaskan languages (cf. Kingston 2005). It is assumed that tone developed from voicing and glottalisation contrasts in consonants through a stage of non-modal phonation, relating tonogenesis to registrogenesis (cf. Thurgood 2002).

With the process of tonogenesis in mind, it is striking that there are languages that disconnect the features F0 and non-modal phonation in their phonology, i.e. laryngeally complex languages.

11 For easier readability, the letters for the glottal fricative and glottal stop also represent aspirated and constricted voice quality.

2.2.2. Laryngeals in other Oto-Manguean languages

Silverman (1997) described three Oto-Manguean languages (Jalapa Mazatec, Comaltepec Chinantec, Copala Trique) that use tone and laryngeal features in their phonology as laryngeally complex. The notion of laryngeal complexity has since been applied to two other Oto-Manguean languages (Herrera 2000)[12]. In this section, I describe the distribution of laryngeals in these five languages.

In *Jalapa Mazatec*, vowels carry one of three tones and they contrast for length, nasality and voice quality, i.e. breathy and creaky voice.

Stand alone laryngeals /ʔ/ and /h/ may precede vowels, as exemplified in (2.2). Additionally, there are also syllable initial laryngealised and voiceless nasals and glides, as given in (2.3). In creaky and breathy vowels, the non-modal voice quality is also expressed in the initial part of the vowel and spreads to the last part of preceding sonorants, as in (2.4). In summary, non-modal phonation only occurs in pre-vocalic position and in the beginning of vowels in Jalapa Mazatec.

(2.2)	***ʔ****a*˧	'why'	***h****a*˥	'men'
(2.3)	***ʔn****a*˧	'shiny'	***n̥͡n****æ*˧	'he falls'
	ʔw*i*˧	'drinks'	***w̥͡w****æ*˧	'use up'
(2.4)	*n͡**n̰æ̰**͡æ*˧	'he says'	*n͡**n̤a̤**͡a*˧	'my tongue'
	ti˥*w͡**w̰æ̰**͡æ*˧	'hits, gives birth to'	*w͡**w̤o̤**͡o*˧	'hungry'

(Silverman 1997: 238)

In *Comaltepec Chinantec*, there are five tones, and vowels contrast for length, nasality and "vowel aspiration" (Silverman 1997, 2014). Glottal stop and fricative occur in syllable initial position, the former also in final position. Post-vocalic aspiration is counted as part of the vowel and it affects the tone (and the intensity) of the vowel (Silverman 1997). Examples for pre-vocalic glottals are given in (2.5). Examples for aspirated vowels in contrast to modal vowels, with and without final glottal stop, are given in (2.6). In summary, non-modal phonation occurs in pre-vocalic and in post-vocalic position in Comaltepec Chinantec.

12 Frazier (2010) claims that Yucatec Maya is also a laryngeally complex language. However, in this language, creaky voice only occurs with one tone. This pattern reminds more of languages like Chinese in which creak is part of one of the tones than of actual laryngeal complexity in which tone and non-modal phonation can combine in different ways.

(2.5)	*ʔoː*˧	'papaya'	***h****i*˥	'book'
(2.6)	*niː****h***˧˥	'sit!'	*ni*˥	'face'
	*li****h***˥	'flower'	*ta*˩˥	'work'
	*hu****hʔ***˥	'pineapple'	*he****ʔ***˧	'frog'

(Silverman 1997: 239ff.)

In *Copala Trique*, vowels carry one of eight tones and laryngeals can pattern in three different ways. The laryngeals /ʔ/ and /h/ can precede vowels ([h] only in Spanish loans), as exemplified in (2.7). Final syllables carry stress and are heavy, i.e. in open stressed syllables, the vowel is long. Syllables can only be closed by [ʔ] or [h], see (2.8). Furthermore, the vowel in the stressed syllable can be interrupted by [ʔ] or [h], see (2.9).

In summary, non-modal phonation occurs in pre- and post-vocalic position and it can interrupt vowels within the same syllable in Copala Trique.

(2.7)	*ʔu*˩*ʔuː*˩	'five'	*li****h****a*	'sandpaper' (< sp. lija)
(2.8)	*jaʔ*˥	'teeth'	*ja****h***˧	'ashes'
(2.9)	*ga*˧*tuʔu*˧	'incencse-burner'	*ɾi*˧*u****h****u*˩	'hollow reed'

(Silverman 1997: 243f.)

Two varieties of *Amuzgo*, San Pedro Amuzgo and Xochistlahuaca Amuzgo, have been described by Herrera (2000, 2010, 2014).

There is a threeway phonation contrast between modal, breathy and creaky voice. It occurs in oral and nasal vowels and with all 6 tones. The non-modal portion follows the modal portion of the vowel and the tonal contour is only realised in the preceding modal part. Examples for breathy and creaky voice in contrast to modal voice are given in (2.10) and (2.11), respectively. The contrast between creaky voice and the sequence /Vʔ/ is exemplified in (2.12). In summary, non-modal phonation occurs in pre- and post-vocalic position as well as in the end of vowels as creaky and breathy voice in Amuzgo.

(2.10)	*tsʔɔ̤* ˧	'arm'	*tsʔɔ* ˧	'liana'
(2.11)	*ntḭ* ˧	'bagasse'	*nti* ˧	'listen'
(2.12)	*to̰*˧	'garbage'	*toʔ*˥	'full'

(Herrera 2010: 43, 48, 50)

San Pablo Güilá Zapotec suprasegmental phonology has been described by Arellanes (2003, 2010, 2015) and Herrera (2000).

Apart from modal voice, there are two grades of laryngealisation, weak /V̰/ and strong /V͡ʔ/. The tonal system consists of four tones and all combinations of tone and voice quality are possible on all vowels. However, the tripartite phonation contrast only surfaces in the stressed syllable. Examples for the realisation of weak and strong laryngealisation are given in (2.13) and (2.14), respectively.

(2.13) /bza̰/ ˩ → [βzàˑˀ] ~ [βzàˑᵊ] 'bean'

(2.14) /da͡ʔ/ ˩ → [dàʔ] 'bed roll'

(Arellanes 2015: 189, 195)

Non-modal phonation and the glottal stop occur in post-vocalic position and the whole tonal contour is realised on the modal part of the vowel. Apparently, there are no glottal consonants in the consonant inventory. Thus, laryngeals are *only* expressed at the end of the vowel, i.e. as two different kinds of vowel laryngealisation.

The occurrence of laryngeals in these five languages is summarised in Table 2.2.

Table 2.2. The distribution of laryngeals in five Oto-Mangean languages.

Language	Prevocalic laryngeals	Postvocalic laryngeals	Interrupted forms
Jalapa Mazatec	yes	---	---
Comaltepec Chinantec	yes	yes	---
Copala Trique	yes	yes	yes
Amuzgo	yes	yes	---
SPG Zapotec	---	*yes*	---

Table 2.2. shows that Jalapa Mazatec, Comaltepec Chinantec and Copala Trique, as well as Amuzgo fit into the implications about the temporal distribution of laryngeals described in Section 2.2.1. San Pablo Güilá Zapotec, on the other hand, only has post-vocalic laryngeals and no pre-vocalic ones. Consequently, it does not conform to these timing implications. As a matter of fact, San Pablo Güilá Zapotec questions Silverman's typology.

2.3. What we know about Chichimeco phonology

There are two explicit phonological descriptions of Chichimeco (Romero 1957-1958, Herrera 2014) and two investigations of sound change (Lastra 2009a, 2011) as well as brief notes on the language's phonemes and their transcription in Angulo (1932) and Lastra (1984, 2009b, 2016). When looking for phonological structures, the sections on other parts of the grammar and the vocabulary in these latter four publications yield more information.

In this section, I give a short overview of previous research on the phonological structures relevant to my own investigation in Chapters 4 and 5. In Chapter 4, I demonstrate that non-modal voice quality and other glottals in Chichimeco can only be characterised appropriately with reference to phonological and morphological structure. Therefore, I describe the morphological and phonological word, syllable structure and phonotactics in this language in Section 2.3.1. As indicated in my second research question, non-modal voice quality may be related to other suprasegmental features. For that reason, in Section 2.3.2., I outline what has been said about tone and vowel nasalisation in Chichimeco and summarise the claims made about non-modal voice quality so far.

To avoid confusion, I adapt other authors' transcriptions to my own where they diverge. In Table A2 in the Appendix, a list of the sounds that are concerned is given.

2.3.1. The word, the syllable and phonotactics

Word structure. In Chichimeco, only function words such as *sáʔ* 'already' and *ki* 'and' are monosyllabic. Content words, on the other hand, by all accounts have to consist of a stem and a prefix and are bisyllabic (cf. Romero 1957-1958, cf. examples in Herrera 2014). The same stem is sometimes used for related nouns and verbs, such as in (2.15). This example also illustrates that the obligatory prefix[13] encodes person and number of the possessor in nouns[14], and person and TAM in verbs (Angulo 1932, Lastra 1984). In the vast majority of words, the prefix and the stem correspond to one syllable each, such as in (2.15) and (2.18). In some words, however, part of the stem is syllabified into the first syllable and suffixes can be included in the second syllable, such as in (2.16). The second syllable in such words, i.e. the stem syllable, is always stressed. This means that the vowel has a longer duration and a higher intensity (Herrera 2014). Most importantly for this thesis, breathy vowels seem to occur only in the stressed stem syllable (cf. Herrera 2014, Romero 1957-1958; see Section 2.3.2.). Additionally, the full range of phonemic contrasts (cf. Table 2.3.) only appears in the stressed syllable.

13 This obligatoriness apparently only concerns the lexical level. In other words, there are no content words that only consist of the stem, or one syllable on this level of description. In connected speech, however, deletion processes frequently result in words like *ká* < *ikág* (1SG), and *nt*^{h}*i* < *nínt*^{h}*i* 'female'

14 As is common in Mesoamerican languages (Stolz & Stolz 2001), Chichimeco expresses personal relation in nouns (cf. Angulo 1932: 154f.). This has also been called 'nominal possession'. This means that for many nouns, especially inalienable ones, the possessor is expressed on the noun itself.

Apart from suffixes like *-k'* '2OBJ' that are syllabified with the stressed stem syllable, there are suffixes that *expand* the word by a syllable. This affixation results in a three-syllable word, e.g. (2.17) and (2.18). Three-syllable words also result from compounding, e.g. (2.19). Suffixes can also concatenate and result in four-syllable words, e.g. (2.20).

In sum, only more morphological complexity than the 'minimal' word, i.e. prefix + stem, can lead to words with more than two syllables.

	Morphological structure	*Phonological structure*	
(2.15)	ná-kṵ̃ é-kṵ̃[15] 1SG-way 1PRES-walk 'I am walking'	/ná.kṵ̃ é.kṵ̃/	(own data)
(2.16)	ká-mbĩr-k' NA-thief-2OBJ 'you are a thief'	/kám.bĩrk'/	(cf. Romero 1957-1958: 296, 299)
(2.17)	nambá-r̃ó 1.hat-FOC '*my* hat'	/nam.bá.r̃ó/	(Lastra 2016: 50)
(2.18)	su-pã́-me 3NEG-know-NEG 'he doesn't know'	/su.pã́.me/	(Lastra 2016: 61)
(2.19)	mánínkýs < mání + ?nkýs?[16] crone < woman + old?	/má.nín.kýs/	(Lastra 2016: 47)
(2.20)	su-sa-bú-me 3NEG-teach-3OBJ-NEG 'he does not teach them'	/su.sa.bú.me/	(Lastra 2016: 93)

Syllable structure and phonotactics. There are no tautosyllabic vowel or consonant sequences in this language, with one exception (see next paragraph). Herrera (2014) argued for constricted[17] and aspirated obstruents instead of sequences of obstruent and /h/ or /ʔ/. This analysis simplified the syllable structure of sequences such as in *nín.thi* (CVC.CCV) to *nín.tʰi* (CVC.CV), excluding consonant clusters within one and the same syllable. Syllables of the structures CV and CVC are most common. Syllables only consisting of V are only allowed word-initially. Herrera (2014) analysed breathy vowels where Angulo (1932), Romero (1957-1958) and Lastra (1984, 2009a, 2009b, 2016) analysed sequences of VhV, thereby obliterating the need for complex nuclei in the

15 There are several verbs that require a certain noun as an object, e.g. *ungwą̤́ é-sũʔ* (3.song 3PRES.sing) 'he is singing (lit. he sings his song)' (Lastra 1984: 29).

16 I could not find the second part of this compound as a word of its own. It stands to reason, however, that it originally was bisyllabic too. This reduction of a syllable in compounds seems to be common and has been lexicalised in some words, e.g. *u-rángý* '3-eye' < *u-rá* '3-face' + ?*ngý*?. When I interviewed native speakers, they would not separate the word for eye into different lexical components.

17 Herrera called these obstruents glottalised.

analysis. In bisyllabic words, the first syllable is either open or closed by a fortis sonorant. The second syllable has an obligatory onset and can be open or closed.

The exception to the constraint against tautosyllabic clusters mentioned above is the end of the word. There is a series of consonant morphemes that can result in a consonant cluster in the coda of the last syllable, see (2.21). The morpheme for the exclusive dual is -mʔ, resulting in a final cluster, see (2.22). There seem to be some words with final consonant clusters without any apparent morphological structure, such as in (2.23).

	Morphological structure	*Phonological structure*	
(2.21)	ká-mbĩr-k' NA-thief[18]-2OBJ 'You are a thief.'	/kám.bĩ**rk'**/	(cf. Romero 1957-1958: 296, 299)
(2.22)	é-tḭ̃-g-umʔ[19] 3PRES-ask.for-1OBJ-DU.EXCL 'She asks us two for...'	/é.tḭ̃.gu**mʔ**/	(cf. Lastra 2016: 105)
(2.23)	ná-tanʔ 1-work 'my work'	/ná.ta**nʔ**/	(cf. Lastra 2016: 186)

Herrera (2014) continued and systematised Lastra's (1984, 2009b) proposal of grouping the consonants into fortis and lenis, expanding this categorisation by constricted and aspirated obstruents. Only the lenis consonants show complementary allophonic variation (Lastra 2016, Herrera 2014). The production of fortis, aspirated and constricted consonants is consistent in all contexts[20]. The consonant and vowel inventory is given in Table 2.3. The distinction into these classes of sounds is important because it explains why certain heterosyllabic consonant clusters are allowed and others are not, e.g. -n.d- and -n.t^h- but *-n.t-. According to this analysis, two adjacent fortis consonants are not permitted.

Loan words do not necessarily conform to the phonotactic and (morpho)phonemic patterns of the language. One example is *porke* < sp. *porque* 'because' since it violates the constraint against two adjacent fortis consonants. Two other examples are *mulíno* < sp. *molino* 'mill' (cf. Lastra 2016: 54) and *kúmbáre*[21] < sp. *compadre* 'comrade' (Angulo 1932: 159) which do not conform to the typical

18 Compare *é-pĩ́* (3PRES-steal). This is probably the same stem with a common morphophonemic alternation of the consonant in which the place of articulation stays the same while voicing, nasality and glottal features alternate. See also Chapter 4.

19 Usually, the suffix for the dual exclusive is only -mʔ. In some cases, the vowel u is inserted.

20 This follows Herrera's analysis of voiced plosives, such as in *kámbĩr* 'thief', as allophones of lenis rather than fortis consonants.

21 It is interesting to note that the first syllable in kúmbáre was reanalysed as a first person prefix. This resulted in the paradigm *kúmbáre* '1-comrade', *kimbáre* '2-comrade', *kímbáre* '3-comrade' (Angulo 1932, cf. Lastra 2017). This morphophonemic alternation does not only follow the frequent vowel alternation in prefixes of u/i/i for the three

structure of the Chichimeco word, i.e. they have three syllables that do not result from morphological complexity. Furthermore, *mulíno* contains the lateral which is not a native phoneme and only occurs in loan words (cf. Romero 1957-1958: 295). Notably, the numerals *sakýsb* 'seven', *ráts'oro* 'ten' and *sang^{w}áro*ʔ 'five' (Lastra 2016) also do not conform to the common patterns just described.

Table 2.3. Consonant and vowel inventory of Chichimeco, adapted from Herrera (2014: 96, 101).

Consonants												Vowels
Fortis	m	p	n	s	t	r	ʦ	ʧ	k	k^w		i y[22] u e o æ a
Aspirated		p^h			t^h				k^h	k^{hw}	h	
Constricted		p'			t'		ʦ'	ʧ'	k'		ʔ	
Lenis	β̃	b	ɾ̃		d/r[23]				g	g^w		

2.3.2. Suprasegmentals

As already mentioned above, Chichimeco is a *tone* language. There are two level tones, high and low, and sandhi phenomena have not been noted. Tone can have a lexical as well as a grammatical function. It is extensively used to distinguish the persons in verbs and nouns. Most commonly, the second person verb or noun has a different tone than the first and third person. Examples for lexical and grammatical tone in nouns are given in (2.24) and (2.25), respectively.

(2.24)	*úk^he*	'ant'	*uk^hé*	'my blood'[24]
	sukṹ	'soot'	*súkũ/súkṹ*	'my cheek'[25]
(2.25)	*kuɾ̃í*	'my heart'	*kúɾ̃i*	'your heart'
	unʔú	'your husband'	*únʔu*	'her husband'

persons but also a common tonal alternation in which the second person has a different tonal pattern than the other persons.

22 In younger speakers, /i/ and /y/ have merged (Lastra 2009a).

23 In this position in the table, Herrera (2014) analysed a lenis /ɾ/ (with [d] as an allophone after nasals), as opposed to fortis /r/ and /t/. However, I am sceptical as to whether /ɾ/ and /r/ are actually two phonemes since they seem to be in complementary distribution. Unfortunately, there is no room in this thesis to discuss this issue. Even though I use a largely phonological transcription in this thesis, the symbols <d> and <r> refer more to the phonetics of these sounds than their phonology.

24 In Lastra (2016), 'my blood' is *kukhé*, in Herrera (2014), it is *kùk^hé* and in Ramírez Ramírez (2015a), it is *kukhé'*. However, when I asked speakers in March 2017, they answered *ukhé* and Ramírez Ramirez (2015b) also cites *ukhé*. It is possible that the sound change concerning the deletion of the initial velar fricative /g-/ (Lastra 2009a) also applies to initial /k-/, at least in some words.

25 I frequently observed this variation of H-L and H-H between speakers, not only in this word. 'my intestine', for example, was produced as *kúmbí/kúmbý* by the speakers I interviewed even though it is listed as *kúmbü* in Lastra (2016) whose main consultant was also one of the speakers I worked with. 'Atole' was produced as *úrʔĩ́* and *úrʔĩ* by different speakers and sometimes by the same speaker.

Romero (1957-1958) mentions that he only found six of the possible eight tonal patterns in trisyllabic words but does not specify which ones. Considering examples given in the literature, it seems that any syllable can carry either tone, at least in the minimal content word, i.e. prefix + stem. Apart from Romero's observation, however, no study on the distribution of tone has been done.

In many tonal languages in Mesoamerica, certain tones are restricted to the stressed syllable. For example, in Northern Pame, a closely related language, tone is only distinctive in the stressed syllable (Avelino 1997). In Otomí and Mazahua, contour tones only occur in stressed syllables while unstressed syllables can only carry level tones (Arellanes et al. ms.). In Chichimeco, no such restriction has been described.

Nasalisation is contrastive on vowels. Of the seven vowel phonemes in Table 2.3., some vowels seem to be more frequently nasalised than others. Angulo (1932) and Romero (1957-1958) agree that nasalised /o/ and /æ/ are uncommon. Lastra (1984, 2016) and Herrera (2014) do, however, list all vowels as nasalised. Lastra (2009a) notes that even though all vowels can be nasalised, /ĩ ã ũ/ are most common. Vowels adjacent to nasal consonants do not contrast for nasalisation (Lastra 1984) and especially vowels surrounding the two lenis nasals are strongly nasalised (Herrera 2014). Examples for nasal and oral vowels are given in (2.26)

(2.26)	*unhĩ́*	'colour'	*unhí*	'he lost (AP)'
	*ríp^h*õs	'smell'	*urʔós*	'their house'
	bã́ʔã	'honey'	*maʔá*	'wormseed (epazote)'

(Herrera 2014: 104)

Except for Romero (1957-1958) and Angulo (1932) in his very scant account of the phonology, none of the authors analyses nasality as a suprasegmental phenomenon. Instead, they count nasal vowels as phonemes of their own (Lastra 1984, 2009b, 2016; Herrera 2014). Even though Romero's argument for the suprasegmental character of nasality is not convincing, its distribution points towards him being right. However, no extensive phonological study of vowel nasalisation has been done and a discussion of this issue would go far beyond the scope of this thesis.

As mentioned in the introduction, *breathy voice* has been analysed as a phonological category (Herrera 2014). Romero (1957-1958) already described "complex nuclei", i.e. V^hV, in which both vowel parts have the same vowel quality, bear the same tone and belong to the same syllable. The distribution of these "complex nuclei" is restricted to non-initial syllables. This statement and the examples he gives imply that they might be restricted to the stem syllable. This assumption is corroborated by the examples listed in Herrera (2014: 105). Examples of breathy vowels, in contrast to modal vowels, are given in (2.27).

(2.27)	*úrʔi̤*	'their necklace(s)'	*úrʔi*	'forest'
	tángʷe̤	'I sat (AP)'	*tangʷé*	'rabbit'
	érʔa̤	'Acacia tree (huisache)'	*erár*	'bilberry cactus (garambullo)'

(Herrera 2014: 105)

In her acoustic study, Herrera analysed these sounds as breathy vowels, identifying Chichimeco as a *laryngeally complex* language (cf. Section 2.2.). By measuring two of the most common acoustic correlates of non-modal voice quality, H1-H2 and H1-A2 (cf. 2.1.1.), she found systematic differences between breathy and modal vowels in two speakers. Additionally, modal vowels exhibited a generally higher intensity than breathy vowels. She lists examples of all seven vowels with breathy voice. All of these examples bear low tone on the syllable with the breathy vowel, i.e. the stem syllable. At the end of her chapter, she encourages future research on the interaction of breathy voice with tone, a possible extension of her analysis to creaky voice as well as the temporal organisation of modal and non-modal voice quality.

The transcription of these sounds as <VhV> in Angulo (1932), Romero (1957-1958) and in Lastra's publications give an important indication of the possible timing of modal and non-modal phonation (cf. Section 2.2.1.). Correspondingly, this supposition could be generalised to creaky voice, following Lastra's transcription of <VʔV>. However, Lastra (2009a, 2011) noted some changes in these timing patterns. She investigated the loss of one of the two vowel components but did not find any conclusive patterns. Nevertheless, these changes might affect specific words in different ways and possibly cannot be described in terms of a general phonological change.

These previous observations about non-modal voice quality in Chichimeco are the basis for the work that I present in the following chapters. More specifically, I address the issues of breathy and creaky voice, the interaction with tone, i.e. whether Chichimeco is indeed laryngeally complex, and the temporal implementation of modal and non-modal voice in Chapters 4 and 5.

3. The data

In this chapter, I present the data I used for the phonological investigation in Chapter 4 and for the acoustic study in Chapter 5. More specifically, I describe the different kinds of recordings that I made in Section 3.1. and the speakers that I recorded with in Section 3.2.

3.1. Recordings

In this investigation, I used recordings I made in Misión de Chichimecas and in San Luis de la Paz, Mexico, in February and March 2017. I made two different kinds of recordings with several speakers; words in isolation and words in a carrier phrase. The words and phrases were elicited in Spanish. I am obliged to Carla[26], to Edson González Arenas and to the CDI in San Luis de la Paz for providing me with suitable recording locations. All data were recorded in stereo with a Roland R-05 recorder in WAV format with a sampling rate of 44.1 kHz and 16 bit. The transcription and tagging of all data was done in ELAN (Wittenburg et al. 2006), segmentation was done in Praat (Boersma 2001).

Minimal pairs. First, I recorded a list of 38 minimal and correspondence pairs in isolation with four speakers (F01, F02, M03 & M04), each word repeated at least three times. This list contains five oral vowels /i y e a u/ and some of the nasal vowels, as well as different voice qualities. All minimal pairs are distinguished by their tone except for four pairs that are distinguished by their voice quality. Minimal pairs that are only distinguished by voice quality are rare. Tonal minimal pairs, on the other hand, are rather frequent since the second person in nouns and verbs often has a different tonal pattern than the other persons. In a subclass of nouns and verbs, the second and third person are segmentally the same and, thus, only distinguished by tone. These tonal minimal pairs are, nonetheless, of importance because they give an indication of the co-occurrence of non-modal voice quality with both tonal categories. A complete list of the minimal and correspondence pairs is given in Table A3 in the Appendix.

Nouns in a carrier phrase. Second, I recorded a list of more than 270 nouns in the carrier phrase *kíní* ____ *émʔa̤* ('This is called _____'). Every phrase was repeated at least three times by four speakers (F01, F02, M01 & M02). Due to background noise, however, some phrases had to be discarded, resulting in only two repetitions for some phrases. This list consists of nouns containing /i, y, a, æ, u/ in the stem that were taken from the word list in Lastra (2016). These words

26 This speaker wished to remain anonymous in publications and chose the name Carla as an alias.

were chosen to investigate voice quality in the four most distinct vowel positions[27]. The vowel /y/ was included because of its merger with /i/ in younger speakers (Lastra 2009a). For this list, I recorded with two speakers in a session. This gave them the opportunity to discuss uncertainties concerning the procedure as well as the words. A list of the nouns included in the study in Chapter 5 is given in Table A4 in the Appendix (cf. Section 5.1. for an explanation for why only some of the recorded nouns were included in this study).

Issues with the carrier phrase. One issue with the carrier phrase was that it was not always accepted by the speakers. In some cases, speakers inserted the pronouns *ká* (1SG), *hé*[28] (2SG) or *íro̰ʔ* (3SG) before the target word. Another version of the carrier phrase that was preferred by some speakers was *kíní* ____ *íʔé émʔa̤* ('This is called ____, like that').

Another issue with the carrier phrase was that the target vowel was often adjacent to the initial vowel of the next word, i.e. *émʔa̤* or *íʔé.* This vowel contact was realised in three different ways; with an epenthetic glottal stop, often produced as creak on the second vowel, as a diphthong-like transition or with a pause between the vowels. Cases in which segmentation of the target vowel was impossible were excluded from the analysis. This variation introduced additional variety into the data. However, notable changes in terms of voice quality were neither audible nor visible in the spectrogram of the segmented target vowel. Nevertheless, some influence on relevant parameters in the target vowel is still expected in an acoustic study. The variation described here should be taken into consideration when interpreting measurements of duration and of spectral properties in these recordings. For future investigations, a carrier phrase avoiding the contact of two vowels, i.e. containing a verb with an initial consonant, would be a better choice.

Additionally to my own data, I analysed part of the recordings published in Lastra (2009b) and Lastra (2016). Her recordings include a list of all the nouns and of most minimal pairs I recorded, each repeated three times in isolation by one speaker (M02).

3.2. Speakers

My main consultants were two female (F01, F02) and two male speakers (M01, M02). One of the male speakers (M02) was also the main consultant of Yolanda Lastra. The two male speakers grew up speaking the language while the two female speakers learned it when they were around 10 years

27 Note that the vowels included in this data set are not the same as the ones in the minimal pairs list. The reason for this is that I recorded all minimal pairs that I could find. These minimal pairs happened to include the vowel /e/ and exclude /æ/. The nouns for the acoustic study, on the other hand, were chosen more systematically concerning their vowel quality, since minimal distinctiveness did not have to be taken into account.

28 The full pronoun forms of the first and second person singular are *ikág* and *ihék'*, respectively. These forms are often reduced to [ká] and [hé].

old. All four of them are fluent in Chichimeco but seemed to speak more Spanish in their everyday life. For example, except for a few words, they are not passing on the language to their children. Even though the women are not full native speakers in the conventional sense (cf. Bowern 2008), they turned out to be well-suited consultants for this task due to their experience with linguistic elicitation, and their willingness and interest in recording with me. Since both of them stayed at home they were also available for doing longer and more frequent recording sessions.

Additionally, I did shorter recordings with two other male speakers (M03, M04). These two speakers use Chichimeco at least as much as Spanish in their daily life and also speak the language with their children.

To avoid age related variation (cf. Lastra 2009a), I chose speakers from the same generation. All speakers are between 35 and 45 years old except for speaker M02. However, concerning glottal features, his production did not vary considerably from that of the other speakers. A list of the speaker's sex and age and the recordings I made with them is given in Table 3.1.

Table 3.1. Speaker's sex and age and the recordings I made with them.

Speaker	Sex	Age	Recordings
F01	female	38	nouns in carrier phrase, minimal pairs
F02	female	36	nouns in carrier phrase, part of minimal pairs
M01	male	~ 38	nouns in carrier phrase
M02	male	~ 75	nouns in carrier phrase, isolated word list (Lastra 2009b, 2016)
M03	male	~ 42	minimal pairs
M04	male	~ 35	minimal pairs

4. The phonology of voice quality

In Section 2.3.2., I gave an overview of the previous research on non-modal voice quality, i.e. breathy voice, in Chichimeco. So far, no research has been done on creaky voice, on the relationship of non-modal voice quality with tone and on the timing of modal and non-modal voice quality. In this chapter, I present my own research on these topics that is continued in Chapter 5.

For my investigation, I tried to answer my research questions that are repeated here:

1. Are breathy and creaky voice produced consistently within and between speakers? And, does creaky voice constitute a phonological category distinct from that of the glottal stop?
2. Do the non-modal voice qualities occur with all vowels and with both tones? If they do occur with both tones, what is the exact acoustic realisation of these combinations?
3. Do the non-modal voice qualities only occur in the stressed syllable? Is only one non-modal voice quality allowed per syllable?

In Section 4.1., I describe the method used for this investigation of phonological structures. Since this investigation and the acoustic study in Chapter 5 follow very different methodologies, I discuss the methods for the latter in Section 5.1. In Section 4.2., I propose an analysis of creaky and breathy voice as phonological categories in Chichimeco.

In addition to discussing creaky and breathy voice, in Section 4.3., I characterise how non-modal voice quality is related to the other glottal features. More specifically, this concerns the glottal consonants /ʔ h/ and constricted and aspirated consonants (cf. Figure 2.1.). In the course of this chapter, I use glottalisation in two different senses. First, I use it in a general sense for the phenomenon including all glottals. Second, I use this term for the morphophonemic pluralisation rule described in Section 4.3.1.

In Section 4.3.2., I propose a prosodic governing of laryngeal features on the level of the syllable. With this theoretical analysis, an appropriate description of the patterns found in Chichimeco can be presented.

Finally, I present a characterisation of Chichimeco as a laryngeally complex language in the terms of Silverman (1997) in Section 4.4.

4.1. Methods for the phonological analysis

In this phonological investigation, the goal was to find consistent phonetic productions of non-modal voice quality that can be classified into phonological categories. For this purpose, I examined words in isolation and largely relied on my auditory impression and on the waveform and spectrogram display in Praat. Additionally, I used native speakers' corrections of my pronunciation and comments on how young speakers vary in their pronunciation as indicators for significant differences in production. At this stage, I did not make any systematic acoustic measurements.

In this phonological investigation, I closely followed the practical recommendations of established field linguists and phonologists, such as Hyman (2010) and E. Herrera (personal communication, March 2017). They advise to start out with minimal pairs, if some can be found, but not to exclusively rely on them. Instead, generalisations should be made about the patterns found in minimal pairs and other words. These generalisations should be tested with more data and, if necessary, adjusted. In general, the focus should lie on *patterns*, which characterise phonological systems more than single phonemes. This follows the principle that we as speakers of a language can identify nonsense words as conforming or "belonging" to the phonology of our language or not (cf. Maye & Gerken 2000).

In the phonological analysis of creaky and breathy voice, as well as of the distribution of glottals, I followed a practical approach in accordance with these recommendations. This approach can be characterised as an iterative process of hypothesis testing and included the following steps:

1. First, I looked for minimal pairs in Lastra (2009b). I collected one triplet and 38 minimal and correspondence pairs, i.e. pairs that are not strictly minimal pairs only differing in one feature but that are still comparable. Most of them contrast only in tone since the second person in verbs and nouns often differs in tone from the first and third person. Some words contrast in their glottal features (see Table A3 in the Appendix).
2. Then, I checked these word pairs with four speakers (F01, F02, M03 and M04). To complement my own data, I compared them to the recordings of the tokens produced by speaker M02 enclosed in Lastra (2009b).
3. Some speakers provided other minimal pairs during the interview. Additionally to recording and transcribing all the minimal and correspondence pairs with the speakers, I tried to pronounce the words myself and asked speakers to correct me. Some of the speakers were relentless in doing this, correcting me several times until they were content with my pronunciation. This immediate feedback was a great help in testing my hypotheses on phonological categories.
4. By comparing the patterns I found in the minimal and correspondence pairs, I made generalisations answering my research questions.

5. I counter-checked these patterns with recordings of other words in Lastra (2009b, 2016) and in my own recordings, revising my assumptions about phonological categories when necessary.
6. From these generalisations, I established categories taking into consideration my research questions.
7. Lastly, I categorised all the nouns with /i y æ a u/ in their stems that I recorded in the carrier phrase for the phonetic investigation so that I could investigate the actual production of these categories in a controlled context. This acoustic study is presented in Chapter 5.

The results of this investigative process are presented in the following sections.

4.2. Phonological analysis: Non-modal voice quality

Previous authors have sometimes transcribed creaky and breathy vowels as sequences of two vowels with the same vowel quality interrupted by a glottal consonant; as VʔV or VhV, respectively (cf. Angulo 1932, Romero 1957-1958, Lastra 1984, 2009a, 2009b, 2016). However, such sequences do occur in the language and should be distinguished from creaky and breathy voice for two reasons. First, these sequences occur at the morphological boundary between the prefix and the stem, such as in *ka-ʔá* '1SG-hand'. This position also coincides with a syllable boundary. On the other hand, creaky and breathy voice have a different distribution than these sequences. Second, non-modal voice quality is produced in a different way. I address these issues in Sections 4.2.1. and 4.2.2., discussing creaky and breathy voice separately. In Section 4.2.3., I give a preliminary summary of these findings.

4.2.1. Creaky voice

Phonological creaky voice occurs with most vowels in my data. I did not find examples of creaky voice for all vowels with both tones. Creaky voice on /y/, as well as on /æ/ and /o/ in combination with high tone are missing from my data. This is not too surprising considering the general infrequency of /æ/ and of [y] due to its merger with /i/. It stands to reason that the absence of creaky voice on these vowels is probably a gap in my data rather than in the phonological system of the language. Of course, this claim will have to be tested in the future.

In my recordings, there were some words in which creaky voice was produced with nasality, e.g. *mugḭ̃́* 'oil, butter' and *násṵ̃* 'viper'. However, I cannot make comments on the systematic co-occurrence of creaky voice and nasality with respect to all vowels or tone due to the scarcity of these examples in my data.

Furthermore, phonological creak occurs with both tones. In combination with low tone, it is produced most often as classical 'picket fence' or as irregular creak (cf. Keating, Garellek & Kreiman 2015) towards the end of the vowel. An example spectrogram is given in Figure 4.1. When this vowel is followed by a consonant in the same word, however, creak is produced during the main portion of the vowel in its middle. This can be seen in the spectrogram in Figure 4.2.

In Section 2.1.2, I mentioned that the ideal production of creaky voice is with a low F0 and that its simultaneous production with a high F0 is uneconomical and can change the voice quality. In Chichimeco, creaky voice is also produced with high tone. In this case, however, the actual production is different from the production of creak with low tone; it can be realised as quite irregular creak towards the end (see Figure 4.3.), as tense voice or as a vowel interrupted by a short glottal constriction (see Figure 4.4.). This variation seems to be mostly speaker-related. With this independent application of tone and phonological creaky voice, Chichimeco qualifies as a *laryngeally complex* language.

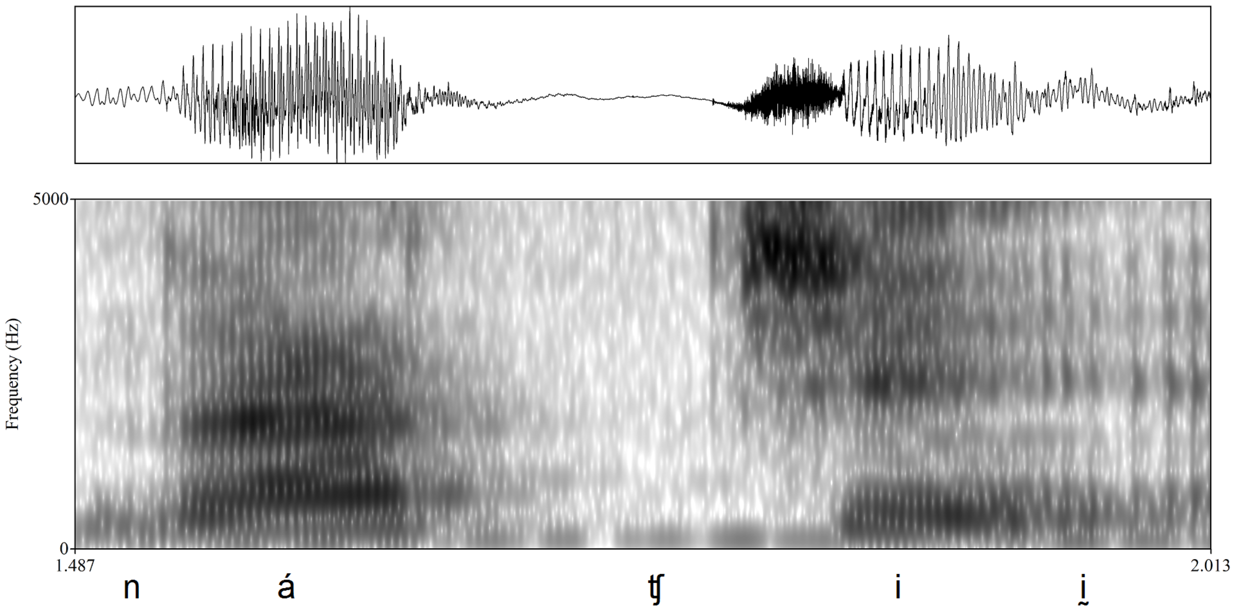


Figure 4.1. Spectrogram and waveform of *ná-ʧḭ* (1-spine) 'my spine' produced by speaker F01. Creak is produced towards the end of the vowel.

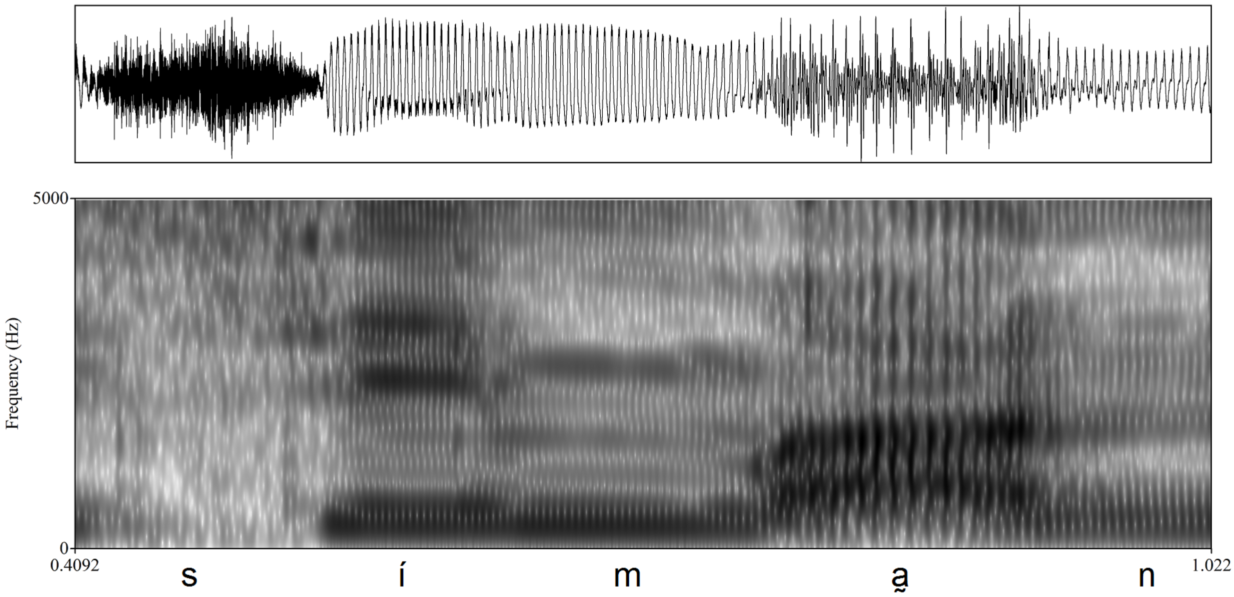


Figure 4.2. Spectrogram and waveform of *síma̰n* 'dog' produced by speaker F01. Creak is produced during the main portion in the middle of the vowel.

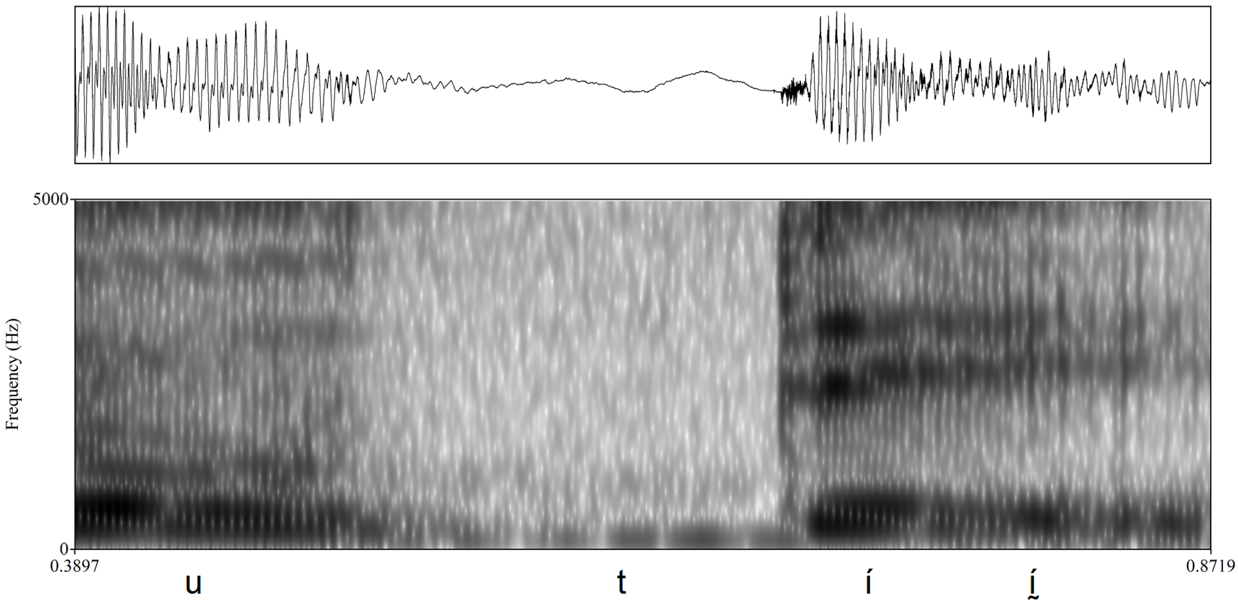


Figure 4.3. Spectrogram and waveform of *u-tḭ́* (2-necklace\2) 'your necklace' produced by speaker F01. Irregular creak with high tone is produced towards the end of the vowel.

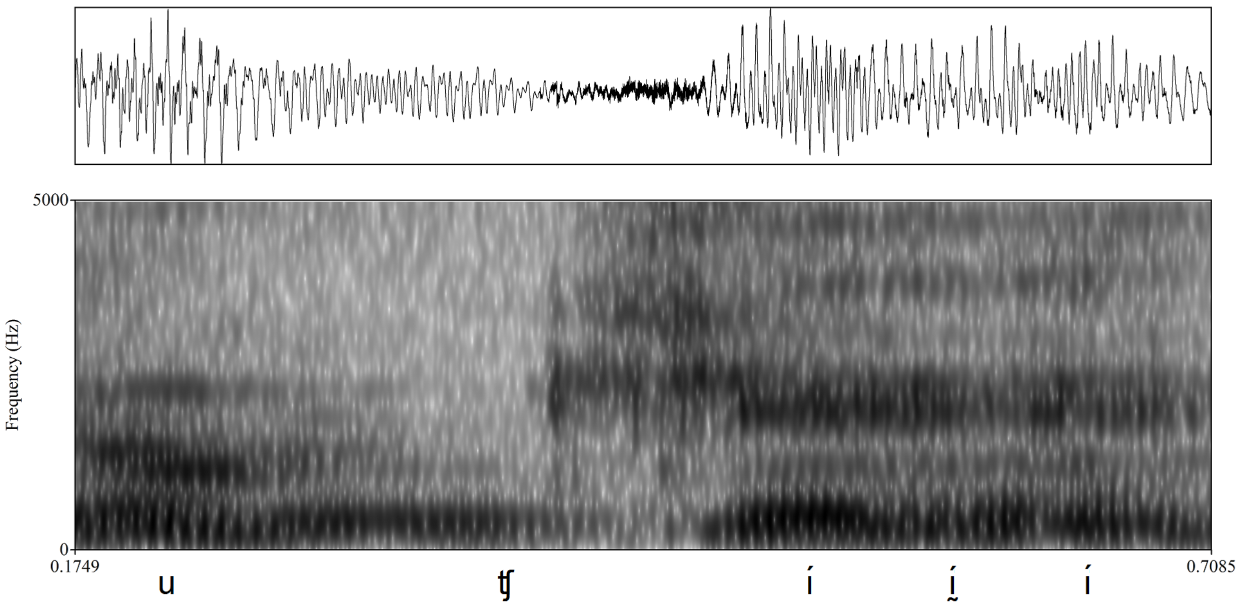


Figure 4.4. Spectrogram and waveform of *u-ʧḭ́* (2-spine\2) 'your spine' produced by speaker M02. Constriction with high tone is produced in the middle of the vowel, surrounded by (more) modal voice quality.

Examples for creaky voice with most vowel qualities and with both tones are given in (4.1). Syllable structure is indicated where it does not correspond to morpheme structure.

When comparing the words in (4.1) and in Figures 4.1.-4.4., it becomes apparent that creaky voice quality only occurs in the second syllable of these words, i.e. the stressed stem syllable.

(4.1)	**/V̰́/**		**/V̰̀/**	
/i/	*ki-ʧḭ́n* 2-axe\2	'your axe'	*ná-ʧḭn* 1-axe	'my axe'
	u-tḭ́ 2-necklace\2	'your necklace'	*ná-tḭ* 1-necklace	'my necklace'
/y/				
/e/	*ni-bḛ́* 2-hunger\2	'you are hungry'	*nú-mbḛ /núm-bḛ/* 1-hunger	'I am hungry'
/æ/			*é-tsæ̰* 1PRES-take.away	'I take away'
/a/	*u-sã̰́-b /u.sã̰́b/* 1PRES-distribute-3OBJ	'I distribute it'	*súba̰ /sú.ba̰/* palm.tree	'palm tree'
/o/			*tí-ʧo̰* 1PRES-vomit	'I vomit'
/u/	*ũ-kṵ̃́* 2-way\2	'your way'	*ṹ-gṵ̃* 3-way\3SG	'his/her way'

Now, I address the opposition between phonological creaky voice and a phonological glottal stop. Both categories occur towards the end of the stressed stem syllable. Creaky voice and a final glottal stop are each produced relatively consistently when words are pronounced in isolation. However, this opposition does not seem to be a very strong one for several reasons. First, a final glottal stop /-ʔ/ is often produced as phonetic creaky voice, especially if the preceding vowel carries low tone and towards the end of the phrase. This results in an occasional coincidence of the production of /V̰/ and /Vʔ/ in the only position in which they contrast. Second, there is some inter- and intra-speaker variation. Speaker M02, for example, consistently produced *mámb**a̰*** 'long' and *kím**ḛ*** 'white' where speaker M01 produced *mámb**aʔ*** and *kím**eʔ***, even in the carrier phrase. Some words varied in their production within several speakers, for example *kúng**aʔ**/kúng**a̰*** 'frog'. These examples illustrate that the contextual overlap of /V̰/ and /Vʔ/ is not only related to tone or the position within the phrase. Third, I only found two minimal pairs contrasting /V̰/ and /Vʔ/; *nát**a̰**n* 'wasp' – *ná-t**anʔ*** (1-work) 'my work', and *é-s**a̰*** (1PRES-pray) 'I pray' – *é-s**aʔ*** (1PRES-pluck) 'I pluck it'. In general, minimal pairs only contrasting in tone are much more common than minimal pairs contrasting in voice quality. Of course, the presence or absence of minimal pairs alone does not constitute a phonological category. However, the relative absence of this specific minimal contrast is quite striking and fits well with the other observations made here.

So, why are not all instances of phonetic creaky voice an allophone of /Vʔ/? An answer to this question can be found in the description of the morphophonemic rule of pluralisation and the general distribution of /V̰/ and /Vʔ/ with other glottals in Section 4.3. First, however, I discuss breathy voice.

4.2.2. Breathy voice

Phonological breathy voice is in many ways analogous to creaky voice. It occurs with all vowels, with both tones and I found instances in which it occurred together with vowel nasality. Examples of breathy nasal vowels are *rú-k'**ṳ̃*** (1-waist) 'my hip/waist' and *ri-k'**ṳ̃́*** (2-waist\2) 'your hip/waist'. Just as creaky voice, breathy voice only occurs in the stressed stem syllable and is most often produced towards the end of the vowel. In a syllable with a final consonant it is phonetically realised as breathy voice towards the end, see Figure 4.5. In an open syllable, it can be realised as breathiness or as voicelessness in the end of the vowel, see Figure 4.6. and Figure 4.7. Some of the speakers produced some words with breathy voice interrupting the vowel. Different from creaky voice, however, the exact realisation does not seem to depend on tone. The simultaneous independent application of breathy voice and tone is analogous to creaky voice. Therefore, the *laryngeal complexity* of Chichimeco involves creaky as well as breathy voice.

Examples of breathy vowels with all vowel qualities and both tones are given in (4.2). Syllable structure is given separately where it does not coincide with morpheme structure.

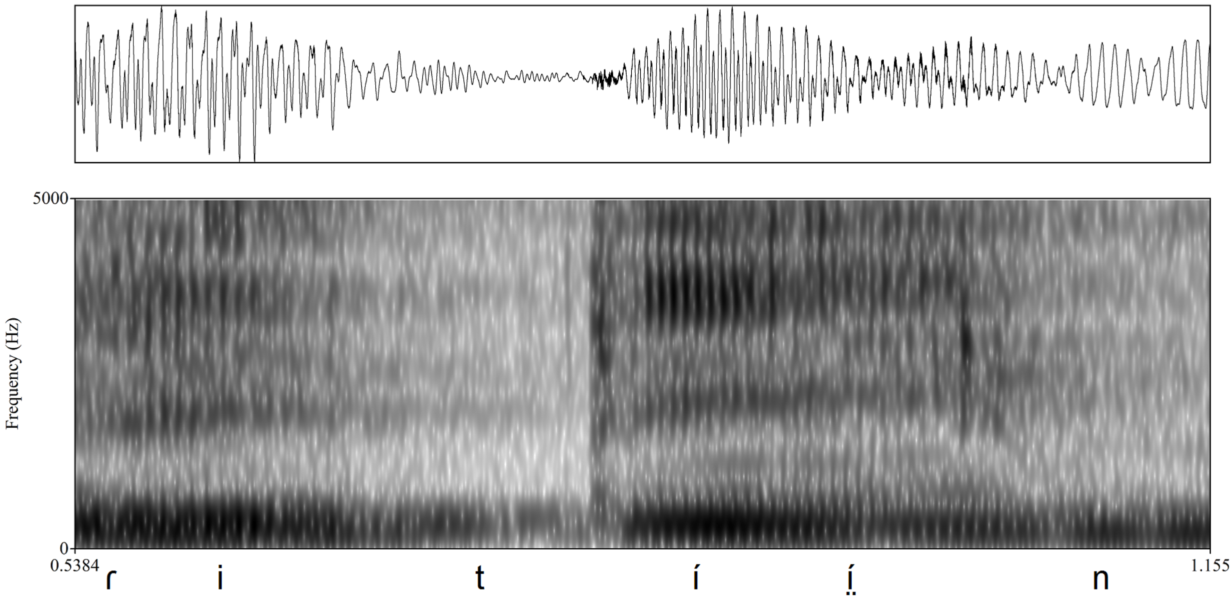


Figure 4.5. Spectrogram and waveform of *ri-tí̤n* (3-masa) 'his/her masa' produced by speaker M01. Breathy voice is produced towards the end of the vowel and extends into the final nasal consonant.

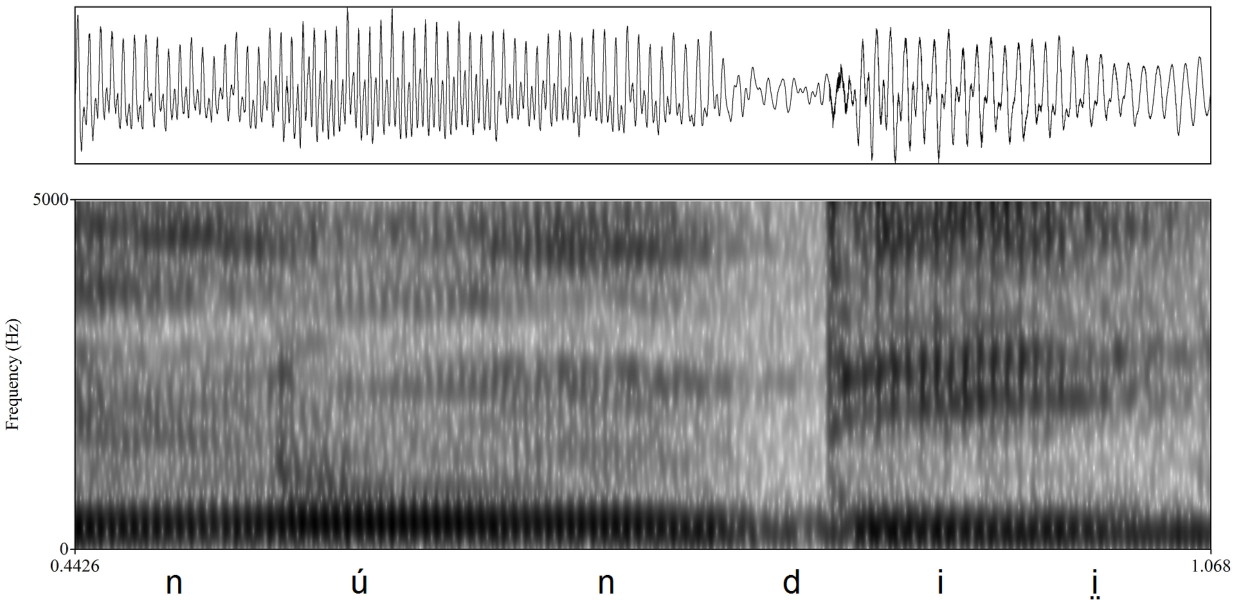


Figure 4.6. Spectrogram and waveform of *nú-ndi̤* (1-cigarette) 'my cigarette' produced by speaker M01. Breathiness is produced towards the end of the vowel.

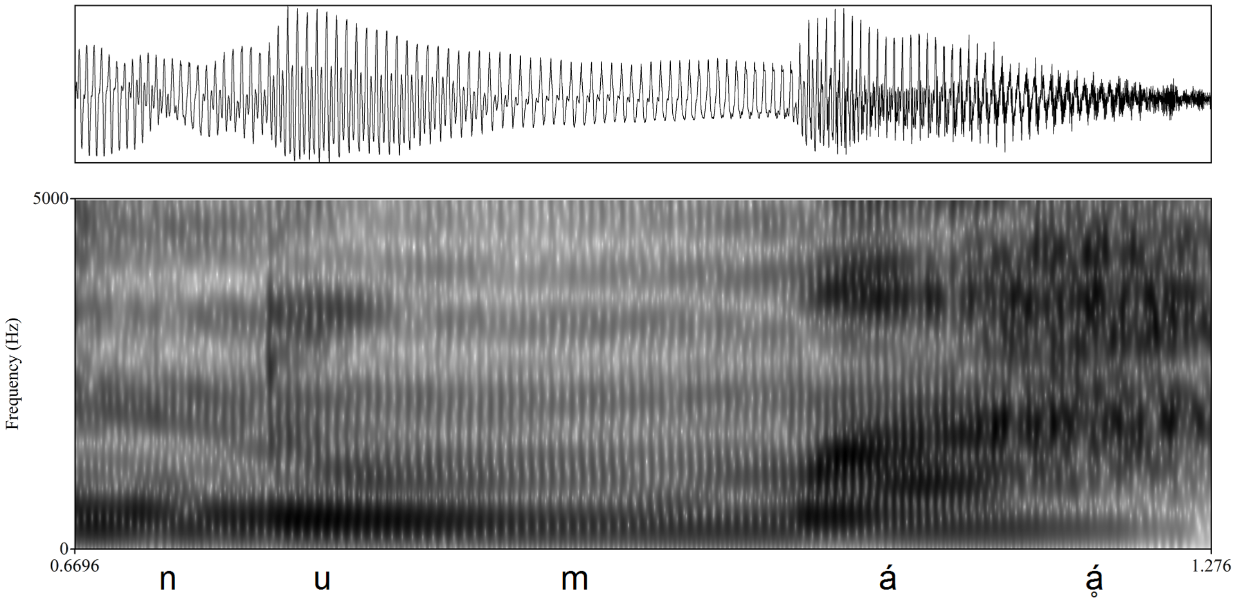


Figure 4.7. Waveform and spectrogram of *nu-má̤* (1-plate) 'my plate' produced by speaker F02. The vowel is produced modal in the beginning and with less voicing and more aspiration towards the end.

(4.2)	/V̤́/		/V̤̀/	
/i/	*ri-tí̤n* 3-masa	'her masa'	*rí-ti̤n* 2-masa\2	'your masa'
/y/	*ni-rý̤* 2-cigarette\2	'your cigarette'	*ní-ndy̤ /nín.dy̤/* 3-cigarette	'his/her cigarette'
/e/	*ni-ré̤n* 2-money\2	'your money'	*ní-nde̤n /nín-de̤n/* 3-money	'his/her money'
/æ/	*ni-t'ǽ̤* 2-navel\2	'your navel'	*ní-t'æ̤* 3-navel	'his/her navel'
/a/	*ni-má̤* 3-plate	'his/her plate'	*ní-ma̤* 2-plate\2	'your plate'
/o/	*na-ʦó̤ʔ* 1-beard	'my beard'	*ú-ʦo̤ʔ* 2-beard\2	'your beard'
/u/	*ri-k'ṳ̃́* 2-waist\2	'your waist/hip'	*rú-k'ṳ̃* 1-waist	'my waist/hip'

The production as a strong voiceless aspiration towards the end of the vowel and its complementary distribution with /h/ suggest that breathy voice might just be an allophone of a final /h/. However, there are phonetic and phonological arguments against this. First, the phasing of aspiration in /V̤/ is different from that of /h/. In those instances when /V̤/ is realised as a strong aspiration in the end of the vowel, this aspiration is phased very gradually. In words containing /h/, however, phasing is more abrupt. Furthermore, /h/ is often strengthened to [x] in inter-vocalic position. This never happens in the case of /V̤/, even if it is followed by another vowel. Second, there are words in which breathy voice is followed by a glottal stop, such as ***risḛ́ʔ*** 'iron'. The analysis of this word as ***riséhʔ*** violates an apparent universal that Kehrein & Golston (2004) found. They argue that no natural language contrasts conflicting laryngeal features within a syllable constituent. This issue is addressed again and put into a greater context in Section 4.3. Of course, this last argument implies that only vowels can be nuclei in Chichimeco and that any consonant therefore automatically belongs to either the syllable onset or coda.

For these reasons, I follow Herrera's analysis and propose breathy voice as a phonological category /V̤/ analogous to phonological creaky voice, and the absence of final /h/.

4.2.3. Summary of non-modal voice quality

In summary, I can give the following preliminary answers to my research questions. Creaky and breathy voice are mostly produced consistently within and between speakers. The exact acoustic correlates of these productions are examined in Chapter 5. Nevertheless, there is some substantial variation corresponding to Lastra's (2011) observations that should be studied in more detail in the future. In some words, one of my six consultants consistently produced /Vʔ/ where the others produced /V̰/. In other words containing creaky vowels, however, he did not diverge from the other speakers. He seems to have both /V̰/ and /Vʔ/ as phonological categories but he does not put all the words in the same categories as the other speakers. To a less systematic degree, this also concerns the distinction between /V̤/ and /V/. Some of the speakers produced modal voice in some words that were pronounced with a breathy vowel by other speakers. Concerning this change, however, I did not find any specific tendencies of certain speakers.

Additionally to the speakers included in this study, I made a short recording with a female native speaker in her 20s. Her production of glottals differed considerably from that of my other older consultants. For example, she retained /V̰/ in very few words and mostly produced [Vʔ] or sometimes even [V] in these cases. This was also the case for the second speaker included in the recordings enclosed in Lastra (2009b) and it is a change in younger speakers that my consultants commented on. Since these two speakers diverged so much in their pronunciation and because I had relatively little data for them, I excluded them from the study of non-modal voice quality and glottals in this thesis.

Creaky and breathy voice occur with both high and low tone. This fact makes Chichimeco a *laryngeally complex* language (cf. 2.2.). Concerning nasality, I can only note that both non-modal voice qualities do co-occur with vowel nasality but I cannot make any claims about systematicity. Breathy voice occurs on all vowels and it is reasonable to assume that this is also the case for creaky voice, even though I did not find examples for creaky voice on all vowels with both tones in my data. Judging from my auditory impression and looking at the spectrogram, both non-modal voice qualities are predominantly, but not exclusively, expressed towards the end of the vowel. This issue is addressed again in Chapter 5. The timing of modal and non-modal phonation, however, also seems to be dependent on syllable structure, i.e. whether a final consonant is present or not.

The research questions number 3 (on p. 28) can be described more accurately when taking into account other glottal sounds (cf. Section 4.3.).

4.3. Phonological analysis: Glottalisation

In the two previous Sections, I have established creaky and breathy voice as phonological categories. In Section 4.3.1., I illustrate that they are part of a bigger phenomenon of glottalisation by describing a morphophonemic rule and their general distribution with other glottals. In Section 4.3.2., I argue that their distribution points towards a prosodic governing of laryngeal features and that different levels of description have to be taken into account in order to describe this phenomenon accurately. In Section 4.3.3., I give a summary of these findings.

4.3.1. The phenomenon of glottalisation and glottal distribution

In general, glottalisation exclusively occurs in the stressed stem syllable on the lexical level, like creaky and breathy voice.

There is a morphophonemic rule that pluralises the 3rd person possessor in nouns and the 3rd person subject in verbs. In this rule, the initial stem consonant is glottalised, i.e. either constricted or aspirated. In the case of obstruents, this results in constricted and aspirated obstruents. For the sonorants /m n r/, it results in a sequence of the sonorant and a glottal stop or fricative. I call this rule *glottalisation*. There are certain restrictions concerning whether the initial stem consonant is constricted or aspirated. If the vowel in the stem is modal, either one can occur. This is illustrated in (4.3). If the stem vowel is breathy, the initial consonant can only be constricted, as in (4.4). The stem in these examples is marked in bold.

	Rule	***Singular***			***Plural***	
(4.3)	CV → C'V	*ná-**tsa***	'my food'	→	*ú-**ʦ'a***	'their food'
		1-food			3-food\3PL	
		*ú-**za***	'his/her food'			
		3-food\3SG				
		*é-**ʦen***	'I close'	→	*é-**ʦ'en***	'they close'
		1PRES-close			3PRES-close\3PL	
	CV → Cʰ V	*na-**kú***	'my foot'	→	*e-**kʰú***	'their foot (feet?)'
		1-foot			3-foot\3PL	
		*e-**gú***	'his/her foot'			
		3-foot\3SG				
		*e-**pã̋***	'I know'	→	*e-**pʰã̋***	'they know'
		1PRES-know			3PRES-know\3PL	
(4.4)	CV̤ → C'V̤	*ná-**mbe̤n***	'my horn'	→	*ú-**p'e̤n***	'their horn'
		1-horn\1			3-horn\3PL	
		*ú-**be̤n***	'his/her horn'			
		3-horn\3SG				
		*é-**pi***	'I owe'	→	*é-**p'i***	'they owe'
		1PRES-owe			3PRES-owe\3PL	

If the stem vowel is creaky, however, a striking pattern emerges. In these cases, the initial consonant is glottalised and the vowel *changes* its voice quality from creaky to breathy. Examples for such words are given in (4.5). It is important to note that this change only occurs if the vowel is creaky and not for syllables containing /Vʔ/. In these words, the stem consonant is aspirated instead and the final glottal stop remains unchanged, as illustrated in (4.6). The different behaviour of /V̰/ and /Vʔ/ in this rule can only be explained if they are, indeed, different phonological categories.

	Rule	***Singular***			***Plural***	
(4.5)	CV̰ → C'V̤	*ná-**tḭ***	'my necklace'	→	*ú-**rʔi̤***	'their necklace'
		1-necklace			3-necklace\3PL	
		*ú-**rḭ***	'his/her necklace'			
		3-necklace\3SG				
		*(riʧʰýr) é-**sa̰***	'I read (paper)'	→	*(riʧʰýr) é-**ʦ'a̤***	'they read (paper)'
		1PRES-read			3PRES-read\3PL	
(4.6)	CVʔ → CʰVʔ	*na-**kã̋ʔ***	'my mucus'	→	*u-**kʰã̋ʔ***	'their mucus'
		1-mucus			3-mucus\3PL	
		*u-**gã̋ʔ***	'his/her mucus'			
		3-mucus\3SG				
		*é-**kãʔ***	'I dye'	→	*é-**kʰãʔ***	'they dye'
		1PRES-dye			3PRES-dye\3PL	

This rule gives us an important indication about which patterns combining gottals in the same syllable are allowed and which ones are not. If we take a look at the possible distribution of glottals within the same syllable we can make some interesting generalisations.

As illustrated in Figure 2.1., there are two different kinds of glottalisation in Chichimeco; constriction, characterised by the laryngeal feature [constricted glottis], and aspiration, characterised by the laryngeal feature [spread glottis]. These laryngeal features can be expressed on consonants and vowels. Furthermore, consonants and vowels can, of course, be non-glottal, i.e. laryngeally unspecified.

In general, any of the consonant phonemes can occur in the onset of the stressed syllable, i.e. fortis, lenis, constricted or aspirated consonants (cf. Table 2.2.). In the nucleus of the stressed syllable, any vowel can occur. Vowels in this position can be modal, creaky or breathy, with or without nasalisation. The consonant inventory in the coda of the stressed syllable is more limited than in the onset. In my data, the stressed syllable was most frequently open. In closed syllables, I only found the constricted consonants /ʔ k' ʦ'/, the voiced consonants /n m b g r/ and the voiceless consonant /s/. Of these possible coda consonants, six are most commonly suffixes; /-g/, /-k'/ and /-b/ are the object suffixes for the first, second and third person, respectively, and /-s/, /-r/ and /-n/ are suffixes for the dual, plural and for the plural of the possessor, respectively. Many of these suffixes are lexicalised. The dual suffix, for example, is part of the lexical form in *tắ-ʔĩ**s*** (1SG-scissors) 'my scissors' and cannot be separated from the stem. In other words, **tắ-ʔĩ* does not exist, similar to 'scissors' in English which is only used with the plural suffix. Some of these final consonants occur without any apparent affixation or lexicalisation of these suffixes, e.g. *ru-tí̤**n*** (1-masa) 'my masa', *etí**s*** 'candle' or *é-ʔo**ʔ*** (1PRES-hear) 'I hear'.

The possible occurrence of constriction, aspiration and non-glottal articulation in different syllable positions is given in Table 4.1. As the segment /h/ and aspirated consonants do not occur in syllable-final position, there is no aspiration in the coda.

Table 4.1. Segments specified for [constricted glottis], [spread glottis] and laryngeally unspecified segments in different syllable constituents in Chichimeco.

	Onset	**Nucleus**	**Coda**
[constricted glottis]	ʔ p' t' k' ʦ' ʧ'	V̰	ʔ k' ʦ'
[spread glottis]	h pʰ tʰ kʰ	V̤	–
unspecified	p t k b d g ...	V	Ø n m b g r s

Of the 18 logically possible combinations of these features in the different syllable positions, only 10 actually occur. A list of these valid syllable structures with example words, as well as of the 8 syllable structures that do not appear in Chichimeco, are given in Table 4.2.

Table 4.2. List of valid and invalid syllable structures with respect to their glottal specification in Chichimeco. Examples for valid syllable structures with different tones are given and the stressed syllable is marked in bold.

Exemplary syllable structure	***Onset-Nucleus-Coda***	***Example***
ʔVØ	[constr]-unspec-unspec	/*bã̋.*___ʔã___/ 'aguamiel, honey', /*kan.*___ʔí___/ 'his hand'
ʔVʔ	[constr]-unspec-[constr]	/*é.*___ʔoʔ___/ 'I hear', /*é.*___ʦ'ǽʔb___/ 'he/she covers it'
ʔV̤Ø	[constr]-[spread]-unspec	/*ním.*___ʔa̤b___/ 'he/she is sad', /*ri.*___k'ṳ̋___/ 'your hip'
hVØ	[spread]-unspec-unspec	/*nín.*___tʰy___/ 'female', /*sá.*___pʰa___/ 'year', /*pa.*___há___/ 'bad, evil'
hVʔ	[spread]-unspec-[constr]	/*ma.*___háʔ___/ 'far away', /*nã̋.*___hũʔ___/ 'my name'
CVØ	unspec-unspec-unspec	/*é.*___ʦen___/ 'I close', /*ka.*___tí___/ 'my mouth'
CV̤Ø	unspec-[spread]-unspec	/*kí.*___ta̤n___/ 'dirty', /*ri.*___tí̤n___/ 'his/her masa'
CV̰Ø	unspec-[constr]-unspec	/*sú.*___ba̰___/ 'palm tree', /*ki.*___ʧḭn___/ 'your ax'
CV̤ʔ	unspec-[spread]-[constr]	/*ri.*___sé̤ʔ___/ 'iron', /*u.*___zó̤ʔ___/ 'his beard'
CVʔ	unspec-unspec-[constr]	/*e.*___týʦ'___/ 'candle', /*ű.*___baʔ___/ 'day'
ʔV̤ʔ	[constr]-[spread]-[constr]	–
ʔV̰Ø	[constr]-[constr]-unspec	–
ʔV̰ʔ	[constr]-[constr]-[constr]	–
ØV̰ʔ	unspec-[constr]-[constr]	–
hV̤Ø	[spread]-[spread]-unspec	–
hV̤ʔ	[spread]-[spread]-[constr]	–
hV̰Ø	[spread]-[constr]-unspec	–
hV̰ʔ	[spread]-[constr]-[constr]	–

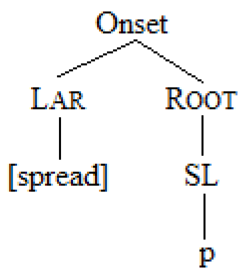
When comparing these valid syllable structures with the apparently invalid ones, we can make certain generalisations. First, there are never more than two glottal features in one syllable. Second, if two laryngeal features are adjacent, they have to be different. This does not apply if a segment is laryngeally unspecified. Third, if the vowel is creaky, no other laryngeal feature is allowed in the same syllable.

The patterns in Table 4.2. can only be explained if we assume a prosodic governing of laryngeal features. For this purpose, I follow an analysis in the terms of Feature Geometry in Section 4.3.2.

4.3.2. Prosodic governing of laryngeal features

Kehrein & Golston (2004) found that natural languages do not display conflicting laryngeal contrasts within one syllable constituent. In other words, no two different laryngeal features ([spread glottis] and [constricted glottis]) can occur within the same syllable constituent, e.g. *a̤a̰ in the nucleus or *hʔ within the syllable onset or coda. This restriction explains why we must assume breathy voice on the vowel rather than a final /h/ in the coda in words like *risé̤ʔ*. Furthermore, there are no pre- vs. post-laryngeal, e.g. [ph] vs. [hp], or segment vs. cluster contrasts, e.g. [ph] vs. [p^h], within a syllable constituent. Therefore, they propose a *prosodic* rather than segmental governing of laryngeal features. In this proposal, the laryngeal node is subordinate directly to the syllable constituent and *adjacent* to the root node rather than subordinate to it like supra-laryngeal features. This is represented in the tree in (4.7) that can explain various segments [p^h ^hp] and clusters [ph hp].

(4.7) [p^h ^hp ph hp]



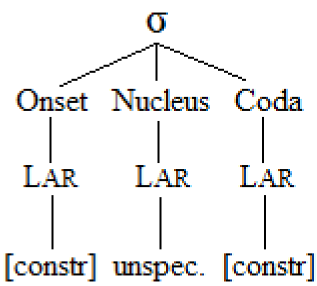
In the case of Chichimeco, I have established in 4.3.1. that there are certain restrictions that concern the syllable as a whole and the relationship of the syllable constituents to each other. Therefore, I extend this analysis and propose constraints on laryngeal features on an even higher level than the syllable constituent, i.e. on the level of the syllable.

From the generalisations about glottal distribution within the syllable in the previous Section, three constraints can be formulated:

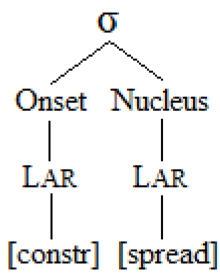
1. No more than two glottal features per syllable.
2. On this level, i.e. the lexical level, there is no spreading of features.
3. The Obligatory Contour Principle (OCP; Leben 1973) prohibits two adjacent identical glottal features.

Examples for two valid and two invalid structures are given in (4.8) and (4.9), and in (4.10) and (4.11), respectively.

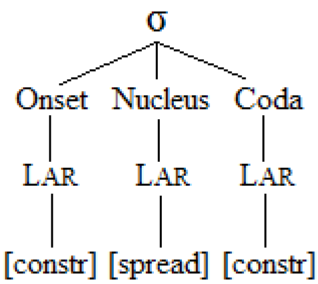
(4.8) /ʔVʔ C'Vʔ C'VC' ʔVC'/



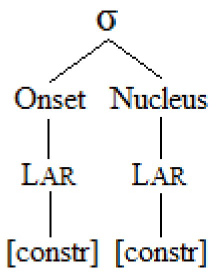
(4.9) /ʔV̤ C'V̤/



(4.10) */ʔV̤ʔ C'Vʔ C'VC' ʔVC'/



(4.11) */ʔV̰ C'V̰/



Every syllable constituent has a laryngeal node, even though it can be unspecified. This explains why a structure like ʔVʔ in (4.8) is allowed. The two [constricted glottis] features are not adjacent in Chichimeco because there is an unspecified laryngeal node between them. A structure like ʔV̤ in (4.9), for example, is allowed because the two adjacent glottal features are different, i.e. [constricted glottis] and [spread glottis], respectively. A structure like ʔV̤ʔ in (4.10), on the other hand, does not occur because there are more than two laryngeal features in the syllable. A structure like ʔV̰ in (4.11) is invalid because two adjacent identical laryngeal features are prohibited by the OCP and the constraint against laryngeal feature spreading.

The only issue that cannot be explained by these three constraints is the absence of hV̰. The morphophonemic pluralisation rule that I described in Section 4.3.1. avoids this construction by changing the voice quality and constricting the consonant, e.g. *é-**ma̰*** (3-call) 'he/she calls' > *é-**mʔa̤*** (3-call\3PL) 'they call' (cf. examples in (4.5)) instead of **é-**mʔa̰*** or **é-**mha̰***. This process indicates that this pattern is not just accidentally absent from my data but that it is, in fact, prohibited. Thus, I propose *hV̰. At this point, however, I do not have an explanation for the invalidity of this structure.

It is very important to note that my characterisation of the distribution of glottals and their restriction so far concerns a very specific level, i.e. the lexical level. These restrictions do not necessarily apply to other levels of description.

On the phonetic level, for example, a glottal stop is frequently inserted when a word starts with a vowel. In this case, there is a glottal in a syllable other than the stressed stem syllable. Moreover, spreading of the feature [constricted glottis] is quite common on the phonetic level. This results in co-articulatory creaky voice that spreads from an initial, e.g. epenthetic, or final glottal stop, producing forms like [V̰ʔ] which are *not* allowed on the level of the phonological representation. Another possible level of description is that of affixation. Affixing the second person object suffix *-k'* to words like ***é-mʔa̤*** (3-call\3PL) 'they call' results in a form like ***é-mʔa̤-k'*** (3-call\3PL-2OBJ) 'they call you'. Note that this word is syllabified as /ém.**ʔa̤k'**/ and therefore violates the constraints against three glottal features within the same syllable that I postulated earlier on the *lexical* level. Thus, three glottal features within the same syllable are allowed but only if there is a *morphological boundary* within this syllable. Affixation might also result in words that have glottal features outside the stressed stem syllable, such as in (4.12).

(4.12) si-te̤r-k'-os-me → /si.te̤r.**k'**os.me/
IMP.NEG-marry-2-DU-NEG
'you (two) don't marry'
(Lastra 2016: 64)

4.3.3. Summary of glottalisation

The morphophonemic pluralisation rule described in this section demonstrated that /V̰/ and /Vʔ/ are indeed different categories since they behave in different ways. This glottalisation rule gives an indication of which combinations of different glottals, i.e. creaky and breathy voice, constricted and aspirated consonants and the glottal consonants /ʔ/ and /h/, are allowed within the same syllable. I generalise that no more than two glottal features, i.e. [constricted glottis] or [spread glottis], may occur in a syllable, except if there is a morphological boundary in the syllable. Furthermore, if two glottal features are adjacent they may not be identical. These generalisations can explain the patterns that occur in this language as well as the absent patterns except for *hV̰. Furthermore, since they make reference to the syllable structure, they indicate a prosodic governing of laryngeal features.

The analysis of glottalisation showed that phonological creaky and breathy voice, as well as most other glottals, only occur in the stressed syllable. Phonetic creaky voice, however, is one of the possible realisations of an epenthetic glottal stop outside of the stressed syllable. Furthermore, only one non-modal voice quality is allowed within the same syllable on the lexical level. On the phonetic level, however, phonological glottal stops are often realised as creak on the following vowel. This may result in productions like [a̰aa̤] of syllables like /ʔa̤/. In these cases, it could be argued that two different non-modal voice qualities do occur in the same syllable on the surface. Thus, taking into consideration the different levels of description is essential and yields different answers to the research questions in 3. (p. 28).

4.4. Chichimeco as a laryngeally complex language

By recapitulating the description of creaky and breathy voice and the distribution of glottals in this chapter, some light can be shed on Chichimeco as a laryngeally complex language in Silverman's (1997) terms.

In his description of patterns in other laryngeally complex languages, he does not distinguish systematically between what is phonological, and how phonological (suprasegmental) categories are realised (cf. Sections 2.2.1. and 2.2.2.). In other words, he groups together glottal segments that can occur in pre- and post-vocalic position, and non-modal voice quality that can be realised in different ways on the vowel, i.e. in the beginning (pre-vocalic), towards the end (post-vocalic) or in the middle of the vowel (inter-vocalic). Thus, an initial glottal consonant, such as in [hV], is considered a pre-vocalic laryngeal just like the realisation of non-modal voice quality in the beginning of a vowel, such as in [V̤V].

When following Silverman in grouping together glottal segments and the temporal realisation of non-modal voice quality on the vowel, the following generalisations can be made about timing relations in Chichimeco. In these terms, laryngeals occur in pre-vocalic position in the form of glottal, constricted and aspirated consonants (cf. possible onsets in Table 4.1.). This corresponds to Silverman's first timing pattern (see Section 2.2.1., p. 15). In post-vocalic position, they occur in the form of the glottal stop and constricted consonants (cf. possible codas in Table 4.1.). Furthermore, creaky and breathy voice are often produced towards the end (see spectrograms in Sections 4.2.1. and 4.2.2.). The presence of pre- and post-vocalic laryngeals corresponds to Silverman's second timing pattern. In some cases, non-modal voice quality is realised in the middle of the vowel (see Figure 4.4.), which corresponds to Silverman's third timing pattern. However, the timing of non-modal voice quality in the middle or towards the end of the vowel is not contrastive in Chichimeco.

On the contrary, the exact realisation seems to be dependent on the speaker, as well as on the consonantal context (cf. 4.2.1.). In words with a final consonant, non-modal voice quality is not sequenced with modal voice quality but produced for the whole duration of the vowel (see Figure 4.2.). This means that the timing of non-modal voice quality in Chichimeco cannot be characterised completely in Silverman's notions alone (cf. Section 2.2.1.). In addition, segmental structure, i.e. the presence or absence of a final consonant, plays a role. The timing of modal and non-modal voice quality is addressed again in Chapter 5. In Table 4.3., I give an expanded version of Table 2.2., including Chichimeco.

Against Silverman's expectations (cf. Section 2.2.1.), however, the two categories [V̰] and [Vʔ] are not maximally distinct and are, indeed, confounded sometimes.

Table 4.3. The distribution of laryngeals in six Oto-Mangean languages, including Chichimeco.

Language	**Prevocalic laryngeals**	**Postvocalic laryngeals**	**Interrupted forms**
Jalapa Mazatec	yes	---	---
Comaltepec Chinantec	yes	yes	---
Copala Trique	yes	yes	yes
Amuzgo	yes	yes	---
SPG Zapotec	---	*yes*	---
Chichimeco	yes	yes	(non-contrastive)

5. The acoustics of Chichimeco voice quality

In this chapter, I answer those parts of the research questions that could not be answered in Chapter 4. In particular, this concerns timing patterns of modal and non-modal voice quality, the acoustic correlates of the different voice quality categories, i.e. breathy vowel /V̤/, modal vowel /V/ and creaky vowel /V̰/, and whether there is a systematic interaction of these categories with tone. In Section 5.1., I describe the methods used in this study and in Section 5.2., I present my results and discuss the data. In section 5.2.1., I address timing and tone and in Section 5.2.2., I discuss the acoustic correlates of the different voice qualities by presenting a statistical analysis. In Section 5.2.3., I give a summary of the results of this chapter.

5.1. Methods for the acoustic study

In this acoustic study of phonological non-modal voice quality, I analysed the recordings of nouns in the carrier phrase (cf. 3.1.). Of the ca. 270 nouns that I recorded, I analysed 29 in this study (see Table A4 in the Appendix). This noun list includes at least one word each for modal, breathy and creaky voice, for low (L) and high tone (H), and for the vowels /i/ and /a/. The vowels /i/ and /y/ have mostly merged in my consultants, except for speaker M02. The vowel /u/ was not included for all voice quality conditions because in most words with non-modal /u/ the vowel was also nasalised. Only words with an open stem syllable were included since the timing of modal and non-modal voice quality seems to be dependent on the final consonantal context (cf. Section 4.2.1. and Figure 4.2.). Furthermore, I controlled for glottal context, i.e. excluded words with glottal, constricted or aspirated consonants in the stem. The rest of the nouns were excluded because they did not fit the bisyllabic word structure, or because they included nasal vowels (cf. Sections 2.1.1. and 2.1.2 for the effects of vowel nasality and glottal features on spectral tilt measurements). In other words, I only analysed words that had a syllable structure of -CV, -CV̤ or -CV̰ in the stem. For each noun and each speaker, I analysed two to five repetitions. For the exact number of tokens for each speaker see Table A5 in the Appendix.

To reduce the variation in the data, obvious inter- and intra-speaker variation (cf. Section 4.2.1.) was excluded from this data set. Of the 29 words included in this study, one repetition of a word was excluded due to intra-speaker variation; speaker M01 produced *nímb**íʔ*** once for 'his/her bed' while he and the other speakers produced *nímb**ḭ́*** otherwise. Nouns with consistent inter-speaker variation, such as *kúng**aʔ**/kúng**a̰*** 'frog' were excluded from this study altogether. However, I only found three such words and, thus, they do not constitute a high percentage of my data. Most other of the 241 nouns were excluded for the previously mentioned reasons.

First, I segmented the target vowel, i.e. the vowel in the second syllable of the target word, in Praat. For the analysis of voice quality, the vowel was then divided into four parts of equal duration with a Praat script. This segmentation of the vowel in four was done to enable the investigation of a possible sequencing of modal and non-modal voice quality as noted in other laryngeally complex languages by Silverman (1997). In the next step, measurements of spectral tilt characteristics were extracted by VoiceSauce (Shue et al. 2011). The following spectral measurements were taken and averaged for each of the four parts of the target vowels: H1*-H2*, H2*-H4*, H1*-A1*, H1*-A2*, H1*-A3* and Cepstral Peak Prominence (CPP). The asterisk in these measurements indicates that they are "corrected for the effect of formants (frequencies and bandwidths)" (Shue et al. 2011: 1847).

The data was categorised according to the glottal context of the target vowel, i.e. breathy, modal and creaky voice, for H- and L-tone and for speaker.

For the presentation of timing tendencies and general inter-speaker variation, I give mean values of each measure for each voice quality, divided into speakers and tones (see. Figure 5.1., Figure 5.2. and Table A6 in the Appendix).

In order to test the relationship between the six measures and the voice quality of the vowel, I performed a multiple linear regression analysis for each measure in R (R Core Team 2016). In this model, 'voice quality' and 'speaker' were the predictor variables (with an interaction term) and the respective measures were the outcome variables. The results of this analysis are presented in Table 5.1. and in Figure 5.3. and are discussed in Section 5.2.2.

5.2. Results and Discussion

The measures that I have analysed are expected to be dependent on voice quality (cf. Section 2.1.1.). In general, the higher the spectral tilt measurements are the less constricted is the voice quality. This refers to the measures H1*-H2*, H2*-H4* and H1*-An*. Higher measurements for the Cepstral Peak Prominence (CPP) indicate a more modal voice quality. In this section, I examine to what degree the different voice qualities in Chichimeco can be characterised by these measures.

Different voice qualities are also related to tone, i.e. fundamental frequency, and speakers might produce different voice qualities in different ways. For this reason, I present the Chichimeco data differentiated not only for voice quality category but also for tone and speaker.

5.2.1. Timing and tone

In general, there is considerable variation in the Chichimeco data. For most measures, the ranges of values of the different voice quality categories overlap. Compare, for example, the tendencies of different speakers in Figures 5.1. and 5.2. and the mean values of the different voice quality categories and their standard deviations in Table A6. Relatively higher values of standard deviation, such as in time intervals 3 and 4 in H1*-H2*, H2*-H4* and H1*-A3* or generally higher values for the male speakers in some of the measures, indicate a greater spread in the data. Nevertheless, there are still recognisable tendencies in the data which I describe in this chapter.

Mean values for the measurements sorted by different voice qualities are given in Figure 5.1. and Figure 5.2. The mean and standard deviation values visualised in these figures are given in Table A6. In these two figures, each graph shows the change over the course of time for the respective measurement, plotted separately for each speaker (different symbols) and for H- and L-tone (different colours).

In general, in *modal* vowels, the values for the spectral tilt measures rise and the CPP decreases in the course of time (see 1-6b in Figure 5.1. and Figure 5.2.) which indicates that modal vowels become less modal and more breathy towards the end. The low values of CPP in time interval 1, i.e. at the beginning of the vowel, are probably due to co-articulation with the previous stem consonant.

Breathy vowels show an increase in values of H2*-H4*, H1*-A1* and H1*-A3* (see 2a, 3a and 5a) and a decrease of CPP (see 6a) in the course of the vowel, indicating that breathy vowels also become less modal and more breathy towards the end. Speaker F02's preferred timing pattern in breathy vowels, on the other hand, seems to be a stronger breathiness in the middle of the vowel rather than at the end. This is indicated by the higher mean values of the squares in time intervals 2 and 3 in all spectral tilt measures except for H1*-A2* (see square symbols in Figure 5.1. and Figure 5.2.). Speaker F01 also follows this pattern for L-tone in some spectral tilt measures, i.e. H1*-H2*, H2*-H4* and H1*A1* (see light grey circle symbols in 1-3a).

The generally smaller symbols, i.e. a higher standard deviation, in time interval 4 in breathy (1-6a) and modal vowels (1-6b) indicate more variation in the data towards the end. This could at least partly be due to the different realisations of the vowel contact in the carrier phrase (cf. 3.1.). Note however, that this does not seem to be the case for creaky vowels to the same degree. The symbol sizes in time interval 4 in (1-6c) show a more stable pronunciation even towards the end.

Values of *creaky* vowels are generally lower than those of breathy and modal vowels for H1*-H2*, H2*-H4* and H1*-A3* (see 1c, 2c and 5c). In creaky vowels, values of CPP are also lower than for

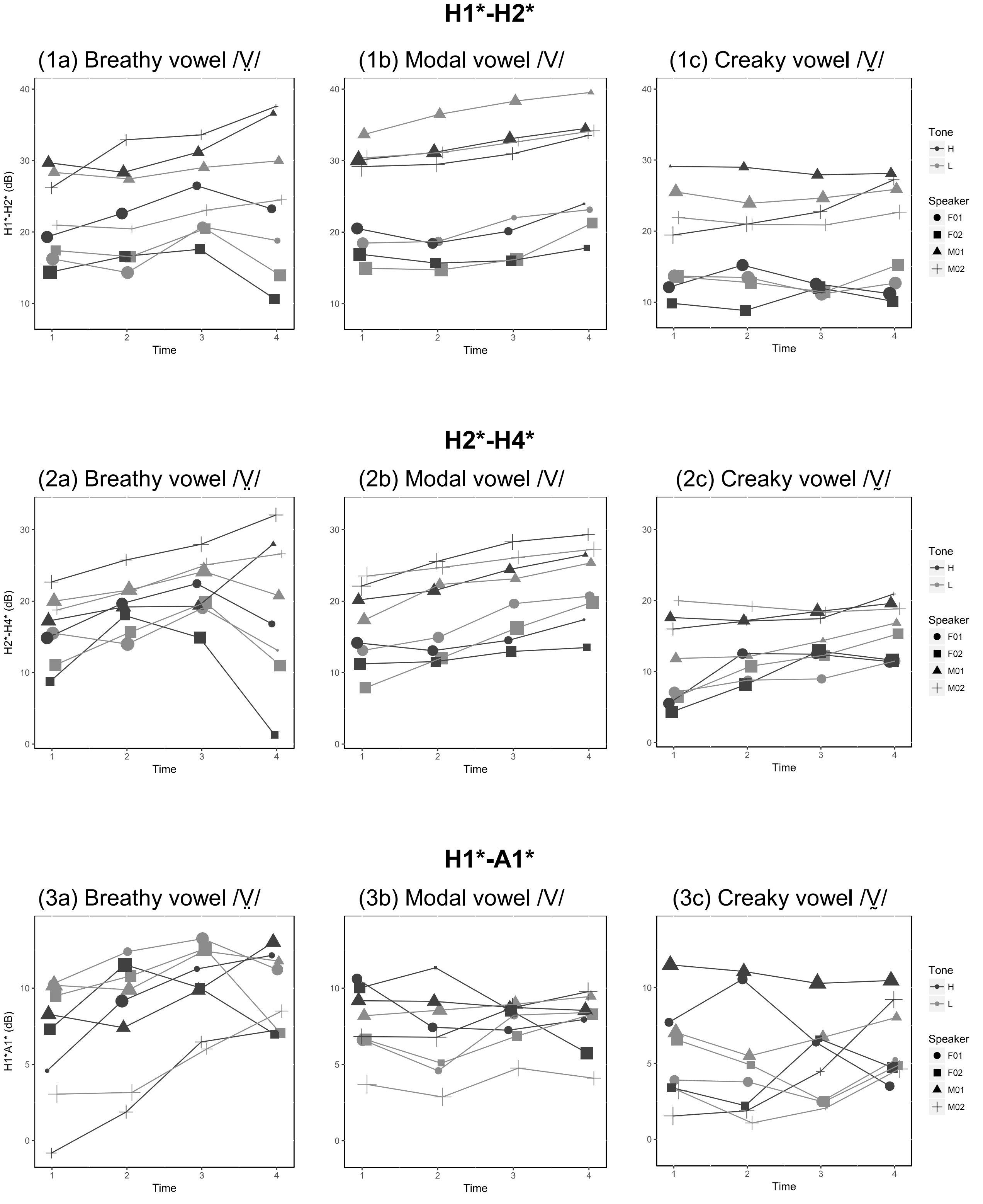


Figure 5.1. Mean values of the three spectral measurements (H1*-H2*, H2*-H4*, H1*-A1*) for breathy (left), modal (centre) and creaky vowels (right). Higher values for the spectral measurements indicate less constriction (cf. 2.1.1.). The numbers 1-4 on the x-axis indicate the course of time and the symbol size indicates the standard deviation; the bigger the symbol the smaller the standard deviation and, therefore, the smaller the variation in the data. Compare mean values and values of standard deviation in Table A6. High and low tone are colour-coded (H-tone = dark grey, L-tone = light grey), speakers are marked by symbol character (F01 = circle, F02 = square, M01 = triangle, M02 = plus).

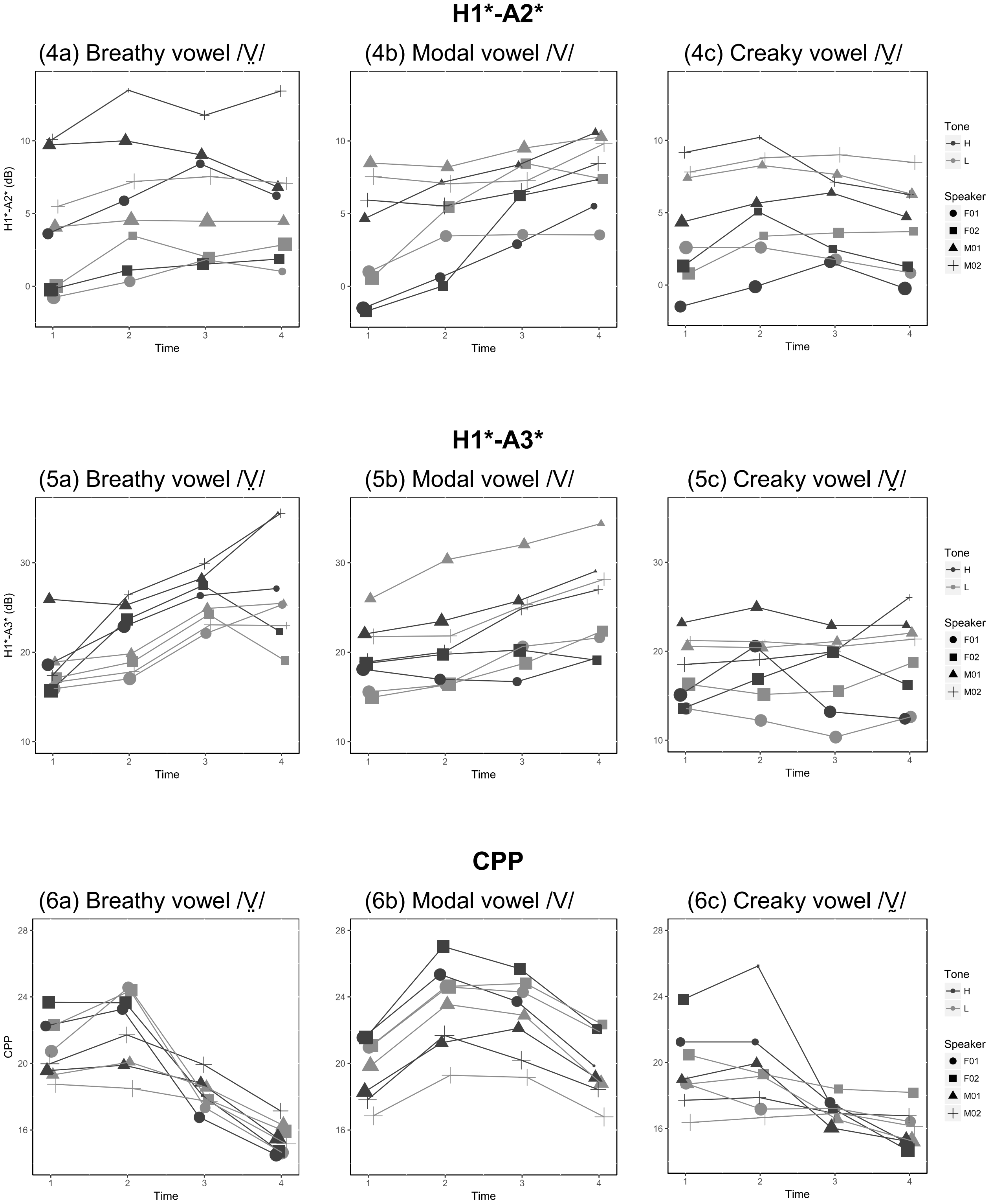


Figure 5.2. Mean values of two spectral measurements (H1*-A2*, H1*-A3*) and of Cepstral Peak Prominence (CPP) for breathy (left), modal (centre) and creaky vowels (right). Higher values for the spectral measurements indicate less constriction and higher values of CPP indicate a more modal voice quality (cf. 2.1.1.). The numbers 1-4 on the x-axis indicate the course of time and the symbol size indicates the standard deviation; the bigger the symbol the smaller the standard deviation and, therefore, the smaller the variation in the data. Compare mean values and values of standard deviation in Table A6. High and low tone are colour-coded (H-tone = dark grey, L-tone = light grey), speakers are marked by symbol character (F01 = circle, F02 = square, M01 = triangle, M02 = plus).

modal voice (cf. 6b and 6c). This fact follows the generalisation that a more constricted voice quality exhibits lower values for these measures. Note, however, that this tendency is not visible in the values of H1*-A2* (see 4a-c). In Chichimeco, H1*-A2* seems to be an unsuitable indicator for the distinction of the different voice qualities (see also Section 5.2.2.). For creaky vowels, there is no apparent temporal change visible in the spectral tilt measures. Only the values of CPP show that voice quality becomes less modal towards the end. The frequent timing of creakiness at the end of the vowel that I observed in Section 4.2.1. (cf. the spectrograms in Figure 4.1. and Figure 4.3.) is only represented in the CPP values but not in the spectral tilt measures. Some of these measures did, however, show generally lower values for the whole duration of creaky vowels (see also Section 5.2.2.). This means that measuring spectral tilt characteristics might not be the best way to quantify creaky voice in Chichimeco.

It is interesting to note that the measures including the amplitude of the second harmonic, i.e. H1*-H2* and H2*-H4*, display different groupings for men (higher values) and women (lower values) for modal and creaky vowels.

Tone does have some effect on these six measures. However, there are no clear patterns that are valid for all speakers or all measures. The realisation of the different voice qualities with the two tones is rather speaker-dependent. For example, the values of speaker M01 for creaky voice are generally lower for L-tone than for H-tone, except for the measures H1*-A2* and CPP (cf. triangle symbols in 1-6c). In modal vowels, this tendency is reversed for speaker M01. In other words, H-tone has lower values than L-tone, but only in the measures H1*-H2*, H1*-A2* and H1*-A3*, and in CPP (cf. triangle symbols in 1b and 4-6b).

The observations about inter-speaker variation were included in the statistical model presented in the next section.

5.2.2. Acoustic correlates of breathy, modal and creaky voice

In this analysis, I wanted to test which of the measures, i.e. spectral tilt measures and CPP, relates best to the voice quality of the vowel by applying a multiple linear regression model to each measure (see Section 5.1.). A linear regression model determines to what extent the relationship between the measures and the three voice qualities, i.e. breathy, modal and creaky voice, is a *linear* one. This model was chosen because the relationship between the voice qualities is expected to be quite linear; highest values are expected for breathy vowels, intermediate values for modal vowels, and lowest values for creaky vowels. For CPP, lower values are expected for non-modal than for modal vowels. Since Figure 5.1. and Figure 5.2. showed that speakers vary considerably in their productions, 'speaker' was included in the model as a predictor variable. Variation due to tone is rather unsystematic and, therefore, tone was not included in this model (cf. Section 5.1.). In this data, non-modal voice quality was more strongly produced towards the end of the vowel for breathy vowels, except for speaker F02 who produced it in the middle of the vowel. For this reason, the model was only applied to time interval 3 in which the values for the different voice qualities are expected to be most different for all speakers. The results of the multiple linear regression analysis are presented in Table 5.1. and in Figure 5.3. Note, however, that only some of these results are statistically significant (see significance codes in Table 5.1.). The insignificant p-values indicate a weak to no relation between the measures and the voice quality in this model. This could mean that either there is no correlation between the respective measures and the voice quality categories, or that the relationship between the voice qualities cannot be characterised as linear for all measures and speakers. In other words, the applied multiple linear regression model does not fit the data well. For some of the measures and some speakers, it may certainly be the case that there is no correlation. Figueiredo Filho et al. (2013) argue that data should also be analysed graphically and not only according to statistical significance. Considering Figures 5.1.-5.3., however, it is more likely that the relationship between the different measures and the three voice qualities is not always a linear one. Therefore, a non-linear model might better characterise this relationship.

Table 5.1. Results of the multiple linear regression analysis for the five spectral tilt measures and for CPP for each speaker in time interval 3. Standard errors are given in brackets. P-values are given for the model for each measure (Significance codes: <0.001=***, <0.01=**, <0.05=*, <0.1=°).

		Voice quality		
Value	**Speaker**	**Breathy vowel**	**Modal vowel**	**Creaky vowel**
H1*-H2*	*F01*	23.1 (±1.9)***	21 (±2.4)	13.5 (± 2.3)***
(R^2=0.39)	*F02*	19.2 (±2.3)	20.1 (±3.4)	14.1 (±3.2)
	M01	29.9 (±2.7)*	29 (±3.4)*	17.9 (±3.3)
	M02	27.3 (±2.7)	27.7 (±3.4)*	17.7 (±3.3)
H2*-H4*	*F01*	20.5 (±1.7)***	17.0 (±2.2)	12.4 (±2.2)***
(R^2=0.24)	*F02*	17.6 (±2.3)	17.5 (±3.0)°	14.7 (±3.0)
	M01	22.3 (±2.4)	21.9 (±3.0)	12.2 (±3.0)
	M02	26.2 (±2.4)*	21.3 (±3.0)	10.3 (±3.0)
H1*-A1*	*F01*	12.5 (±1.0)***	7.7 (±1.3)***	5.2 (±1.2)***
(R^2=0.19)	*F02*	11.5 (±1.4)	8.6 (±1.8)	5.8 (±1.7)
	M01	11.4 (±1.4)	9.8 (±1.8)	9.5 (±1.7)*
	M02	6.2 (±1.4)***	12.7 (±1.8)**	10.1 (±1.8)**

Table 5.1. Continuation

H1*-A2*	*F01*	4.6 (±1.3)***	3.2 (±1.6)	1.2 (±1.5)*
(R^2=0.14)	*F02*	1.8 (±1.8)	10.2 (±2.3)**	5.0 (±2.1)°
	M01	6.2 (±1.8)°	7.3 (±2.3)	3.8 (±2.2)
	M02	9.2 (±1.8)**	2.3 (±2.3)	2.5 (±2.2)
H1*-A3*	*F01*	23.9 (±2.0)***	18.6 (±2.6)*	12.5 (±2.4)***
(R^2=0.19)	*F02*	25.7 (±2.8)	17.7 (±3.6)	14.1 (±3.3)
	M01	26.2 (±2.8)	26.7 (±3.6)*	17.0 (±3.8)
	M02	25.8 (±2.8)	23.2 (±3.6)	16.3 (±3.4)
CPP	*F01*	17.1 (±0.5)***	24.0 (±0.7)***	16.9 (±0.6)
(R^2=0.56)	*F02*	17.9 (±0.7)	24.4 (±1.0)	17.3 (±0.9)
	M01	18.7 (±0.7)*	21.0 (±1.0)**	14.9 (±0.9)*
	M02	18.6 (±0.8)*	18.1 (±1.0)***	15.2 (±0.9)°

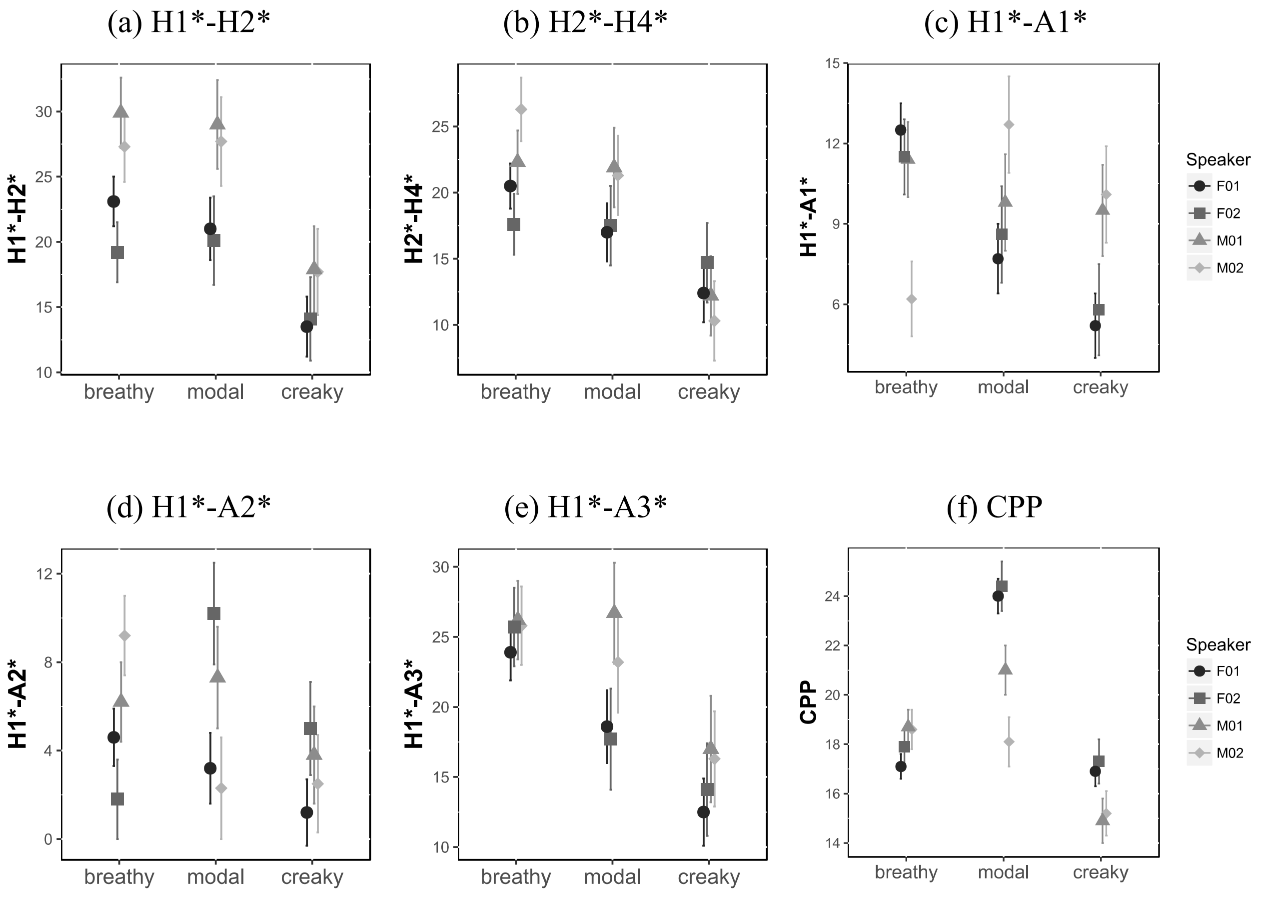


Figure 5.3. Results of the multiple linear regression analysis (with standard error bars). In each graph, the values of Table 5.1. are plotted for breathy vowels (left), for modal vowels (centre) and for creaky vowels (right). Speakers are indicated by colour and symbol.

Even though many of the values in Table 5.1. are not statistically significant, certain tendencies can be described by comparing the values in Figure 5.3. with the mean values in time interval 3 in Figures 5.1. and 5.2. In Table 5.1. and in Figure 5.3., we can see that the H1*-H2* values for breathy and modal vowels are very similar for all speakers. For creaky vowels, however, they are relatively lower (see (a) in Figure 5.3.). These low values for creaky voice indicate that H1*-H2* distinguishes between creaky vowels, on the one hand, and breathy and modal vowels on the other. This measure does not distinguish between breathy and modal vowels. The same behaviour is found for the H2*-H4* values for speakers F02 and M01 (see square and triangle symbols in (b) in Figure 5.3.). For H1*-A1*, the values are as expected, i.e. highest for breathy and lowest for creaky vowels, except for speaker M02 who has a very low value for breathy vowels and speaker M01 whose values for modal and creaky vowels are almost the same (see (c) in Figure 5.3.). This also applies to the measure H1*-A3*, except for speaker M01 who has a rather high value for modal vowels (see (e)). The divergence of speakers M01 and M02 in the spectral tilt measures might be due to more noise in the higher frequencies in their production of breathy voice (cf. 2.1.1.). The values for CPP do conform to the expected pattern, i.e. higher values for modal than for non-modal vowels, except for speaker M02 who has a very low value for modal voice (see (f)). This low value for modal voice indicates an overall less modal voice for this speaker which could be due to his higher age (see Section 3.2.; cf. Schötz 2006). The two male speakers have lower CPP values for creaky than for breathy vowels. The values for H1*-A2* do not correspond to the expected pattern except for speaker F01 who has the highest value for breathy and lowest value for creaky vowels (see (d)). However, taking into account the standard error, the values for the different categories are not substantially different from each other for speaker F01.

5.2.3. Summary of the Acoustic Study

In summary, I conclude my observations of the acoustic measurements. These observations can be characterised as tendencies rather than as absolute findings because there is considerable variation in the data and only some of the results show statistical significance.

First, the preferred timing pattern for breathy vowels seems to be an increase in breathiness towards the end of the vowel, i.e. higher values for the spectral tilt measures and lower values for CPP. This realisation confirms the observations made about timing in the context of Chichimeco as a laryngeally complex language in Silverman's (1997) terms made in Section 4.4. Only one speaker (F02) showed a preference for an increase in breathiness in the middle of the vowel. Her timing pattern fits previous authors' observations of a sequencing of modal-breathy-modal, i.e. [aa̤a], of breathy vowels in Chichimeco (cf. Section 2.3.2.). Incidentally, modal vowels also lose some of their voicing and become more breathy towards the end.

The localisation of creaky voice towards the end noted in Section 4.2.1. is only represented in the CPP values but not in the values of the spectral tilt measures. Some of the spectral tilt measures display overall lower values for creaky vowels but these measures do not reflect the observed sequencing of modal and creaky voice quality, such as in Figure 4.1., Figure 4.3. or Figure 4.4.

Second, H1*-H2* only distinguishes creaky vowels from the other vowels, but not modal and breathy vowels from each other. This also applies to H2*-H4* for two speakers. For H1*-A1* and H1*-A3*, values are generally higher for breathy than for modal vowels and lower for creaky vowels. CPP values are generally higher for modal vowels than for non-modal vowels. These results follow the expectation that lower spectral tilt values result from more constriction in the vocal folds and that lower CPP values represent a less modal voice quality. In general, H1*-A2* is a rather inadequate predictor for phonation type in Chichimeco. The values for this measure do not conform to the expected decrease in values in the order *breathy* > *modal* > *creaky* and the speakers in this study do not follow any specific tendency.

It is important to note that it is language-specific which of these measurements can distinguish between different voice qualities. Usually, only a few measures actually distinguish voice quality categories in a particular language (cf. Keating et al. 2010, Garellek & Keating 2011). Therefore, it is not surprising that we also find more conclusive patterns for certain measures in Chichimeco, i.e. H1*-H2*, H2*-H4*, H1*-A3* and CPP, than for others. Furthermore, if a language has three categories, like Chichimeco, the measures distinguishing between modal and creaky voice might be different from those distinguishing modal from breathy voice. In Jalapa Mazatec, for example, more measures distinguished between the laryngealised-modal contrast than between the breathy-modal contrast for some tones (Garellek & Keating 2011). In Chichimeco, H1*-H2* and H2*-H4* show conclusive patterns for creaky vs. modal vowels but not in the comparison with breathy vowels for all speakers.

Third, there were some differences in the values for H-tone and L-tone for some speakers. However, I did not find any conclusive patterns of the examined measures concerning tone. A suitable statistical model including tone might bring some light into this issue.

In this study, I did not measure F0. The judgements of tone on the respective syllables were based on previous descriptions (cf. Angulo 1932; Romero 1957-1958; Lastra 1984, 2009b, 2016; Herrera 2014), examples given in these publications and on my auditory impression. Thus, I did not investigate the realisation of tone with the different voice qualities. One basic assumption of Silverman (1997) is that tone is only realised on the modal part of the vowel in most laryngeally complex languages. From the measurements I took in this study, I cannot conclude whether Chichimeco conforms to this expectation. In other words, I did not examine how tone is realised in modal vs. non-modal vowels.

Fourth, women have lower values than men for two spectral measures containing the amplitude of the second harmonic, i.e. H1*-H2* and H2*-H4*, but only in modal and creaky vowels, i.e. vowels that are not phonologically breathy. This contradicts a frequently observed general stronger breathiness of women's voices (Titze 1989, Klatt & Klatt 1990, Hanson 1997).

More significant results about the relationship between the examined measures and the voice quality categories could be achieved by applying a modified non-linear model to the data in the future.

6. Conclusion

Non-modal voice quality is a growing research topic in the investigation of the phonological systems of the world's languages. Non-modal vowels, as well as other glottal sounds, are a distinct feature of Chichimeco. However, except for one phonetic-phonological study by Herrera (2014), some observations about language change by Lastra (2009a, 2011) and a few brief side notes by other authors, this topic has not received the attention it deserves. The purpose of my research was to start filling this gap.

In this thesis, I investigated the phonology and the phonetics of non-modal voice quality in Chichimeco. I wanted to validate Herrera's analysis of phonological breathy voice in Chichimeco and extend it to creaky voice. For this purpose, I examined the consistency in the production of words including breathy and creaky vowels. Additionally, I investigated the co-occurrence with other phonetic-phonological features, such as tone, as well as the distribution and the domain of these sounds. I did this by recording minimal pairs and a list of nouns in a carrier phrase with six speakers of Chichimeco in spring 2017. With this data, I did a phonological and an acoustic analysis. In this examination, I made auditory and visual observations (i.e. spectrograms) as well as acoustic measurements of spectral tilt (H1*-H2*, H2*-H4*, H1*-A1*, H1*-A2* and H1*-A3*) and relative noise in the signal (Cepstral Peak Prominence).

Regarding the speakers included in my study, I found a relatively consistent production of modal, breathy and creaky voice within and between speakers. Accordingly, I established breathy and creaky vowels as phonological categories. Furthermore, I showed that creaky voice is not just a realisation of a final glottal stop. This is illustrated by the generally distinct pronunciation in isolation and by the morphophonemic pluralisation rule in which words with creaky voice and with a final glottal stop behave in different ways. Some variation between the speakers nevertheless shows that the boundary between /V̰/ and /Vʔ/ seems to be shifting. This is even more so the case in younger speakers of the language that I excluded from this investigation due to exactly this age-related variation.

Breathy voice occurs with all vowel qualities in the language. For creaky voice, some vowels are missing in my data but I generalise that this non-modal voice quality can also occur on all vowels. I showed that both non-modal voice qualities co-occur with vowel nasality. However, I cannot say if they co-occur with nasality on all vowels.

Herrera (2014) established Chichimeco as a laryngeally complex language that combines tone and breathy voice quality in different ways. I confirm this claim and extend it to creaky voice. In other words, creaky and breathy voice both occur with high and low tone. Thus, Chichimeco joins the ranks of other (Oto-Manguean) laryngeally complex languages.

In these languages, modal and non-modal voice quality are commonly sequenced to allow for a clear production and perception of both tone and phonation type. Chichimeco confirms Silverman's (1997) implications about timing in such languages. The predominant timing pattern in Chichimeco is the realisation of non-modal phonation towards the end of the vowel. For creaky voice, however, only one acoustic measurement (CPP) confirmed the sequencing of modal and creaky voice that I observed auditorily and in spectrograms. From previous authors' transcription of Chichimeco, it follows that they observed a different timing pattern in which non-modal phonation was realised in the middle of the vowel. Only one speaker in my data exhibited this pattern for breathy vowels. Additionally, I discovered that the timing of modal and non-modal voice quality also seems to depend on the consonantal context. However, words with final consonants were excluded from the acoustic study and this connection of timing to segmental context was not pursued further in this thesis.

In the acoustic study of the realisation of the different voice quality categories towards the end of the vowel, I found that some acoustic correlates fit the expectations better than others. H1*-A1*, H1*-A3* and CPP values were as expected, except for single speakers who diverged from this pattern. H1*-H2* seems to only distinguish creaky voice. The same is the case for H2*-H4* for two of the speakers. H1*-A2* was a generally inadequate predictor of the different voice quality categories and did not correspond to the expected pattern for any of the speakers. However, there was considerable variation in the data and only few of the extracted values were statistically significant. Better results could be obtained by applying a modified and more extensive statistical analysis to a larger amount of nouns and speakers.

I did not find any conclusive interaction of tone with the acoustic measurements. More specifically, I did not find timing patterns particular to the different tones and no systematic patterns for the acoustic measures valid for different speakers. For this reason, tone was not included in the statistical analysis in this thesis. Including tone in an appropriate statistical model could also yield better results for the acoustic measures distinguishing between modal, breathy and creaky vowels. In future investigations, final consonants and nasal vowels should also be included in a statistical analysis to give a more comprehensive insight into the behaviour of non-modal voice quality in Chichimeco.

Future studies should not only investigate the realisation of non-modal voice quality in combination with different tones but also the realisation of tone with modal vs. non-modal vowels, i.e. whether tone is only realised on the modal part of phonologically non-modal vowels.

The characterisation of non-modal voice quality in this thesis goes beyond my research questions. In the investigation of the distribution and the domain of non-modal voice quality, I found that creaky and breathy voice as well as other glottal sounds are related in a systematic way in this language. Creaky and breathy vowels, constricted and aspirated consonants and the glottal consonants /h/ and /ʔ/ primarily only occur in the stressed stem syllable in Chichimeco. To accurately characterise the distribution of these sounds, different levels of description have to be taken into account. On the lexical level, certain restrictions prohibit the co-occurence of specific glottal sounds within the same syllable. If two glottals are adjacent, they have to be of different character. In other words, two [constricted glottis] or [spread glottis] features cannot be adjacent within the syllable. The only structure that cannot be explained by this generalisation is the invalid syllable structure of *hV̰. Furthermore, no more than two glottals can occur in the same syllable unless there is a morphological boundary in the syllable. In connected speech and in certain contexts, on the other hand, there is considerable co-articulation, for example from a final glottal stop to the previous vowel, resulting in identical laryngeal features on adjacent syllable constituents.

It is now widely acknowledged that tone is a suprasegmental phenomenon which has been formalised in Autosegmental Phonology. This concept has since been extended to other phonetic and phonological features in Feature Geometry. In my investigation, I showed that creaky and breathy voice are related to other glottal features with respect to syllable structure in Chichimeco. My analysis of glottals in Chichimeco confirms and extends Kehrein & Golston's (2004) proposition that glottalisation in particular is also a prosodic phenomenon.

As noted above, I addressed the phonological interaction of glottal features. Beyond that, future research should examine how different glottal features within the same syllable, e.g. initial glottal stop and breathy voice /ʔV̤/, are realised phonetically, including acoustic parameters and how this affects the timing of non-modal voice quality.

In my data, I noticed some variation concerning glottals. The findings presented here are possibly only valid for the age group of the speakers analysed in this study. The variation that I have noted can be viewed in terms of diachronic change and a more extensive investigation would extend Lastra's (2009a, 2011) studies of age-related variation. Young speakers show different phonological/phonetic behaviour that should be investigated and put into relation to the findings in this thesis.

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Appendix

Table A1. Distribution of glottal and glottalised consonants, divided into constriction /ʔ p' t' k' ʦ' ʧ'/ and aspiration /h p^h t^h k^h/.

Position	**Constriction**		**Aspiration**	
Syllable-initial glottal segments	/ná.**ʔ**u/	*my hoe*	/ta.**h**ír/ [x]	*my/his/her pistol*
	/ũn.**ʔ**ṹ/	*your husband*	/un.**h**í/	*colour*
	/um.**ʔ**á/	*sun*	/um.**h**ã́/	*lamb*
	/tar.**ʔ**ý/	*their needle(s)*	/bar.**h**ṹ/	*Mexican grackle*
Syllable-final glottal segments	/un.hí**ʔ**/	*his/her name*	—	—
	/ú.ran**ʔ**/	*his/her work*	—	—
Syllable-initial glottalised consonants	/u.**p'**á/	*their hat*	/sá.**p**^{h}a/	*year*
	/ú.**t'**u/	*his/her hoe*	/kí.**t**^{h}æ̰/	*his/her oven*
	/sá.**k'**ḭi̤/	*orphan*	/rí.**k**^{h}ur/	*tortilla*
	/nán.**t'**a/	*one*	/nín.**t**^{h}i/	*female*
	/ú.**ʦ'**a/	*their food*	—	—
	/ʧi.**ʧ'**é/	*his/her wing*	—	—
Syllable-final glottalised consonants	/i.hé**k'**/	*you (SG)*	—	—
	/ná.pã**ʦ'**/	*my shoe*	—	—

Table A2. A comparison of my transcription of certain sounds in the present thesis with other authors' transcriptions. A slash indicates that the authors used both characters, either in different publications or representing allophones.

Phonological description	***My transcription***	***Herrera***	***Lastra***	***Romero***	***Angulo***
Alveolar and post-alveolar affricate	**ʦ, ʧ**	ts, tʃ	c/ts, č/ch	¢,č	ts, tc
Glottalised and aspirated consonants	**p', t', k'** **p**^{h}**, t**^{h}**, k**^{h}	p', t', k' p^h, t^h, k^h	pʔ/p', tʔ/t', kʔ/k' ph, th, kh	$p^ʔ$, $t^ʔ$, $k^ʔ$ ph, th, kh	[29]
Lenis plosives	**b d/r g**	β ɾ ɣ	b d/r g	b d/r g/h	b/v d/r g
Lenis nasals	**β̃, r̃**	β̰, ɾ̰	m̺/m, n̺/n[30]	m, n	m, n
Nasalised vowels	**Ṽ**	Ṽ	V̨	V̨	V̨
High front rounded vowel	**y**	y	ü	ü	ü
Low tone	**V**	V̀	V	V	V̀

29 Angulo (1932: 185) notes that he did not transcribe these sounds consistently.
30 In Lastra (2009b), <m> and <n> are used for the lenis nasals, in contrast to <mm> and <nn> for intervocalic fortis nasals. The same applies to Romero's use of <m> and <n> in the next column.

Table A3. List of minimal and correspondence pairs, sorted according to the tone and the voice quality in the second syllable.

H-tone		**L-tone**	
Modal voice			
*u-r**í*** 2-son.in.law	'your son-in-law'	*úr**i*** person	'person'
*u-nh**í*** 3-penis	'his penis?'	*ú-nh**i*** 2-penis\2	'your penis?'
*ni-nt'**í**(ʔ)* 3-clothes	'his/her clothes'	*ní-nt'**i**(ʔ)/ní-rʔ**i**(ʔ)* 2-clothes\2	'your clothes'
*ta-ʔ**ý*** 1/3-needle	'my/his/her needle'	*kí-ʔ**y*** 2-needle\2	'your needle'
*kumb**ý*** 2.intestines	'your intestines'	*kúmb**y** (kúmb**ý**)* 1/3.intestines	'my/his/her intestines'
*ri-s**é*** 3-feather	'his/her feather'	*rí-s**e*** 2-feather\2	'your feather'
*u-ts**á*** 2-food\2	'your food'	*ná-ts**a*** 1-food	'my food'
*u-nh**á**ʔ/ú-nh**á**ʔ* 3-pulque	'his/her pulque'	*ú-nh**a**ʔ* 2-pulque\2	'your pulque'
*ki-h**á**ʔ* 2-spoon\2	'your spoon'	*tá-h**a**ʔ (also tá-h**á**ʔ)* 1-spoon	'my spoon'
*ki-n**ú*** 3-milpa	'his/her milpa'	*kí-n**u*** 2-milpa\2	'your milpa'
*u-t'**ú*** 2-hoe\2	'your hoe'	*ú-t'**u*** 3-hoe	'his/her hoe'
Modal voice + nasal			
*ni-t'**ĩ́*** 2-sleep\2	'you are sleepy'	*ní-t'**ĩ*** 3-sleep	'he/she is sleepy'
*si-n**ĩ́*** 3-lips	'his/her lips'	*sí-n**ĩ*** 2-lips\2	'your lips'
*kũr**ĩ́*** 1/3.heart	'my/his/her heart'	*kṹr**ĩ*** 2.heart	'your heart'
*kĩ-ʔ**ĩ́**s* 2-scissors\2	'your scissors'	*tã́-ʔ**ĩ**s* 1/3-scissors	'my/his/her scissors'
*si-s**ẽ́**ʔ* 3-arm	'his/her arm'	*sí-s**ẽ**ʔ* 2-arm\2	'your arm'
*sĩ-β**ã́**s* 3-bed.roll	'his/her bed roll'	*sĩ́-β**ã**s* 2-bed.roll\2	'your bed roll'
*si-ng**ṹ**n* 2-fence\2	'your fence'	*sí-ng**ũ**n (síng**ṹ**n)* 3-fence	'his/her fence'

Table A3. Continuation

ũnʔṹ 2.husband	'your husband'	*ṹnʔũ (ṹnʔṹ)* 3.husband	'her husband'
sukṹ soot	'soot'	*sú-kũ (sú-kṹ)* 1-cheek	'my cheek'
Breathy voice			
ri-tí̤n 3-masa	'his/her masa'	*rí-ti̤n* 2-masa\2	'your masa'
ki-ký̤n 2-mirror\2	'your mirror'	*kí-ky̤n* 2PRES-spy\2 *ná-gy̤n* 3-mirror\3SG	'you spy/spot' 'his/her mirror'
na-mbé̤n 1-instrument\1	'my instrument/music'	*ná-mbe̤n* 1-horn\1	'my horn'
u-ngʷé̤n 2-horn\2	'your horn'	*ú-ngʷe̤n* 2-instrument\2	'your instrument/ music'
u-wé̤n 3-instrument\3SG	'his/her instrument/ music'	*ú-we̤n* 3-instrument\3SG	'his/her horn'
na-mbá(á̤) 1-hat\1 *ná-mbá/(á̤)* 1-prey\1	'my hat' 'my prey'	*ná-mba(a̤)* 1-belly\1	'my belly'
u-ng(ʷ)á(á̤) 2-belly\2	'your belly'	*ú-ng(ʷ)a(a̤)* 2-hat\2	'your hat'
u-wá(á̤) 3-hat\3 *ú-wá(á̤)* 3-prey\3	'his/her hat' 'his/her prey'	*ú-wa(a̤)* 3-belly\3	'his/her belly'
ni-má̤ 3-plate	'his/her plate'	*ní-ma̤* 2-plate\2	'your plate'
Creaky voice			
unḭ́ 2.wife	'your wife'	*únḭ* 3.wife	'his wife'
ki-ʧḭ́n 2-axe	'your axe'	*tá-ʧḭn* 3-axe	'his/her axe'
ni-mbḭ́ 2-bed\2	'your bed'	*ní-mbḭ* 3-bed	'his/her bed'
ni-βḛ́ 2-hunger\2	'you are hungry'	*nú-mbḛ* 1-hunger	'I am hungry'
u-kṵ̃́ 2-way\2	'your way'	*ná-kṵ̃* 1-way	'my way'

Table A3. Continuation

Minimal contrast in glottal features			
*unh**í*** colour	'*colour*'	*u-nh**íʔ*** 3-name	'*his/her name*'
*úr**i*** person	'*person*'	*ú-r**i̤*** 3-necklace\3SG	'*necklace*'
*ri-s**é*** 3-feather	'*his/her feather/skin*'	*ris**ḛ́ʔ*** iron	'*iron*'
*ná-t**a**nʔ* 1-work	'*my work*'	*nát**a̰**n* wasp	'*wasp*'
*úrʔ**ĩ*** 'atole' atole	*úrʔ**ḭ̃*** 'tamal' tamal	*ú-rʔ**i̤*** 'their necklace(s)' 3-necklace\3PL	

Table A4. List of nouns recorded in the carrier phrase that were used for the acoustic study in Chapter 5. The target vowel in each word is marked in bold.

H-tone		L-tone	
Modal voice			
*u-ʦ**á*** 2-food\2	'your food'	*ná-ʦ**a*** 1-food	'my food'
*ku-n**ú*** 1-milpa	'my milpa'	*ú-z**a*** 3-food\3SG	'his/her food'
*ki-n**ú*** 3SG-milpa	'his/her milpa'	*kí-n**u*** 2-milpa\2	'your milpa'
*ka-t**í*** 1-mouth	'my mouth'	*ú-t**i*** 2-mouth\2	'your mouth'
*ka-t**á*** 1-face	'my face'	*ú-t**a*** 2-face\2	'your face'
Breathy voice			
*nu-m**á̤*** 1-plate	'my plate'	*ní-m**a̤*** 2-plate\2	'your plate'
*ni-m**á̤*** 3-plate	'his/her plate'	*nú-nd**i̤*** (M02: *nú-nd**y̤***) 1-cigarette	'my cigarette'
*ni-r**í̤*** (M02: *ni-r**ý̤***) 2-cigarette\2	'your cigarette'	*ní-nd**í̤*** (M02: *ní-nd**y̤***) 2-cigarette	'his/her cigarette'
		*úz**i̤*** maize	'maize'
Creaky voice			
*ki-β**á̰*** 2-spirit\2	'your spirit/soul'	*kú-mb**a̰*** 1-spirit	'my spirit/soul'
*u-ʧ**ḭ́*** 2-spine\2	'your spine'	*kí-mb**a̰*** 3-spirit	'his/her spirit/soul'
*u-t**ḭ́*** 2-necklace\2	'your necklace'	*ná-ʧ**ḭ*** 1-spine	'my spine'
*nú-mb**ḭ́*** (M02: *nú-mb**ý̰***) 1-bed	'my bed'	*ná-t**ḭ*** 1-necklace	'my necklace'
*ni-mb**ḭ́*** 2-bed\2	'your bed'	*ú-r**ḭ*** 3SG-necklace\3SG	'his/her necklace'
*ní-mb**ḭ́*** (M01: *ní-mb**i***) 3-bed	'his/her bed'	*súβ**a̰*** palm.tree	'palm tree'

Table A5. Tokens for each voice quality for each speaker included in the multiple linear regression analysis in Chapter 5. Tokens for high- and low-tone, respectively, are given in brackets.

	Breathy	Modal	Creaky
F01	n= 24 (H 10, L14)	n=39 (H 20, L 19)	n=48 (H 21, L 27)
F02	n=27 (H 12, L 15)	n=35 (H 17, L 18)	n=45 (H 18, L 27)
M01	n=26 (H 10, L 16)	n=37 (H 18, L 19)	n=43 (H 20, L 23)
M02	n=25 (H 10, L 15)	n=36 (H 16, L 20)	n=43 (H 20, L 23)
Total	n=102 (H 42, L 60)	n=145 (H 71, L 76)	n=179 (H 79, L 100)

Table A6. Mean values and standard deviations for each acoustic measurement, given for the four time intervals of breathy, modal and creaky vowels of the four speakers with high- and low-tone, respectively. Standard deviations are given in brackets.

Measure	VQ	Tone	t1	t2	t3	t4	Speaker
H1*-H2*	***breathy***	*H*	19.3 (±4.8)	22.6 (±5.9)	26.5 (±12.0)	23.3 (±11.8)	*F01* (n=10)
(range=64.2)			14.4 (±1.3)	16.6 (±1.3)	16.6 (±8.0)	17.6 (±8.9)	*F02* (n=12)
			29.7 (±8.7)	28.3 (±8.2)	31.2 (±10.8)	36.6 (±15.4)	*M01* (n=10)
			26.2 (±12.5)	32.9 (±12.8)	33.6 (±14.1)	37.6 (±16.7)	*M02* (n=10)
		L	16.2 (±2.6)	14.3 (±3.5)	20.7 (±7.9)	18.8 (±15.1)	*F01* (n=14)
			17.4 (±9.8)	16.5 (±7.7)	20.5 (±8.0)	14.0 (±5.4)	*F02* (n=15)
			28.3 (±10.5)	27.4 (±11.3)	29.0 (±11.4)	30.0 (±13.0)	*M01* (n=16)
			21.0 (±14.3)	20.4 (±16.1)	23.1 (±13.3)	24.5 (±14.5)	*M02* (n=15)
	modal	*H*	20.5 (±6.8)	18.4 (±8.2)	20.1 (±10.5)	23.9 (±12.5)	*F01* (n=20)
			16.9 (±5.8)	15.7 (±9.1)	16.0 (±8.9)	17.8 (±11.7)	*F02* (n=17)
			30.1 (±5.4)	31.1 (±6.2)	33.1 (±8.3)	34.5 (±10.3)	*M01* (n=18)
			29.2 (±4.8)	29.5 (±8.2)	31.0 (±9.9)	33.5 (±12.2)	*M02* (n=16)
		L	18.5 (±7.0)	18.7 (±9.6)	22.0 (±12.0)	23.1 (±11.6)	*F01* (n=19)
			15.0 (±5.5)	14.7 (±5.9)	16.2 (±5.7)	21.3 (±8.5)	*F02* (n=18)
			33.7 (±8.8)	36.5 (±9.4)	38.3 (±9.3)	39.5 (±12.1)	*M01* (n=19)
			30.4 (±8.1)	31.1 (±10.6)	32.6 (±11.6)	34.2 (±10.4)	*M02* (n=20)
	creaky	*H*	11.9 (±5.2)	14.7 (±5.7)	16.0 (±6.0)	15.9 (±6.5)	*F01* (n=21)
			10.2 (±7.2)	7.3 (±6.6)	9.9 (±5.1)	8.2 (±6.3)	*F02* (n=18)
			24.4 (±13.2)	24.5 (±11.3)	25.1 (±9.1)	25.7 (±9.5)	*M01* (n=20)
			20.4 (±7.3)	22.0 (±9.4)	22.9 (±9.5)	24.8 (±10.9)	*M02* (n=23)

Table A6. Continuation

		L	14.3 (±3.5)	13.8 (±3.0)	11.5 (±2.8)	14.1 (±5.5)	*F01* (n=27)
			13.7 (±4.8)	12.0 (±6.2)	10.4 (±6.1)	14.0 (±6.5)	*F02* (n=27)
			25.3 (±6.9)	23.4 (±7.5)	24.3 (±7.7)	25.9 (±8.7)	*M01* (n=23)
			21.8 (±10.0)	21.0 (±11.1)	20.9 (±10.9)	22.5 (±8.7)	*M02* (n=23)
H2*-H4*	***breathy***	*H*	14.8 (±4.4)	19.7 (±6.0)	22.4 (±8.9)	16.8 (±10.4)	*F01* (n=10)
(range=60.6)			8.7 (±9.0)	18.0 (±8.4)	14.9 (±5.4)	1.3 (±10.0)	*F02* (n=12)
			17.2 (±5.9)	19.2 (±5.8)	19.3 (±8.6)	28.0 (±11.4)	*M01* (n=10)
			22.7 (±8.2)	25.8 (±9.5)	28.0 (±7.1)	32.1 (±7.7)	*M02* (n=10)
		L	15.5 (±3.9)	14.0 (±3.0)	19.0 (±5.1)	13.1 (±11.7)	*F01* (n=14)
			11.1 (±5.4)	15.7 (±6.1)	19.8 (±4.4)	11.0 (±6.1)	*F02* (n=15)
			20.0 (±5.5)	21.6 (±4.5)	24.2 (±3.7)	20.8 (±8.4)	*M01* (n=16)
			18.7 (±10.7)	21.5 (±10.6)	25.1 (±8.2)	26.6 (±11.3)	*M02* (n=15)
	modal	*H*	14.2 (±6.1)	13.1 (±7.9)	14.5 (±10.7)	17.4 (±13.2)	*F01* (n=20)
			11.2 (±6.1)	11.5 (±9.0)	13.0 (±8.5)	13.5 (±11.5)	*F02* (n=17)
			20.2 (±8.5)	21.5 (±8.0)	24.4 (±9.9)	26.5 (±12.9)	*M01* (n=18)
			22.1 (±3.8)	25.6 (±7.2)	28.3 (±7.6)	29.3 (±9.9)	*M02* (n=16)
		L	13.1 (±7.3)	14.9 (±7.0)	19.7 (±8.8)	20.7 (±9.3)	*F01* (n=19)
			7.9 (±6.5)	12.0 (±5.6)	16.2 (±3.5)	19.8 (±5.1)	*F02* (n=18)
			17.3 (±7.5)	22.3 (±9.6)	23.1 (±10.3)	25.3 (±10.7)	*M01* (n=19)
			23.5 (±5.8)	24.7 (±9.0)	26.1 (±9.4)	27.3 (±8.0)	*M02* (n=20)
	creaky	*H*	9.1 (±6.5)	14.8 (±7.6)	15.1 (±8.2)	15.1 (±8.0)	*F01* (n=21)
			6.0 (±4.3)	7.4 (±3.7)	11.7 (±3.3)	10.0 (±4.5)	*F02* (n=18)
			12.7 (±9.6)	12.3 (±10.3)	15.3 (±8.3)	18.2 (±8.5)	*M01* (n=20)
			16.4 (±10.5)	16.8 (±12.8)	16.4 (±12.7)	18.0 (±12.9)	*M02* (n=23)
		L	8.2 (±6.4)	10.9 (±9.6)	10.3 (±8.8)	11.7 (±6.9)	*F01* (n=27)
			7.3 (±4.4)	10.6 (±4.6)	12.0 (±6.4)	14.3 (±6.7)	*F02* (n=27)
			11.7 (±8.3)	10.1 (±12.0)	13.0 (±11.6)	16.4 (±10.1)	*M01* (n=23)
			17.7 (±11.1)	16.8 (±10.7)	15.9 (±10.9)	16.5 (±9.9)	*M02* (n=23)
H1*-A1*	***breathy***	*H*	4.6 (±7.1)	9.2 (±2.4)	11.3 (±6.8)	12.1 (±6.7)	*F01* (n=10)
(range=35.2)			7.3 (±3.7)	11.5 (±1.8)	10.0 (±5.0)	7.0 (±5.7)	*F02* (n=12)
			8.3 (±3.0)	7.4 (±4.2)	9.9 (±3.9)	13.0 (±3.2)	*M01* (n=10)
			-0.8 (±6.4)	1.9 (±5.2)	6.5 (±5.7)	7.2 (±7.3)	*M02* (n=10)
		L	10.3 (±5.6)	12.4 (±5.6)	13.3 (±2.7)	11.2 (±3.7)	*F01* (n=14)
			9.5 (±3.7)	10.8 (±3.6)	12.6 (±2.5)	7.1 (±4.9)	*F02* (n=15)
			10.2 (±1.9)	9.9 (±2.3)	12.4 (±2.5)	11.8 (±5.9)	*M01* (n=16)
			3.1 (±3.0)	3.2 (±3.3)	6.0 (±6.0)	8.5 (±5.4)	*M02* (n=15)

Table A6. Continuation

	modal	*H*	10.6 (±4.9)	7.4 (±5.6)	7.3 (±6.4)	7.9 (±7.2)	*F01* (n=20)
			10.0 (±4.8)	11.3 (±7.7)	8.5 (±4.2)	5.8 (±3.5)	*F02* (n=17)
			9.2 (±4.1)	9.1 (±4.8)	8.7 (±5.4)	8.5 (±3.8)	*M01* (n=18)
			6.8 (±4.7)	6.8 (±2.9)	8.7 (±2.5)	9.8 (±3.1)	*M02* (n=16)
		L	6.6 (±3.7)	4.6 (±6.8)	8.2 (±6.3)	8.4 (±5.8)	*F01* (n=19)
			6.6 (±4.0)	5.1 (±7.0)	6.9 (±5.5)	8.3 (±4.3)	*F02* (n=18)
			8.2 (±5.0)	8.6 (±4.2)	8.9 (±4.0)	9.5 (±6.2)	*M01* (n=19)
			3.7 (±2.7)	2.9 (±3.3)	4.8 (±4.5)	4.1 (±5.5)	*M02* (n=20)
	creaky	*H*	7.4 (±4.9)	11.4 (±4.3)	7.7 (±5.1)	4.3 (±4.2)	*F01* (n=21)
			3.9 (±4.2)	4.6 (±5.6)	6.6 (±4.6)	4.0 (±3.7)	*F02* (n=18)
			10.3 (±2.9)	10.6 (±4.3)	10.0 (±3.1)	10.5 (±3.8)	*M01* (n=20)
			3.0 (±4.1)	2.7 (±5.2)	4.6 (±5.6)	7.5 (±4.6)	*M02* (n=23)
		L	4.8 (±4.9)	5.3 (±5.6)	3.2 (±4.4)	5.2 (±5.8)	*F01* (n=27)
			7.3 (±3.8)	6.1 (±5.9)	3.6 (±4.8)	5.0 (±4.7)	*F02* (n=27)
			8.2 (±4.1)	5.9 (±4.1)	7.2 (±4.3)	8.3 (±5.1)	*M01* (n=23)
			3.5 (±3.1)	2.1 (±4.9)	3.2 (±6.6)	5.7 (±4.1)	*M02* (n=23)
H1*-A2*	***breathy***	*H*	3.6 (±5.8)	5.9 (±6.4)	8.4 (±7.5)	6.2 (±7.6)	*F01* (n=10)
(range=46.0)			-0.2 (±3.6)	1.1 (±6.6)	1.5 (±5.3)	1.9 (±6.6)	*F02* (n=12)
			9.7 (±6.3)	10.0 (±6.4)	9.0 (±6.5)	6.8 (±7.0)	*M01* (n=10)
			10.1 (±7.9)	13.5 (±9.2)	11.8 (±8.6)	13.4 (±7.9)	*M02* (n=10)
		L	-0.8 (±3.5)	0.3 (±5.6)	1.8 (±7.1)	1.0 (±8.0)	*F01* (n=14)
			0.0 (±3.4)	3.5 (±7.9)	2.0 (±5.5)	2.9 (±3.5)	*F02* (n=15)
			4.1 (±5.3)	4.5 (±4.7)	4.5 (±4.0)	4.5 (±7.2)	*M01* (n=16)
			5.5 (±7.0)	7.2 (±5.9)	7.5 (±5.7)	7.1 (±7.5)	*M02* (n=15)
	modal	*H*	-1.5 (±2.9)	0.6 (±6.7)	2.9 (±7.5)	5.5 (±9.5)	*F01* (n=20)
			-1.7 (±5.3)	0.0 (±7.3)	6.2 (±5.8)	7.3 (±10.4)	*F02* (n=17)
			4.7 (±8.0)	7.1 (±10.0)	8.4 (±9.7)	10.6 (±9.4)	*M01* (n=18)
			5.9 (±7.3)	5.5 (±5.5)	6.5 (±5.3)	8.4 (±6.7)	*M02* (n=16)
		L	1.0 (±3.8)	3.5 (±5.2)	3.6 (±6.3)	3.5 (±6.3)	*F01* (n=19)
			0.6 (±3.2)	5.4 (±6.1)	8.5 (±7.2)	7.4 (±7.1)	*F02* (n=18)
			8.5 (±6.0)	8.2 (±6.7)	9.5 (±5.9)	10.3 (±6.8)	*M01* (n=19)
			7.5 (±5.5)	7.1 (±5.0)	7.3 (±5.3)	9.8 (±5.7)	*M02* (n=20)
	creaky	*H*	-0.1 (±3.3)	-0.7 (±2.3)	1.0 (±3.3)	1.1 (±3.1)	*F01* (n=21)
			2.1 (±2.8)	3.4 (±5.8)	1.2 (±5.4)	0.9 (±4.2)	*F02* (n=18)
			2.6 (±4.1)	3.2 (±5.5)	3.9 (±6.6)	2.9 (±5.8)	*M01* (n=20)
			6.8 (±6.3)	8.5 (±7.6)	6.0 (±6.7)	5.1 (±6.6)	*M02* (n=23)

Table A6. Continuation

		L	2.3 (±2.2)	2.0 (±3.7)	1.4 (±3.2)	0.9 (±4.0)	*F01* (n=27)
			0.7 (±3.4)	2.6 (±6.6)	2.9 (±5.3)	3.3 (±6.6)	*F02* (n=27)
			6.2 (±7.7)	7.3 (±7.2)	6.7 (±7.0)	5.6 (±6.2)	*M01* (n=23)
			6.9 (±6.7)	8.1 (±7.0)	8.1 (±5.2)	7.5 (±5.8)	*M02* (n=23)
H1*-A3*	***breathy***	*H*	18.6 (±4.0)	22.9 (±3.1)	26.3 (±13.3)	27.1 (±14.0)	*F01* (n=10)
(range=60.5)			15.7 (±2.0)	23.7 (±5.6)	27.5 (±10.7)	22.3 (±13.8)	*F02* (n=12)
			25.9 (±10.0)	25.2 (±9.2)	28.2 (±11.4)	35.6 (±15.6)	*M01* (n=10)
			17.4 (±13.0)	26.4 (±14.4)	29.9 (±13.0)	35.5 (±14.2)	*M02* (n=10)
		L	15.9 (±1.4)	17.0 (±3.2)	22.1 (±7.6)	25.3 (±12.1)	*F01* (n=14)
			17.1 (±8.8)	18.9 (±7.8)	24.2 (±10.2)	19.1 (±12.1)	*F02* (n=15)
			18.9 (±11.5)	19.8 (±11.3)	24.9 (±11.2)	25.5 (±14.2)	*M01* (n=16)
			16.7 (±13.2)	17.8 (±13.4)	23.1 (±11.5)	23.0 (±15.1)	*M02* (n=15)
	modal	*H*	18.1 (±3.0)	17.0 (±7.1)	16.7 (±10.6)	19.3 (±14.4)	*F01* (n=20)
			18.7 (±4.4)	19.7 (±6.3)	20.3 (±5.3)	19.1 (±10.7)	*F02* (n=17)
			22.0 (±7.8)	23.5 (±7.4)	25.7 (±10.5)	29.0 (±14.5)	*M01* (n=18)
			18.9 (±6.1)	20.0 (±9.2)	24.9 (±10.8)	27.0 (±13.3)	*M02* (n=16)
		L	15.6 (±4.4)	16.4 (±5.8)	20.6 (±6.5)	21.6 (±8.2)	*F01* (n=19)
			15.0 (±3.7)	16.4 (±3.7)	18.8 (±5.5)	22.4 (±8.6)	*F02* (n=18)
			26.0 (±10.3)	30.6 (±9.7)	32.1 (±9.9)	34.4 (±13.3)	*M01* (n=19)
			21.8 (±8.4)	21.8 (±10.2)	25.3 (±12.0)	28.2 (±10.3)	*M02* (n=20)
	creaky	*H*	15.5 (±4.5)	19.4 (±4.5)	15.1 (±4.6)	13.7 (±5.6)	*F01* (n=21)
			15.3 (±6.7)	18.4 (±6.2)	16.3 (±6.6)	13.5 (±7.6)	*F02* (n=18)
			17.9 (±11.0)	19.1 (±10.9)	18.5 (±10.5)	19.6 (±11.3)	*M01* (n=20)
			15.0 (±9.3)	16.2 (±11.5)	16.7 (±10.4)	19.7 (±14.6)	*M02* (n=23)
		L	14.8 (±5.1)	13.7 (±5.4)	10.5 (±3.6)	12.4 (±5.0)	*F01* (n=27)
			16.4 (±3.2)	15.1 (±4.0)	15.5 (±6.5)	17.6 (±8.5)	*F02* (n=27)
			20.4 (±8.3)	19.0 (±10.0)	19.9 (±11.1)	20.8 (±10.2)	*M01* (n=23)
			19.0 (±13.2)	20.0 (±13.8)	19.5 (±12.9)	20.5 (±8.8)	*M02* (n=23)
CPP	***breathy***	*H*	22.3 (±2.5)	23.3 (±2.1)	16.8 (±2.1)	14.5 (±0.9)	*F01* (n=10)
(range=44.0)			23.7 (±1.5)	23.6 (±1.6)	18.1 (±4.3)	14.7 (±1.6)	*F02* (n=12)
			19.6 (±2.1)	19.9 (±2.9)	18.8 (±2.9)	15.5 (±0.9)	*M01* (n=10)
			20.0 (±1.2)	21.7 (±2.1)	19.9 (±2.2)	17.1 (±2.3)	*M02* (n=10)
		L	20.7 (±1.3)	24.6 (±1.8)	17.3 (±2.5)	14.6 (±0.7)	*F01* (n=14)
			22.3 (±2.0)	24.4 (±1.6)	17.8 (±2.4)	15.9 (±1.2)	*F02* (n=15)
			19.3 (±2.7)	20.1 (±3.2)	18.6 (±2.5)	16.3 (±1.7)	*M01* (n=16)
			18.7 (±1.9)	18.5 (±2.0)	17.7 (±2.2)	15.2 (±0.8)	*M02* (n=15)

Table A6. Continuation

modal	*H*	21.6 (±1.7)	25.3 (±2.3)	23.7 (±3.0)	19.9 (±5.1)	*F01* (n=20)
		21.6 (±1.5)	27.0 (±2.2)	25.7 (±2.7)	22.1 (±3.7)	*F02* (n=17)
		18.3 (±1.9)	21.2 (±3.2)	22.1 (±3.5)	19.2 (±3.2)	*M01* (n=18)
		17.8 (±2.1)	21.7 (±1.6)	20.2 (±2.1)	18.4 (±3.2)	*M02* (n=16)
	L	21.0 (±2.2)	24.6 (±2.0)	24.3 (±2.5)	21.9 (±5.0)	*F01* (n=19)
		21.1 (±2.2)	24.6 (±1.5)	24.8 (±2.7)	22.3 (±3.7)	*F02* (n=18)
		19.8 (±1.8)	23.6 (±2.7)	22.9 (±3.3)	18.8 (±2.7)	*M01* (n=19)
		16.8 (±2.0)	19.3 (±2.8)	19.2 (±2.7)	16.8 (±1.8)	*M02* (n=20)
creaky	*H*	20.9 (±2.2)	20.5 (±3.1)	16.8 (±2.1)	15.3 (±1.8)	*F01* (n=21)
		23.1 (±1.8)	25.7 (±2.8)	17.2 (±2.1)	15.2 (±1.3)	*F02* (n=18)
		19.2 (±2.4)	20.1 (±2.8)	16.1 (±1.8)	14.9 (±0.9)	*M01* (n=20)
		18.6 (±2.6)	18.8 (±2.9)	16.6 (±1.5)	16.4 (±2.0)	*M02* (n=23)
	L	19.1 (±1.8)	17.7 (±2.0)	16.9 (±2.6)	16.3 (±1.9)	*F01* (n=27)
		20.5 (±1.9)	20.1 (±2.9)	18.7 (±2.7)	17.7 (±2.7)	*F02* (n=27)
		18.9 (±2.2)	19.5 (±3.2)	16.7 (±2.2)	15.1 (±0.9)	*M01* (n=23)
		16.7 (±1.7)	17.2 (±2.3)	16.8 (±2.1)	16.0 (±1.6)	*M02* (n=23)