THE PHONETICS AND PHONOLOGY OF LHEIDLI INTERVOCALIC CONSONANTS

by

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I hereby certify that I have read this dissertation prepared under my direction and recommend that it be accepted as fulfilling the dissertation requirement.

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DEDICATION

To my family and friends, and to the Lorax.

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ABSTRACT

This dissertation explores the phonetics and phonology of intervocalic consonants in Lheidli, a dialect of Dakelh (Carrier) Athapaskan spoken in the interior of British Columbia. Through a series of studies on Lheidli, I show quantitatively what has previously been noted impressionistically in the Athapaskan literature: intervocalic consonants are remarkably long.

The implication of these consonants for the structure of Lheidli is approached from two perspectives. First, I investigate their role from a purely phonetic approach, focusing on their effect on the perceived rhythmic structure of Lheidli. I propose a new model of rhythm, the Enhancement/Inhibition model, in which the perception of rhythm is created by the interplay between primary and secondary correlates of rhythm. Within the proposed model, the Lheidli data show that one of the important secondary correlates is inherent segmental duration, an element that has not yet been considered in the literature.

Second, I investigate the role of intervocalic consonants from a phonological approach, focusing on their effect on syllabification. I present the results of a series of studies on the distribution of vowel duration and quality, the distribution of consonant duration, native speaker syllabification intuitions, and the interaction between stress placement and intervocalic consonant duration. Together these studies lead me to analyze Lheidli intervocalic consonants as non-contrastive, moraic geminates.

I conclude by discussing the implications of the Lheidli data for phonetic and phonological theory. I argue the duration of intervocalic consonants is encoded in the

Lheidli grammar as part of the language-specific phonetics. Furthermore, because this duration interacts with syllabification, it is encoded in the phonology as weight. Although in Lheidli the phonetic duration of intervocalic consonants is encoded in the phonology as well as the grammar, I propose that not all language-specific phonetic properties are specified in the grammar. This is the case for rhythm, for example, which is an effect of other phonetic and phonological factors of the language rather than being a linguistic primitive itself.

She lunched on papaya poo poo or mango mu mu or some other fruity foo foo bursting with overripe tropical vowels. In hot climates, *A* provides a shady arch, *O* is a siphon through which to suck liquids, *U* a cool cave or tub to slide into; *A* stands like a surfer with its legs apart, *O* hangs like a citrus from a bough, *U* rolls its hula hips - and *I* and *E* mimic the cries of monkeys and jungle birds from which they were derived. Consonants, like fair-skinned men, do not thrive in torrid zones. Vowels are built for the southern comfort, consonants for northern speed. But O how the natives do bOOgIE-wOOgIE while the planters WaLTZ.

Tom Robbins, *Still life with woodpecker (p.79)*

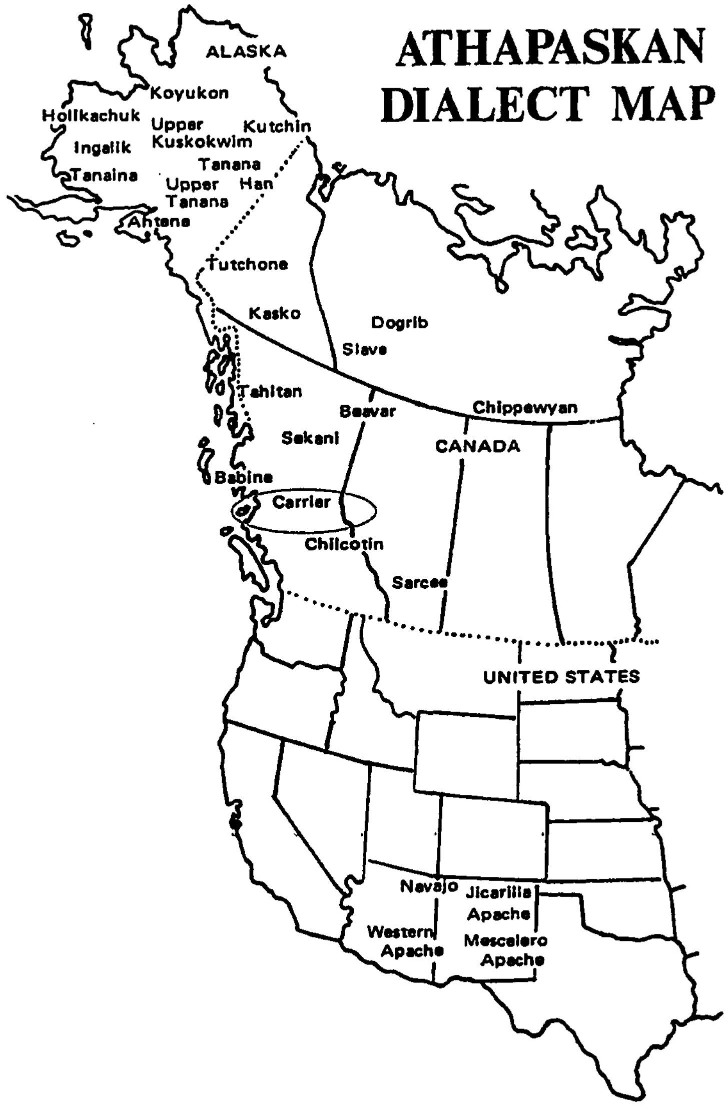

Figure 1 Athapaskan Language Map, taken from Antoine (1974)

CHAPTER 1 INTRODUCTION

The goal of this dissertation is to explore the nature of intervocalic consonants in Lheidli and, through analyses of the phonetic and phonological properties of Lheidli intervocalic consonants, to gain a better undsertanding of the relationship between the phonetics and phonology in language.

I start by investigating the phonetic nature of intervocalic consonants, and go on to discuss their implications for the structure of Lheidli. From a phonetic perspective, I argue that these consonants play a crucial role in establishing the perception of rhythm in Lheidli. From a phonological perspective, I propose that intervocalic consonants are non-contrastive, moraic geminates which behave as coda consonants to the preceding syllable as well as onsets to the following one. Merging the phonetic and phonological analyses of Lheidli intervocalic consonants, I propose that the remarkable duration of intervocalic consonants in Lheidli must be encoded in the grammar as part of language-specific phonetics, as well as being encoded in the phonology as weight. In contrast to this, the rhythm of Lheidli - another phonetic property of this language - need not be encoded at all since it falls out from other phonetic and phonological properties of the language, including segmental duration.

In this chapter I begin by presenting the reader with an overview of the Lheidli language, and an introduction to the unusual length of its intervocalic consonants (1.1). I then provide a discussion of the notions *phonetics*, *grammar*, and *phonology* - notions that are relevant throughout this dissertation (1.2). I continue with an introduction of the primary topics covered this dissertation (1.3), and of the research methodology used in studies throughout this dissertation (1.4). Finally, I outline the general organization of the dissertation (1.5).

1.1 Lheidli language background

This dissertation is based on data collected in the summers of 2000 and 2001 with one of the last four speakers of Lheidli, a dialect of Dakelh (Carrier) spoken in the Prince George area, in British Columbia, Canada. In this section, I introduce the Lheidli language, and provide the reader with a first glimpse of the sounds which form the focus of my doctoral work: intervocalic consonants.

1.1.1 The language situation

Lheidli is a dialect of Dakelh (Carrier), an Athapaskan language spoken in the central interior of British Columbia, Canada. Although *Carrier* is sometimes used to talk about both Dakelh and the Bukley Valley Lake District language (BVLD), it is now accepted that these are two separate - though closely related - languages. Dakelh consists of several dialects, which are more or less closely related. The following tree illustrates the hierarchical relationships between the various dialects of Dakelh, and between Dakelh and BVLD[1].

[1] This tree is taken from the Yinka Dene Language Institute (YDLI) website (YDLI, 2002).

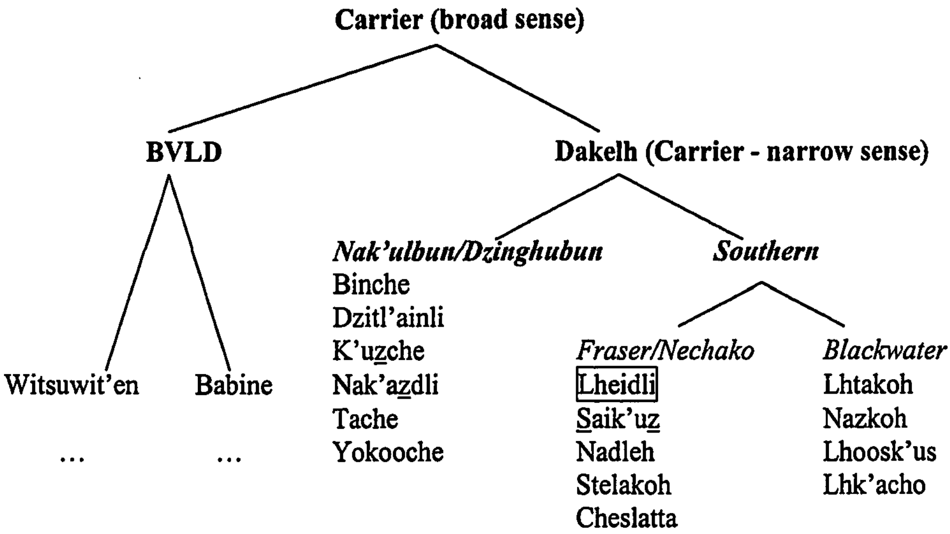

Figure 1.1 The Carrier languages

Like most native languages of North America, Dakelh is rapidly being lost. In total, there are approximately 1,000 speakers of Dakelh, but many of the dialects are at present spoken by only a handful of elders.

Lheidli, the dialect of Dakelh considered in this dissertation, is spoken around the area of Prince George. At present, there are under five fluent speakers, and approximately 10 semi-fluent speakers. Hardly any written material exists for this dialect, and only recently has there been a push to document it. The situation of Lheidli - and Dakelh - is typical of languages spoken in British Columbia, and more generally across North America. Its rapid decline is rooted in a trend towards the loss of multi-culturalism and multi-lingualism, of which governement-run residential (boarding) schools were the first manifestation. Very few children who attended residential schools retained enough knowledge of their heritage language to teach it to their children. Thus, within only two generations many languages were almost entirely wiped out.

My work on Lheidli will contribute to the field of linguistics by presenting new data bearing on current phonetic and phonological theory. My hope is that it will also contribute to the preservation of Lheidli, and more generally increase awareness of endangered languages in North America.

1.1.2 Lheidli intervocalic consonants

One of the most striking features of the (intervocalic) consonants in Lheidli - and in Athapaskan languages in general - is their unusually long duration. The following waveform illustrates the relative length of different segments in Lheidli.

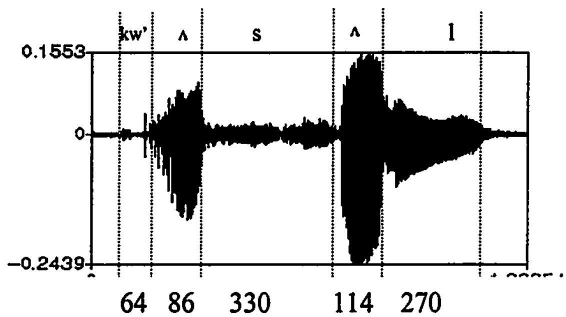

Figure 1.2 Waveform of *kw'ùsul* [k^{w}'ʌsʌl] ('beads').
Durations are in milliseconds.

The first thing to notice is the duration of /s/ (330 ms) relative to the length of its surrounding vowels (86 ms and 114 ms): /s/ is between 2 and 3 times longer than the vowels. This is typical of Athabaskan languages, and very different from languages like English, in which the vowels constitute a much larger proportion of words. As a comparison, Figure 1.3 gives the waveform of English 'bustle'. Whereas /s/ is 3.8 times longer than the preceding vowel in Lheidli 'kw'usul' (Figure 1.2), it is only 1.6 times longer than the preceding vowel in English 'bustle' (Figure 1.3).

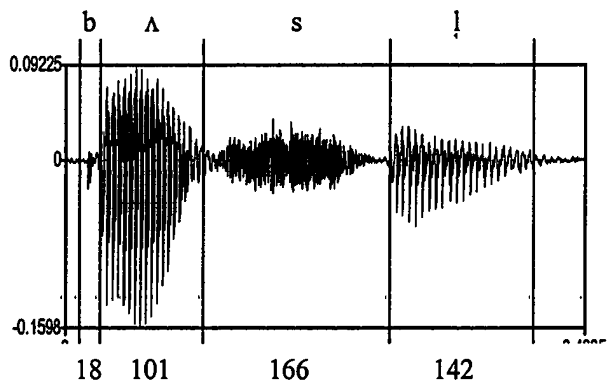

Figure 1.3 Waveform of *bustle* [bʌsl̩].
Durations are in milliseconds.

The second thing to note about the Lheidli words *kw'usul* (Figure 1.2) is the difference in length between the /s/ on the one hand, and /kw'/ on the other. The duration of intervocalic consonants, and the variability in the duration of consonants in different positions form the focus of this dissertation. Lheidli intervocalic consonants are of particular interest because of their implications for phonetic (rhythm) and phonological (syllabification) timing in Lheidli, and consequently of other Athapaskan languages.

1.2 Phonetics, grammar, and phonology

Before introducing the topics covered in this dissertation, I start by defining the terms *phonetic*, *grammatical*, and *phonological*. These terms appear throughout Chapters 3 through 6, and understanding the distinctions between them is crucial to following the main ideas presented in this dissertation. Let us start with the term *phonetic*.

Phonetic

> A phonetic property is a property of the acoustic signal or of the patterns of articulation involved in speech[2].

For example, segmental duration is considered a phonetic property, because it is phonetically measurable from the acoustic signal. Other phonetic properties include the fluctuations in pitch and amplitude related to prominence, and fluctuations in sonority related consonant-vowel alternations (the CV alternation corresponds in the acoustic signal to the alternation between low and high amplitude segments of the waveform - see Galves et al. (2002) for details). All of these properties are measurable on the acoustic signal, using speech analysis software.

[2] I will not discuss articulation further in this dissertation, but rather focus on the acoustic signal.

Grammatical

A grammatical property is a language-specific property, i.e. a property which a speaker must know in order to speak that language.

Systematic differences between languages are encoded in the grammar, since they are what make languages distinct. Following recent literature on phonetic knowledge, I argue that language-specific phonetics is encoded in the grammar (Keating, 1985, Pierrehumbert and Beckman, 1988, Kingston and Diehl, 1994, Cohn, 1998, etc.). For example, inherent segmental duration is encoded in the grammar: one of the reasons we know Lheidli is Lheidli and not English is because of its long consonants. Another phonetic feature encoded in the grammar is the realization in stress. Languages differ in how they realize stress: through manipulations of pitch, of amplitude, of duration, or of a combination of all three. For this reason, how a particular language realizes stress must be encoded in the grammar[3].

Phonological

A phonological property is a language-specific (grammatical) property, which affects other sounds and sound patterns within a particular language.

[3] The precise location in which phonetic information is encoded within the grammar is not discussed further here. What is important is that this location is separate from that of 'phonology', defined below.

For example, syllable structure is a phonological property in that it affects the manner in which consonants and vowels can alternate. A language allowing CV syllables will have very different *consonant-vowel* sequences than one allowing CV, CVC, CCCVCCC, etc. Furthermore, the syllable structure of a language determines in part how the language deals with unsyllabifiable strings (through epenthesis vs. deletion, for example).

The distinction between the grammatical and phonological components of language involves the role that these components play within languages. I propose that elements of phonetic implementation which differ across languages, but which do not play an active role within a language, are in the grammar but not the phonology. Take for example voice onset time (VOT) in French and English[4]. Both languages use VOT contrastively, to distinguish between two sets of stops, transcribed as /p t k/ and /b d g/. In French, the two sets of stops correspond to 'prevoiced' vs. 'voiceless unaspirated'. In English, the two sets correspond to 'voiceless unaspirated' vs. 'voiceless aspirated'. The VOT boundary between the two sets of stops is much lower in French than in English (Ladefoged, 2001, p.128):

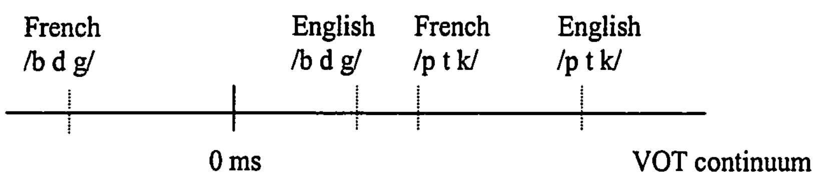

Figure 1.4 VOT in French vs. English

[4] Voice across languages is discussed in Keating (1984), Kingston and Diehl (1994).

Although English and French differ in the placement of the VOT boundary which distinguishes /p t k/ from /b d g/, within each language these sounds are used in the same way. Because the phonetic implementation of these sounds differs in English and French, it must be encoded in the grammar. More specifically, the placement of the VOT boundary must be in the grammar. However, because these sounds behave the same phonologically within each language, the placement of the VOT boundary need not be encoded in the phonology of each language.

Inherent consonantal duration (in Lheidli) differs from VOT in that it plays an active role within the phonology of Lheidli (see section 1.3.3 below). As we shall see in Chapter 5, phonetic duration interacts with constraints on syllable well-formedness (albeit indirectly through phonological weight): long consonants can only occur intervocalically, and must belong to both preceding and following syllables. If long consonants could occur in any position in Lheidli, and had no effect on syllabification (i.e. were syllabified as simple onsets), they would not have to be encoded in the phonology[5]. Because Lheidli's long consonants interact with syllable structure, I argue that their inherent duration must be encoded in the phonology of Lheidli as well as in its grammar.

While some properties of a language's sound system are encoded in the grammar, and others in the phonology, I propose that some properties are not encoded anywhere, but simply fall out from other facts of the language. This is the case for rhythm, for

[5] They would still be encoded in the grammar, since their duration differs from consonants in other languages.

example. In Chapter 4, I argue that rhythm is not a primitive property of language: there is no stipulated rule, or constraint, which specifies what the rhythm should be in language. Rather, rhythm is a phonetic pattern in language that results from other specified properties: presence vs. absence of alternating stresses, segmental duration, syllable complexity, etc. Rhythm is a function of both non-phonological (phonetic) and phonological elements. This is perhaps why it has been so hard thus far to pinpoint its nature.

The following diagram illustrates the relationship between phonetics, phonology, and grammar, as it is understood in this dissertation. Of the phonetic properties of language, some are grammatical (grammatical $\subset$ phonetic). Of the grammatical properties, some are phonological (phonological $\subset$ grammatical).

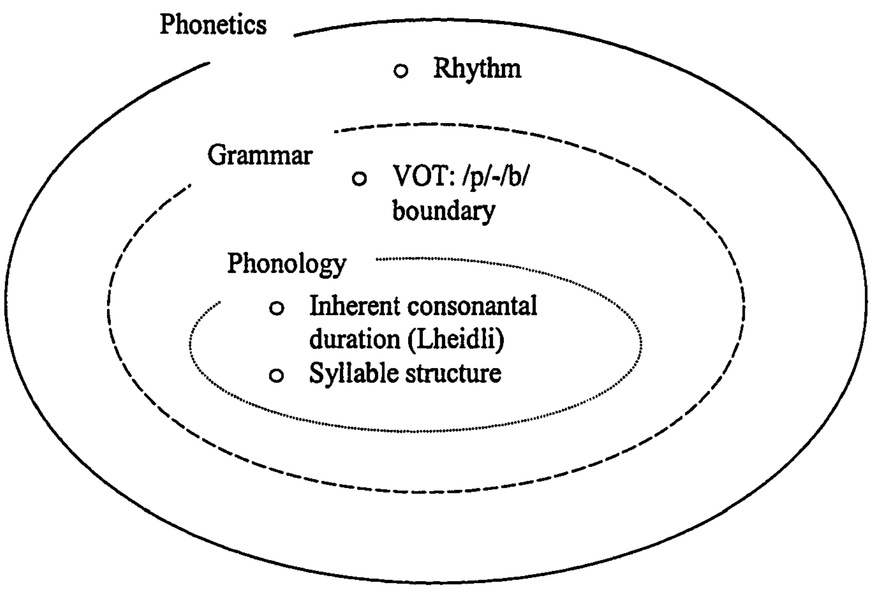

Figure 1.5 Phonetics, grammar, and phonology in language

Figure 1.5 assumes that all phonology falls within the realm of phonetics - an issue that deserves some discussion here. It is arguably the case that phonology sometimes distinguishes between forms with different formal representations, but for which the phonetic implementation is the same. For example, take trisyllabic strings with only one stress, such as in the word *Canada* [ˈkænʌdʌ]. There are at least two possible ways of assigning foot structure to this word: (a) (ˈCa.na)(da), or (b) (ˈCa.na)da. In (a), the word ends in a degenerate foot, i.e. a foot containing only one light syllable - (da) (Hayes, 1995). In (b), the word ends with an extrametrical syllable - da (Hayes, 1995). Within Optimality Theory (McCarthy and Prince, 1993, Prince and Smolensky, 1993), the winning candidate will be a function of the relative ranking of a constraint banning degenerate feet (e.g. FTBIN) and a constraint banning unfooted syllables (e.g. PARSESYLL).

Although forms (a) and (b) differ formally in terms of foot structure, it is not clear that this difference has any effect on the phonetic implementation of these forms. This is one case in which phonological structure does not fall within the realm of phonetics, i.e. it is not implemented phonetically. Given this example, perhaps a better representation of the relationship between phonetics, phonology, and grammar is Figure 1.6:

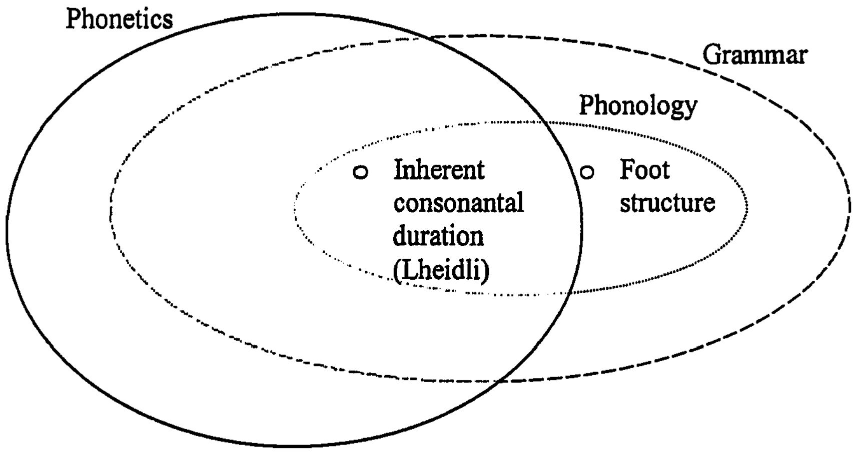

Figure 1.6 Phonetics, grammar, and phonology in language - alternative approach

I leave open the question of whether all phonology falls within the realm of phonetics or not, i.e whether the relationship between phonetics, phonology, and grammar is best represented by Figure 1.5 or 1.6. In this dissertation, the focus is on the elements of phonology which do fall within the realm of phonetics, illustrated by Figure 1.5 and the shaded area of Figure 1.6.

The distinction between phonetic, grammatical, and phonological properties is made throughout this dissertation, and discussed in detail in Chapter 6. These properties reflect different levels of linguistic knowledge corresponding to the domains of phonetics, grammar, and phonology. Table 1.1 summarizes the topics covered in this dissertation and the levels of linguistic knowledge involved in each topic (phonetics, grammar, phonology).

Table 1.1 Topics covered and linguistic property involved

Chapter	*Topic covered*	*Level of linguistic knowledge involved*
2	Lheidli sounds, syllables, and stress	Phonology
3	Lheidli intervocalic consonants (durational properties)	Phonetics Grammar
4	Rhythm (in Lheidli and other languages)	Phonetics
5	Syllabification of intervocalic consonants in Lheidli	Grammar Phonology
6	Phonetics - Phonology interface	Phonetics Grammar Phonology

1.3 Research questions and background literature

In sections 1.3.1 through 1.3.4, I outline the 4 main topics which will be covered in this dissertation: the nature of Lheidli intervocalic consonants (1.3.1), their phonetic and phonological implications (1.3.2 and 1.3.3), and the relationship between phonetics and phonology, with respect to Lheidli intervocalic consonants (1.3.4). Since each topic involves a different body of background literature, this literature is presented in detail in the relevant chapters (3, 4, 5, and 6 respectively). In this chapter, I limit the discussion of the literature to a brief overview for each topic.

Sections 1.3.1 through 1.3.4 correspond to Chapters 3 through 6 respectively. Chapter 2 consists of a general introduction to Lheidli phonology. In this chapter I discuss (a) the vowel and consonant inventories, (b) the basic syllabification, and (c) the stress system. Chapter 2 provides the reader with an overview of Lheidli phonology, which serves as background information for Chapters 3 - 6. Furthermore, it provides the

Lheidli community with written documentation of the sounds and sound patterns of their language.

1.3.1 The phonetic nature of Lheidli intervocalic consonants

The unusual length of intervocalic consonants has been noted for other Athapaskan languages, primarily Navajo. Sapir and Hoijer (1967) and Young and Morgan (1987) have both commented on Navajo intervocalic consonants, referring to "consonant lengthening" and "consonant doubling" respectively. However, these sounds have not yet been studied phonetically in any detail. Therefore, I begin the discussion of intervocalic consonants (Chapter 3) with an in-depth analysis of their durational properties, since they are characteristic not only of Lheidli, but of Athapaskan languages in general. In this chapter, I show experimentally what has been previously been noted impressionistically: intervocalic consonants are indeed extremely long with respect to (a) consonants in other positions, (b) their surrounding vowels, and (c) consonants in other languages. In comparing the duration of Lheidli intervocalic consonants to that of consonants in other languages, I conclude that their duration constitutes a phonetic property that is language-specific and therefore must be encoded in the grammar of Lheidli.

It is important to note that throughout the discussion of Lheidli's intervocalic consonants in Chapter 3, no assumptions are made regarding the phonological representation of intervocalic consonants. Determining how to best characterize them formally (as ambisyllabic consonants, as geminates, or as simple onset consonants with a unique phonetic implementation) is undertaken in Chapter 5.

1.3.2 The contribution of intervocalic consonants to rhythm in Lheidli

Having presented the phonetic nature of intervocalic consonants (focusing on duration), I go on in Chapter 4 to their effect on the perceived rhythm of the language. This chapter is based on a large body of literature on rhythm in language, which is outlined below and discussed in detail in Chapter 4.

Traditionally, languages are said to fall into rhythm classes, which are based on isochronous (recurring regularly) units of speech (Pike, 1945, Abercrombie, 1965, 1967). In stress-timed languages, the isochronous unit is the foot, in syllable-timed languages it is the syllable, and in mora-timed languages it is the mora. Recent literature has shown very little evidence for isochrony in speech, and as a result a push has begun to determine the phonetic and phonological factors which lead to the perception of rhythm in language (Roach, 1982, Dauer, 1983, 1987, Miller, 1984, Nespor, 1990, Ramus et al., 1999, Galves et al., 2002, Grabe and Low, in press). The work on Lheidli presented in Chapter 4 is based primarily on Ramus et al's (1999) work on durational correlates to rhythm classes.

Ramus et al. propose that perceived rhythm is a function of the following primitives: (a) %V: the percentage of the duration of vocalic material in an utterance, relative to the duration of the whole utterance, and (b) ΔC: the variation in the duration of consonantal intervals within an utterance. Ramus et al. assume that %V and ΔC are related to syllable structure: languages which allow only CV syllables will tend to have a higher %V and lower ΔC, since the amount of consonantal material will not vary much (there will always be at most one C for every V). Languages with more complex syllable structure will tend to have a lower %V, since syllables may contain coda consonants and clusters. Furthermore, languages allowing complex syllables will have a higher ΔC, the variability resulting from the bigger range of possible syllables in terms of how much consonantal material they contain (singletons vs. clusters).

When plotted according to %V and ΔC, the languages studied by Ramus et al. fall naturally into clusters (though Ramus et al. claim they don't have to). These clusters correspond to the traditional rhythm classes: English, Dutch and Polish form one group (stress-timed languages), Spanish, Italian, French and Catalan form a second group (syllable-timed). Japanese is isolated from the other groups, reflecting its status as mora-timed. The traditional rhythm classes correspond to the following %V and ΔC values:

(1) Language classification according to %V and ΔC

a. high %V and low ΔC: mora-timed

b. low %V and high ΔC: stress-timed

c. moderate %V and ΔC: syllable-timed

The Lheidli data presented in Chapter 4 provide a reaction to Ramus et al.'s model of rhythm, and illustrate two shortcomings of this model. First, the data show that Ramus et al.'s %V and ΔC are not solely a function of syllable complexity. Indeed, Lheidli has a very low %V and a very high ΔC, even though its syllable structure is relatively simple. Therefore, %V and ΔC must be a function of several properties of the language, of which syllable structure is only one. In Lheidli, the unusual values for %V and ΔC result from inherent segmental (consonantal) duration rather than syllable complexity.

The second shortcoming of Ramus et al.'s model involves its placement of languages like Lheidli on the rhythm continuum. Lheidli falls at the extreme stress-timed end of Ramus et al.'s rhythm continuum. However, it cannot be a stress-timed language, since it does not have alternating stresses (discussed in Chapter 2). Based on this finding, I argue that Ramus et al.'s %V and ΔC are not sufficient parameters for placing languages along the rhythm continuum. I propose a new model of rhythm - the Enhancement/Inhibition model, which includes Ramus et al's %V and ΔC among a larger set of correlates of rhythm. Within this model, rhythm is the result of the interplay between primary and secondary correlates of rhythm. The primary correlate of rhythm consists of alternating stresses in languages which have them, and syllables otherwise. Secondary correlates of rhythm are other phonetic and phonological facts of language which either enhance or inhibit the salience of the primary correlate.

This model is supported by the Lheidli data, which show that segmental duration is one of the secondary correlates of rhythm. Other secondary correlates include ambisyllabicity, lexical stress, pitch, amplitude, sonority, syllable complexity, vowel reduction, contrastive duration, etc. The model solves the problem mentioned above with Ramus et al's model regarding the placement of Lheidli at the stress-timed extreme of the rhythm continuum. Within the Enhancement/Inhibition model, Ramus et al.'s %V and

ΔC are taken as two of many secondary correlates to rhythm. It is their combination with other secondary correlates, and with the absence of alternating stress, that place Lheidli in a different space from both stress-timed and syllable-timed languages.

Within this model, rhythm falls out naturally from other phonetic and phonological properties of language. For this reason, it need not be encoded in the grammar (or in the phonology). Rhythm therefore provides an example of a pattern in language that is not specified in any domain of linguistic knowledge.

1.3.3 The phonological role of Lheidli intervocalic consonants

The third topic covered in this dissertation (Chapter 5) is the phonological role of intervocalic consonants, i.e. what effect they have on syllabification and how they should be represented formally. I begin this chapter by reporting on a series of experiments involving (a) vowel durations and distributions, (b) consonant distributions, (c) native speaker intuitions, and (d) the effect of stress on the duration of intervocalic consonants. Results of these experiments show that intervocalic consonants belong to both the preceding syllable (as codas) and the following syllable (as onsets). Having established that intervocalic consonants are syllabified as codas as well as onsets (5.1 - 5.4), I go on to a discussion of their formal representation (5.5). Based on their phonetic duration and on their syllabification, I argue that Lheidli intervocalic consonants are non-contrastive geminates. Intervocalic consonants are not simply unusually long onsets, but rather are syllabified as part of both preceding and following syllables. For this reason, I argue that segmental duration in Lheidli is a phonological property: phonetic duration is mirrored in the phonology as weight, which is associated to the coda position.

The primary theoretical contribution of Chapter 5 is in clarifying the difference between the terms 'ambisyllabic' and 'geminate', as used both descriptively and formally. Descriptively, these two terms are used in reference to different phenomena. The term 'ambisyllabic' is generally used in discussions of syllable structure, to indicate than an intervocalic consonant belongs to both the preceding and the following syllable (Kahn, 1976, Borowsky et al., 1984, Hammond, 1999, Jensen, 2000). The term 'geminate' is generally used in discussions of consonant duration. More specifically, it refers to (phonetically) long consonants, when they contrast with short ones (Pickett and Decker, 1960, Lahiri and Hankamer, 1988, Giovanardi and di Benedetto, 1998, Aoyama, 2000, Kraehenmann, 2001).

Table 1.2 Descriptive terms and their uses

Descriptive term	*Context of use*
Ambisyllabic	Syllable structure
Geminate	Consonant duration

In sections 5.1 - 5.4, in which the syllabification of Lheidli intervocalic consonants is explored, I refer to intervocalic consonants as 'ambisyllabic' (in the descriptive sense) to indicate that they belong to both the preceding and following syllable. The reason 'ambisyllabic' is used rather than 'geminate' is because in all of the studies reported in sections 5.1 - 5.4, the focus is on the syllabic role of intervocalic consonants rather than on their duration (which is discussed in Chapter 3). The definition I assume for 'ambisyllabic', in the descriptive sense of the term, is given below:

> *Ambisyllabic (descriptive definition)*
>
> The property of intervocalic consonants whereby they belong both to the preceding syllable and the following syllable.

Having ascertained in sections 5.1 - 5.4 that Lheidli intervocalic consonants are descriptively ambisyllabic, I then move to a discussion of which formal term - ambisyllabic or geminate - best characterizes these consonants (section 5.5). In this section I tie together the discussions of their remarkable duration (Chapter 3) and their syllabification (sections 5.1 - 5.4).

Researchers differ in how they formalize the difference between ambisyllabic consonants and geminates (Kahn, 1976, Borowsky, 1984, Hayes, 1989, Tranel, 1991, Hume, 1997a, 1997b, Davis, 1999, Jensen, 2000). Borowsky et al. (1984) argue that ambisyllabic consonants and geminates are the formally identical. They differ only in phonetic implementation. Others provide different structures for ambisyllabic and geminate consonants (Hammond, 1999, Jensen, 2000). The literature on ambisyllabicity and gemination is discussed in detail in Chapter 5, section 5.5. Based on this literature, I take the difference between ambisyllabic and geminate consonants to be in terms of phonological weight[6]. Both ambisyllabic and geminate consonants belong to the preceding and following syllables. They differ in that ambisyllabic consonants are not associated with extra phonological length or weight, whereas geminates are. The formal definitions I assume for 'ambisyllabic' and 'geminate' are given below.

> *Ambisyllabic (formal definition)*
>
> The formal property of intervocalic consonants whereby they behave as a non-moraic coda to the preceding syllable, as well as an onset to the following syllable.

That ambisyllabic consonants are non-moraic (in their coda position) is assumed to be reflected in the phonetics by the fact that ambisyllabic consonants are not lengthened relative to consonants in other positions (Kahn, 1976, Borowsky, 1984, Jensen, 2000). These are contrasted with geminate consonants, which are associated with an extra mora in the coda position:

[6] Or possibly phonological length (rather than weight). The difference between phonological length and weight is discussed in Chapter 5, section 5.5. See also Hume et al. (1997a, 1997b) and Tranel (1991).

Geminate (formal definition)

The formal property of intervocalic consonants whereby they behave as a coda to the preceding syllable, as well as an onset to the following syllable, and whereby they are associated to extra phonological weight.

Geminates differ from ambisyllabic consonants only in that they provide a mora to the preceding syllable. This is reflected in the phonetics by the fact that, unlike ambisyllabic consonants, geminates are lengthened relative to their singleton counterparts.

Table 1.3 Formal terms and their defining property

Formal term	*Defining property*
Ambisyllabic	Not associated with phonological length or weight
Geminate	Associated with phonological length and/or weight

Because Lheidli intervocalic consonants are extremely long (Chapter 3) and belong to both preceding and following syllables (Chapter 5, sections 5.1 - 5.4), I argue that formally these are geminates. More specifically, they are non-contrastive, moraic geminates; non-contrastive because they do not contrast with singletons, and moraic because they occur only in positions licensing morae. This last property 'moraic', is contrasted to phonologically long, non-moraic geminates, which are said to occur in Selkup (Tranel, 1991) and Leti (Hume et al. 1997a, 1997b). Non-moraic geminates are said to be phonologically long, i.e. associated with two X-slots (Kaye and Lowenstamm, 1984, Levin, 1985), even though they are not heavy (moraic).

1.3.4 Lheidli and the phonetics/phonology interface

I conclude this dissertation with an investigation of the phonetics-phonology interface, as exhibited in Lheidli (Chapter 6). More specifically, I weave together the phonetic and phonological properties of Lheidli intervocalic consonants and their effects on phonetic timing (rhythm) and phonological timing (syllable structure). The contribution of this last chapter is in enriching our understanding of the interaction between phonetics and phonology, as well as our understanding of where various pieces of linguistic information are encoded.

We shall see that in Lheidli, inherent consonantal duration must be encoded in the grammar as part of a native speaker's phonetic knowledge (Kingston and Diehl, 1994). Furthermore, inherent consonantal duration is mirrored in the phonology as weight.

Whereas inherent consonantal duration is encoded in the grammar of Lheidli - more specifically in its phonology - I argue that not all properties of Lheidli (or any language) must be specified in the grammar. Rhythm, for example, need not be specified in the phonology (or, more generally, in the grammar), because it falls out from other properties of the language.

1.4 General methodology

In the following chapters, analyses of vowel and consonant durations are analyzed and compared across various conditions. The methodology for eliciting and analyzing speech was the same across all studies, as was the set of words used for analysis. For this reason, a general methodology section is included here in which I outline the overall research question (1.4.1), the subject (1.4.2), the materials (1.4.3), the methodology used in segmenting the speech (1.4.4), and the overall predictions (1.4.5). The statistical tests used vary from study to study, and for this reason are not discussed here, but rather in the relevant sections of subsequent chapters.

1.4.1 Overall research question

The overall goal of the studies reported in the following chapters is to investigate the duration and syllabic role of intervocalic consonants. This is achieved through a series of studies relating to different aspects of the nature of intervocalic consonants and their surrounding vowels. Chapter 3 focuses on their durational properties. The studies reported on in Chapter 3 therefore compare durations of various segments: (a) Lheidli consonants across positions, (b) Lheidli intervocalic consonants and vowels, and (c) consonants in Lheidli vs. in other languages. Chapter 5 focuses on the role in syllabification of intervocalic consonants, which is investigated through several studies exclusively on Lheidli sounds: (a) the duration and distribution of vowels, (b) the distribution of consonants, (c) the syllabification intuitions of a native Lheidli speaker, and finally (d) the distribution of long intervocalic consonants with respect to stress placement. All of these studies involve the same basic methodology, which is outlined in the following sections.

1.4.2 Subject

Data for this dissertation were collected in the field in the summers of 2000 and 2001 from one of the four remaining speakers of the Lheidli dialect of Dakelh. The speaker is female, over 75 years old, and is also a fluent speaker of English.

1.4.3 Materials

The data used in all of the studies reported in subsequent chapters consists of a set of 342 bisyllabic words, each exhibiting one of four different types of syllable structure (the only possible types in Lheidli)[7]:

Table 1.4 Syllable types in Lheidli bisyllabic words

Syllable type	*Example*	*IPA*	*English*
a. (C)V.CV	dune	[dʌne]	man
b. (C)V.CVC	nawus	[nawʌs]	soap berry
c. (C)VC.CV	bunda	[bʌnda]	morning
d. (C)VC.CVC	gombilh	[gombɪɬ]	rabbit snare

The first word type (a) has two open syllables[8]; the second (b) has an open first syllable and a closed second syllable; the third (c) has a closed first syllable and open second syllable; and the fourth (d) has two closed syllables. Only bisyllabic words were used in order to control for word length effects. The four different word types listed in Table 1.4 were chosen for comparing vowels and consonants in closed vs. open syllables in non-

[7] Please see Appendix A for the complete word list used.

[8] We shall see that word-medial open syllables do not in fact exist, as intervocalic consonants close the preceding syllable. 'Open' is used here to refer to these syllables since, prior to investigation, they are assumed to be open given universal syllabification rules (Itô, 1986).

final (initial) position (CV.CV(C) vs. CVC.CV(C), as well as in final position (CV(C).CV vs. CV(C).CVC).

These data form a subset of a larger database of words recorded with the purpose of determining the nature of Lheidli sounds in various phonological and morphological contexts. For example, one list focused on words borrowed from French, another focused on morphologically complex words, another on words contrasting word-final vowels with word-final *vowel-[h]* sequences, etc. Although the original database was comprised of word lists designed to study specific phenomena, it constitutes a resource which can be used for many purposes. In this case, I extracted all of the bisyllabic words and compiled them into a new dataset. Because of this, the words were not controlled for number of items in various conditions of each study. For example, a total of 217 words analyzed had final codas (…CVC#) compared to 125 which did not (…CV#). This means that in a study of the effect of position on vowel duration (see section 5.1.1), there was an uneven number of items in the two 'word-final' conditions: open (V# - 125 items) vs. closed (VC# - 217 items). Words were also not controlled for segmental content. These two issues deserve some discussion here.

1.4.3.1 Number of items used

The number of words analyzed depended on the specific study. In total, recordings were made of 402 bisyllabic words. Each recording consisted of 3 repetitions of the word in question. Only the second repetition was used for analysis, in order to avoid any list effect. Of the 402 recordings made, 238 were of distinct words; the rest of the items (164) were additional recordings of certain words. In order to avoid biasing the data with too many recordings of the same word, only the first and second recordings of words were analyzed. In total, there were 342 of these.

The precise number of items in each condition varied depending on the study. These numbers are therefore reported in the relevant sections of the following chapters. A common characteristic of the studies is that there were different numbers of items in each condition. Again, this is a result of using a pre-recorded set of words, something that is typical in fieldwork. Using large numbers of loosely controlled items, rather than small numbers of strictly controlled items is commonly used in computational work on large corpora. The idea is that with sufficiently larger numbers, it is not necessary to control each condition in a detailed manner. In the phonetic literature, researchers such as Campbell also adopt this approach (Campbell, 1992). In a study on timing in Japanese speech for example, Campbell compares durations across segments, where the number of tokens per segment depends on its frequency - the more common sounds having larger numbers of tokens. In a study of vowel durations, numbers vary from 1426 tokens (for /u/) to 3380 tokens (for /a/). The studies reported here involve fewer tokens than in Campbell's study. However, I follow his approach in using different numbers of tokens for different conditions, in order to include the maximum possible amount of data.

1.4.3.2 Segmental content

The words recorded and analyzed were, for the most part, not chosen for their segmental content. This means that in comparing consonant durations, for example, it was *not* the case that the environments were the same for each item (e.g. [a_a]). However, the environments varied in similar manners for each segment, and the number of items was relatively large. In all of the studies, comparability across conditions was achieved through using consistently variable data, rather than through using strictly controlled data (Campbell, 1992).

1.4.4 Method

1.4.4.1 Data collection and digitization

Word lists were elicited from the subject by having her read words from various word lists, repeating each word 3 times. Data was recorded using a Sony MZR37 mini-disk recorder[9]. Data was recorded in the dining extension of the subject's kitchen using a Sony ECM-T115 lapel microphone so as to minimize background noise such as that from the refrigerator and the clock in the kitchen. The data was digitized at a sampling rate of 22,050 Hz, and analyzed using Praat, a speech analysis program created by Paul Boersma.

1.4.4.2 Speech segmentation

Speech was segmented with reference to the waveform of each word, using a spectrogram and sound as additional references. Segment onsets and offsets were labeled, and the duration of each segment was calculated by subtracting onset time from offset

[9] It has sometimes been noted that mini-disk recorders may create problems related to compression (Maddieson, 2002). However, the problems are minimal, and are important only for very detailed phonetic analysis. For durational measurements of the type taken in the current work, compression is not a problem (Ian Maddieson, personal communication).

time. As mentioned above, only the second of the three repetitions of each recording was analyzed.

In segmenting the data, several guidelines were used. Word-initially, the onset of voiceless stops was defined as the onset of release frication; the onset of voiced stops was defined as the onset of voicing (prevoicing). With voiced stops there was sometimes an irregular pulse at the beginning of stop; this was not considered part of the stop. In the case of word-initial /l/, there was also often one irregular pulse preceding the onset of regular glottal pulses. This was not counted as part of the /l/. In some cases of word-initial /w̥/, there is a small epenthetic [u] preceding /w̥/. In these cases, [u] was considered part of the consonant. In cases where a word-initial vowel was aspirated at its onset, the aspiration was considered part of the vowel (the vowel onset was defined as the point in which aspiration began).

Word-medially, in *voiceless stop - vowel* sequences, the voiceless stop was often associated with quite a long period of aspiration, particular in the case of alveolars (Figure 1.7). Vowel onset was taken as the onset of voicing.

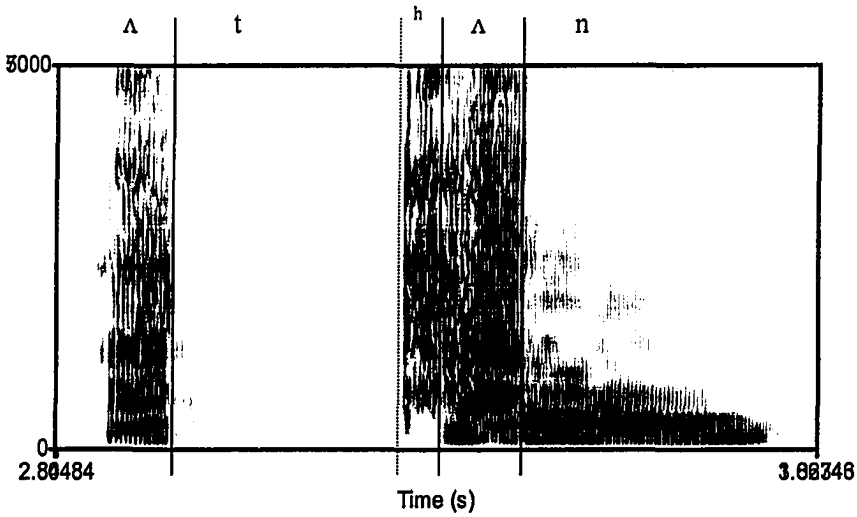

Figure 1.7 Spectrogram of *'utun* [ʔʌtʰʌn] ('freezer').
Solid lines indicate the /tʰ/ and /ʌ/ segment boundaries; the dotted line indicates the beginning of aspiration.

In *ejective - vowel* sequences, the first irregular glottal pulse leading into the vowel was considered part of the consonant. Vowel onset was taken as the onset of regular glottal pulses. In *vowel-voiced stop* sequences, there was often significant closure voicing at the beginning of the stop consonant (Figure 1.8). In such cases, the offset of the vowel was defined as the point at which the amplitude of the formants (and F0) decreased dramatically (solid line in Figure 1.8), not at the end of vibration.

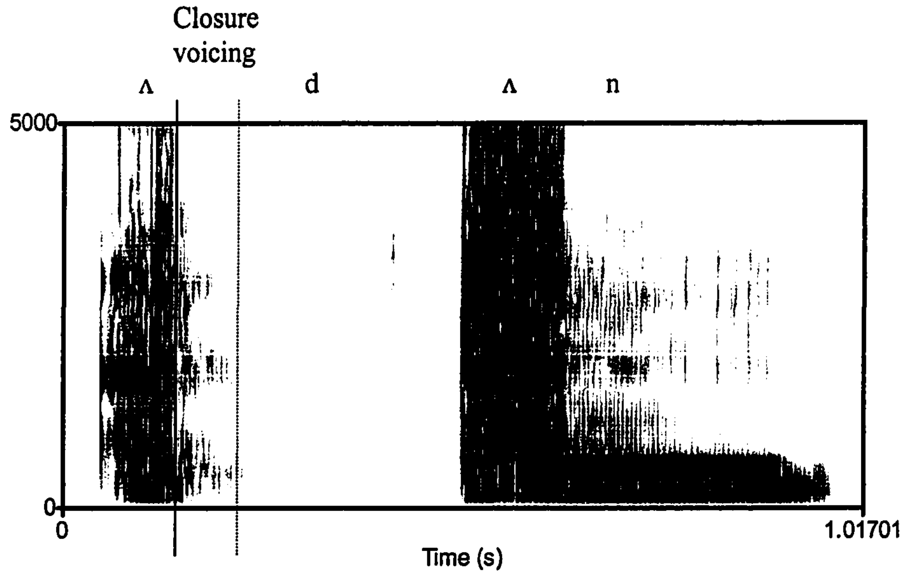

Figure 1.8 Spectrogram of *'udun* [ʔʌdʌn] ('another').
The solid line indicates the end of vowel; dotted line indicates end of closure voicing.

In *glottal stop - vowel* sequences, if there was a clear glottal release (pulse), vowel onset was taken as following the release pulse. If there was no clear release pulse, the vowel was taken to start at the onset of the signal. In /kwʌ/ and /ja/ sequences, the *w-ʌ* and *j-a* boundaries were placed at the middle point in the formant transition. In *vowel-/s/* sequences, the boundary was placed at the point where the amplitude of the signal was lowest. In *vowel-/l/* sequences, there was sometimes a period of aspiration between the two sounds ([V(h)l]). In such cases, the boundary was placed at the point where the amplitude of the signal was lowest. When there was no such aspiration, the boundary was placed at the change in formant structure. In *fricative-stop* sequences, the offset of the fricative was taken as the point where the amplitude of the fricative noise decreased dramatically. In /lhw/ and /lhy/ sequences, if there was a period of silence between the two segments, it was counted as part of /lh/ (Figure 1.9).

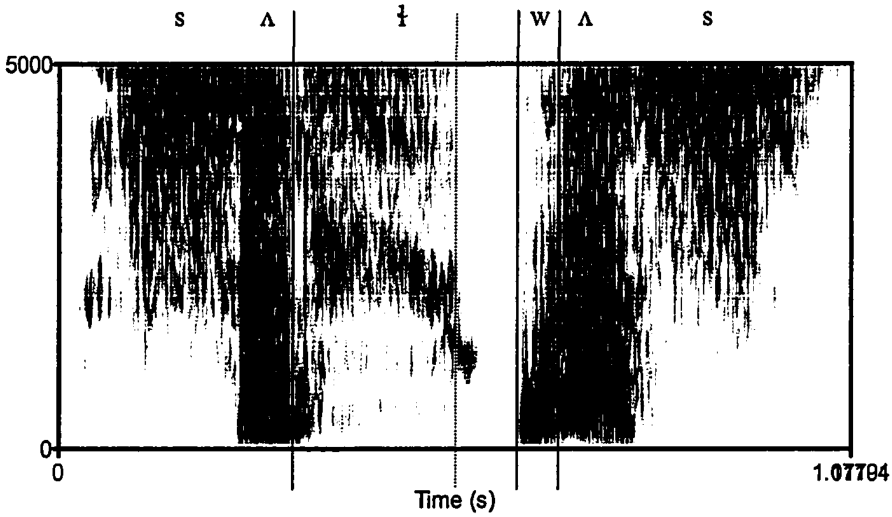

Figure 1.9 Spectrogram of *sulhwus* [sʌɬwʌs] ('he is tickling me').
Solid lines indicate /ɬ/ and /w/ segment boundaries; the dotted line indicates the period of silence between /ɬ/ and /w/.

In */h/-consonant* sequences, if there was a period of silence between the two segments, it was counted as part of /h/. In /gl/ sequences, there was an odd voiceless /l/-like release of /g/ preceding /l/. This was considered as part of /g/, which was itself generally at least partially devoiced (Figure 1.10).

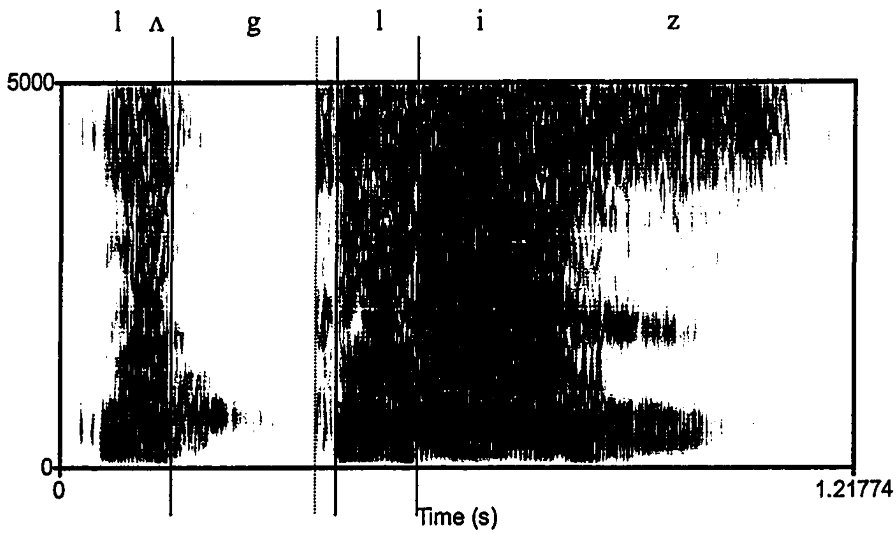

Figure 1.10 Spectrogram of *lugliz* [lʌglɪz] ('church').
Solid lines indicate /g/ and /l/ segment boundaries; the dotted line indicates the /g/ release.

In /nl/ and /sl/ sequences, there was often an epenthetic [d] between /n/ or /s/ and the /l/. It was counted as part of /l/ (Figure 1.11). In all cases, the boundary in /nl/ or /sl/ was taken as the point where the amplitude of the signal was lowest.

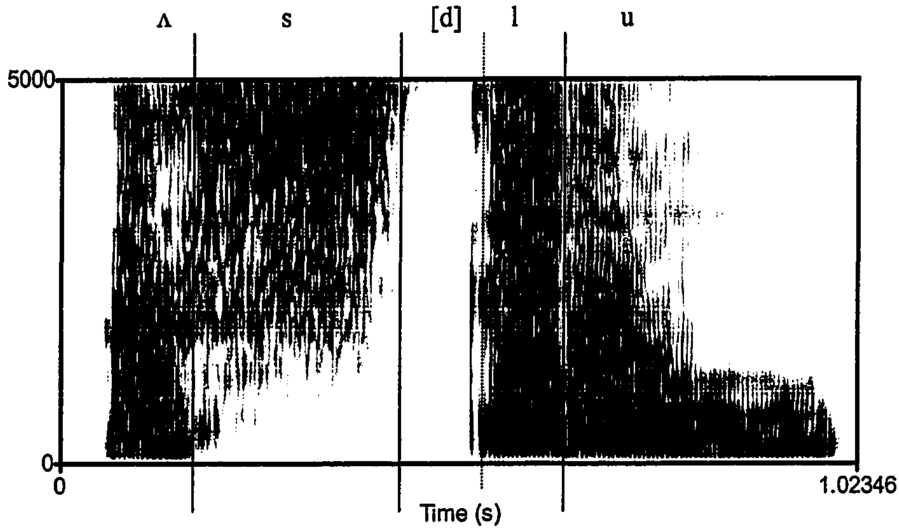

Figure 1.11 Spectrogram of *'usloo* [ʌslu] ('my mother').
Solid lines indicate /s/ and /l/ segment boundaries; the dotted line indicates the end of the epenthetic [d].

In word-final segments, the offset of the segment was taken as the point at which the formant structure disappeared (voiced segments), or the amplitude of the waveform decreased to noise level. In words ending in a vowel, word-final aspiration (devoicing) was considered part of the vowel.

Finally the acoustic distinctions between certain segments and segment sequences were sometimes difficult to make. For example, word-final [v̥] and [vh] were acoustically very similar. As for medial consonants, in some cases the spelling would indicate voicing, even though acoustically the consonants were devoiced. Figure 1.12 illustrates this with the word *stl'esja* [stl'ɛsdʒa] ('I quit'). In the Lheidli practical orthography, the letter 'j' is used to represent the sound /dʒ/. However, Figure 1.12 shows that this sound is completely voiceless in this word.

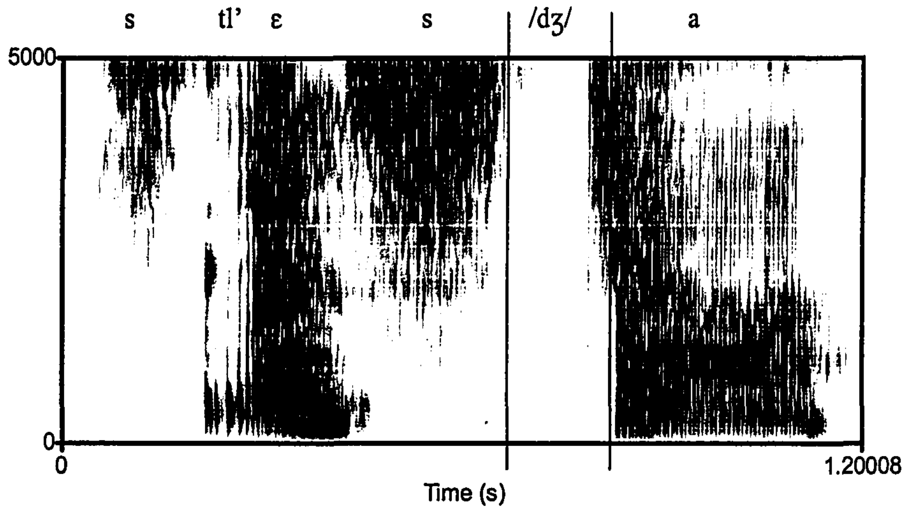

Figure 1.12 Spectrogram of *stl'esja* [stl'ɛsdʒa] ('I quit'). Solid lines indicate the boundaries of /dʒ/, which surfaces as voiceless in this word.

In all words, the labels used corresponded to those used in the transcriptions and practical orthography of Lheidli. The only time the practical orthography was not followed was in the case of missing sounds, which were omitted (in cases where the spelling of a word included a letter which did not correspond to anything in the acoustic signal).

1.4.5 Overall predictions

The predictions found throughout this dissertation vary from study to study, and are therefore discussed in the relevant sections. The starting observation, on which all studies are based, is that intervocalic consonants are extremely long, something that is auditorily obvious. The overall prediction is that this duration will be reflected in the phonetic structure (rhythm) as well as the phonological structure (syllabification) of Lheidli.

1.5 Organization of the dissertation

The general organization of this dissertation is as follows. I begin in Chapter 2 by introducing the sounds, syllables, and stress facts of Lheidli. This will serve as background information for discussion in the following sections. It will also provide the Lheidli community with written documentation on the basic phonological facts of their language.

Chapter 3 introduces the sounds which form the focus of the remainder of the dissertation: intervocalic consonants. I provide a detailed phonetic analysis of these consonants, comparing them to other sounds in Lheidli as well as to similar sounds across different languages. Based on these comparisons, I show that Lheidli intervocalic consonants are remarkably long.

Having determined the precise phonetic nature of intervocalic consonants, I go on in chapters 4 and 5 to investigate what role they play in the language. Chapter 4 investigates their phonetic role. More specifically, I look at their effect on the perceived rhythm of the language. I propose a new model of rhythm: the Enhancement/Inhibition model, in which the perception of rhythm in language is created by the interplay between primary and secondary cues. Based on the Lheidli data, I argue that one of the secondary cues to rhythm not yet considered in the literature is inherent segmental duration.

Chapter 5 focuses on the phonological role of intervocalic consonants, in terms of their effect on syllabification. I propose that intervocalic consonants in Lheidli are non-contrastive moraic geminates., and provide a formal representation for these sounds.

Finally, Chapter 6 concludes with a discussion of the relationship between phonetics and phonology. As mentioned above (section 1.2), I argue that some phonetic components of language must be encoded in the grammar (segmental duration and the realization of stress) as part of the language-specific phonetics. In Lheidli segmental duration is also encoded in the phonology as weight. In contrast to segmental duration and the realization of stress, other phonetic properties of language need not be encoded anywhere; one such property is rhythm.

CHAPTER 2 LHEIDLI SOUNDS, SYLLABLES, AND STRESS

Recall from Chapter 1 that the goal of this dissertation is to gain a better understanding of the phonetic and phonological nature of intervocalic consonants in Lheidli. In order to do this, I start here by introducing the basic facts of the language with respect to: (a) the vowel inventory, (b) the consonant inventory, (c) the basic syllable structure, and (d) the stress system of Lheidli. Discussion provides the background necessary to explore the role of intervocalic consonants in the language. Furthermore, it serves as a written resource of the sounds of Lheidli, useful for the Lheidli community as well as for future research in the field.

2.1 The vowel inventory

Compared to other Athapaskan languages like Navajo, Lheidli has a relatively simple vowel inventory, at least phonologically. Navajo, for example, uses nasalization, length, and tone contrasts productively. Lheidli has no contrastive nasalization, and cases of contrastive length and tone are marginal at best. In this section, I introduce the vowels of Lheidli and discuss the salient properties of the system.

2.1.1 The phonemic inventory

Phonemically speaking, Dakelh has 6 vowels: /i, e, a, ʌ, o, u/. Descriptions of these vowels are given in (1) and follow Poser (2001).

(1) Vowels in Dakelh

	Description	*IPA*	*Orthography*
a.	Low back unrounded	/a/	a
b.	Mid front unrounded	/e/	e
c.	High front unrounded	/i/	i
d.	Mid back rounded	/o/	o
e.	High back rounded	/u/	oo
f.	Mid central unrounded	/ʌ/	u

In closed syllables, /i/ surfaces as [ɪ] and /e/ surfaces as [ɛ]. These tense/lax allophones are discussed in section 2.1.2.

The following examples illustrate the use of the vowels listed in (1)[1]. In all cases the vowels are full (there is no vowel reduction in Lheidli).

(2) Examples of Vowels in Dakelh

	Lheidli	*IPA*	*English Gloss*
/i/	ti	[tʰi]	road
	whusdli	[w̥ʌsdli]	I took care of her
/e/	ke	[kʰe]	foot
	dune	[dʌne]	man

[1] In the examples below, Lheidli words are written using the official practical orthography for the language. The sequence 'oo' is used for [u]; 'u' is used for [ʌ].

/a/	tagih	[tʰagɪh]	three (locative)
	tada	[tʰada]	three (generic)
/o/	tsambayo	[tsambayo]	bathroom
	yoh	[joh]	building, house
/u/	too	[tʰu]	water
	sloo	[slu]	my mother
/ʌ/	sus	[sʌs]	black bear
	kwun	[kwʰʌn]	fire

In addition to the monophthongs illustrated above, Lheidli has 3 diphthongs. The following examples illustrate the use of the diphthong /ai/:

(3) The diphthong /ai/

	Lheidli	*IPA*	*English gloss*
a.	lait'oh	[lait'oh]	he is stupid, useless
b.	lacholbai	[latʃolbai]	yarrow
c.	dut'ai	[dʌt'ai]	bird

Lheidli also has the diphthong /ʌi/, which occurs most often following a velar consonant (though not always):

(4) The diphthong /ʌi/

	Lheidli	*IPA*	*English gloss*
a.	skui	[skʌi]	my husband
b.	k'ui	[k'ʌi]	paper birch
c.	khui	[xʌi]	winter
d.	sugui	[sʌgʌi]	dried (up)

Because of its limited distribution - occurring primarily after velar consonants - Poser assumes that [ʌi] is an allophone of /i/, surfacing following velar consonants (Poser, 2001). However, there are words in which a velar is followed by [i] or [ɪ], for example *tagih* ('day'). Such words argue against Poser's view. Another possibility is that [ʌi] is an allophone of [ai]. However, [ai] also occurs following velars, as in *nulgaih* ('he runs'). Although [ʌi] occurs mostly after velar consonants, it also occurs in words which include the verb stem *-tsui* [tsʌi] ('to be bad'), which also underlies the verb 'to love' (Poser, 2001). For example:

(5) [ʌi] following a non-velar consonant

	Lheidli	*IPA*	*English gloss*
a.	ntsui	[ntsʌi]	it is bad
b.	nintsui	[nɪntsʌi]	you are bad

c.	nk'ehintsui	[ŋk'ɛhɪntsʌi][2]	they love you (sg)
d.	k'enadutsui	[k'ɛnadʌtsʌi]	he loves himself

These words appear to be the only ones in which [ʌi] does not follow a velar consonant. Despite its limited distribution, /ʌi/ is analyzed here as a separate phoneme because it is not in complementary distribution with any other sound in the language.

Finally, Lheidli has the diphthong /aw/, although this sound is relatively rare:

(6) The diphthong /aw/

	Lheidli	*IPA*	*English gloss*
a.	dawneltsuk hont'oh	[dawnɛltsʌk]	how many are there?
b.	toonawtesgus	[tunawtɛsgʌs]	I am going to wash

This diphthong is not discussed further in this dissertation, since no occurrences were found in the set of data used for the experiments reported in later chapters.

All of the diphthongs presented here could be interpreted as *vowel + glide* sequences as well. If this were the case, a word such as *lait'oh* (he is stupid) would be contain a word-medial cluster: [laj.t'oh]. In the word-set used here, there are no instances of CaiCCV, CuiCCV, or CawCCV in which so-called diphthong is followed by a

[2] Note /e/ surfaces as [ɛ] here although it does not seem to occur in a closed syllable. We shall see in Chapter 5 that word-medially, all syllables are closed. Hence /e/ surfaces as [ɛ].

consonant cluster. Given that Lheidli disallows more than two consonants in a row word-internally (see section 2.3), this gap (C-diphthong-CCV) is explained in a straightforward manner if this sequence is analyzed as CvCCCV (in which there would be three consonants in a row). In Chapter 3 we shall see that this analysis is further supported by the durational properties of the sounds involved. A more in-depth investigation is required to determine the exact nature of [ai], [ʌi], and [aw] sequences. For the time being, I follow previous literature (Walker, 1979, Poser, 2000) in referring to these sounds as diphthongs.

2.1.2 Tense vs. lax vowels

The front vowels /i, e/ in Lheidli have tense and lax allophones ([i, e] vs. [ɪ, ɛ]), as noted by Walker for Central Carrier (Walker, 1979). The tense/lax alternations are systematic: [i] and [e] occur in open syllables, whereas [ɪ] and [ɛ] occur in closed syllables. The following words illustrate the use of these vowels:

(7) Tense vs. lax front vowels in Lheidli

	Lheidli	*IPA*	*English gloss*
[i]	ti	[tʰi]	road
	whusdli	[w̥ʌsdli]	I took care of her
[ɪ]	chunih	[tʃʌnɪh]	marten
	hoonliz	[hunlɪz]	skunk

[e]	ke	[kʰe]	our feet
	dune	[dʌne]	man
[ɛ]	tubeh	[tʰʌbɛh]	very
	Dakelh	[dakʰɛɬ]	Dakelh

2.1.3 Length in the vowel system

Vowel length is for the most part not contrastive underlyingly (Poser, 2001). However, there are some exceptions worth discussing. In some cases, long vowels result from morphological concatenation:

(8) Long vowels resulting from morphological concatenation

	Lheidli	*IPA*	*English gloss*
a.	ni-y-ninguz[3]	[ni:nɪngʌz]	he dragged it to a terminus
b.	ni-y-tekai	[ni:tɛkai]	he is going to move it to a terminus

The only minimal pair I've found in which length is not derived by morphological concatenation is the following:

[3] In these two examples, the prefix *ni-* (to a terminus) combines with the third person singular disjoint object marker *y-* to yield long [i:] (Poser, 2001).

(9) Minimal pair illustrating contrastive length

	Lheidli	*IPA*	*English gloss*
a.	sa	[sa]	sun
b.	sa	[sa:]	slowly, long time

This pair may not actually involve contrastive vowel length. It is possible that what is transcribed as a phonemically long vowel in [sa:] 'slowly' is actually a short vowel which is lengthened for pragmatic reasons (as one would lengthen the [o] of 'slowly' in English).

Although a phonological length distinction is marginal in Lheidli vowels, there are consistent phonetic differences in length between vowels in different positions. The question of how syllable structure influences vowel length is taken up in Chapter 5.

2.1.4 The central vowel [ʌ]

The vowel [ʌ] deserves some discussion here because its phonological role is not as simple as that of the other vowels, as discussed below. The minimal pairs provided in (10) show that [ʌ] is a phonemic vowel:

(10) Minimal pairs including [ʌ]

	Lheidli	*IPA*	*English gloss*
a.	‘en	[ʔɛn]	he/she
b.	‘un	[ʔʌn]	over there
c.	lhat	[ɬat]	many
d.	lhut	[ɬʌt]	smoke

Although /ʌ/ is contrastive, it has certain properties which give it special status within the vowel inventory. First, /ʌ/ is by far the most frequent vowel in Lheidli. Of the 684 vowels used for analysis throughout this dissertation, 218 were tokens of /ʌ/ (the next most frequent vowel is /a/, of which there were 146 tokens). Second, the mean duration of /ʌ/ is approximately half that of other vowels: while the mean duration for the 684 vowels in the data is 195 ms, it is 94 ms for /ʌ/. Perhaps related to its short duration, /ʌ/ is the only centralized vowel in the inventory, other than the lax allophones of /i/ and /e/.

A possible explanation for these properties of /ʌ/ involves its role as the default epenthetic vowel in Lheidli. The vowel /ʌ/ occurs systematically in morphologically complex forms, for example in words such as *hubulh* [hʌbʌɬ] ‘with them’, *suhutni* [sʌhʌtni] ‘they call me’, *‘uts’ust’en* [‘ʌts’ʌst’en] ‘we are not working’, etc. Given that consonant clusters are for the most part disallowed in Lheidli (see section 2.3), it seems probable that in each of these words, the vowel [ʌ] is inserted at the surface level to create well-formed syllables from underlyingly consonantal morphemes. McDonough (1996) provides a similar analysis if /i/ in Navajo. Further work is necessary to determine exactly what the role of /ʌ/ is in Lheidli. Based on the limited evidence proved here, it seems likely that the frequency, duration, and quality of [ʌ] are all related to its role as the default epenthetic vowel in Lheidli, the occurrence of which is predictable in certain contexts in verbs and postpositions.

2.1.5 *What is missing?*

As already mentioned, other than the form listed in (9) above, Lheidli has no phonological length distinction in its vowel system. Compared to other Athapaskan languages like Navajo, it is also lacking nasalization. As for tone, Walker argues that Central Carrier has contrastive tone - high vs. low (Walker, 1979). Poser[4] has also suggested that there is a small set of words containing what seems to be a high-toned vowel (as opposed to 'neutral' tone). Poser (2001) interprets these marginal cases as historic remains of what was a tonal system at some previous stage of the language[5]. I have found no evidence for contrastive tone in Lheidli, and therefore assume that it is not productive in this language.

[4] Personal communication.

[5] Note however that it is possible to analyze Lheidli as a pitch-accent language, in which case the high-pitched vowels assumed to be stressed would all be high-toned. See section 2.4 for a discussion of stress vs. pitch-accent in Lheidli.

In summary, the Lheidli vowel inventory is relatively small compared to that of other Athapaskan languages. Navajo has 4 basic vowels qualities, each of which can be associated or not with nasalization (nasal vs. non-nasal), tone (high vs. low), and length (long vs. short). This leads to 32 underlying vowels in Navajo. In contrast to this, Lheidli has only 6 underlying vowels, two of which (front high and mid) have tense and lax allophones.

2.1.6 Conclusion on the vowel inventory

The purpose of section 2.1 was to provide the reader with an overview of the vowel inventory in Lheidli. This will be useful as background information for discussion in future chapters. Furthermore, the description of the inventory will serve as a resource for the Lheidli community, who are eager to have their language documented. The following section continues this overview, focusing on Lheidli's consonant inventory.

2.2 The consonant inventory

As is the case for Athapaskan languages in general, Lheidli has a relatively rich consonant inventory. Although the discussion in this chapter is based on Poser (2001), the phonetic data provided is new, based on my own fieldwork and analyses. In section 2.2.1 I present the general characteristics of the Lheidli consonant inventory, and in section 2.2.2 I move to a more detailed discussion of certain properties of this inventory. Again, the goal here is twofold: (a) to provide documentation of the sounds of Lheidli for future research and language preservation efforts, and (b) to provide the background information needed for the following chapters.

2.2.1 The phonemic inventory

Table 2.1 lays out the Lheidli consonants by manner and place of articulation. Sounds in parentheses are very rare, found only in one or two borrowed words (Poser, 2001). Note that Lheidli, like other Athapaskan languages, contrasts voiceless unaspirated stops and affricates with voiceless aspirated ones, and with ejectives. I follow Ladefoged and Maddieson (1999: 91) and Poser (2001) in representing voiceless unaspirated sounds using the symbols often reserved for voiced consonants. For example, /b/ refers to the voiceless unaspirated bilabial stop.

Table 2.1 Lheidli consonant inventory[6]

	bilabial (labio-dental)	laminal dental	apical alveolar	lateral	palatal	velar	labio-velar	glottal
stops	b (p^h) --		d t^h t'			g k^h k'	g^w $k^{\underset{\circ}{w}}$ k^{w}'	ʔ
affricates		d̪z t̪s t̪s'	dz ts ts'	dl tl tl'	dʒ tʃ tʃ'			
fricatives	 (f)	z̪ s̪	z s	-- ɬ	-- ʃ	ɣ x	 w̥	 h
glides/ liquids			(r)	l	j		w	
nasals	m		n			ŋ		

6 The symbol [$k^{\underset{\circ}{w}}$] is used for the aspirated labialized velar stop.

The following examples illustrate uses of each of the consonants listed above.

(11) Consonants in Dakelh

	Lheidli	*IPA*	*English Gloss*
Stops			
[b]	bunda	[bʌnda]	this morning
[d]	dune	[dʌne]	man
[t^h]	tubeh	[t^hʌbɛh]	very
[t’]	t’an	[t’an]	leaf
[g]	goh	[goh]	rabbit
[k^h]	koo	[k^hu]	house
[k’]	k’oh	[k’oh]	tracks, footprints
[g^w]	gwuzeh	[gwʌzɛh]	whiskey jack
[k^w]	kwun	[k^wʌn]	fire, light
[$k^{w’}$]	kw’us	[$k^{w’}$ʌs]	cloud
[ʔ]	‘ink’ez	[ʔɪŋk’ɛz]	also
Afficates			
[d̪z]	dzulh	[d̪sʌɬ]	mountain
[t̪s]	tsetselh	[t̪sɛ t̪sɛɬ]	axe
[t̪s’]	Ts’undusai	[t̪s’ʌndʌs̪ai]	graveyard (placename)

[dz]	dzen	[dzɛn]	day
[ts]	tsun	[tsʌn]	towards
[ts’]	ts’eke	[ts’ɛke]	woman
[dl]	dlooncho	[dluntʃo]	packrat
[tl]	tloh	[tloh]	grass
[tl’]	tl’oolh	[tl’uɬ]	rope
[dʒ]	jenyo	[dʒɛnyo]	bull moose
[tʃ]	cha	[tʃa]	also
[tʃ’]	ch’ekw	[tʃ’ɛk^{w}]	mountain ash

Fricatives

[f]	lugafi	[lʌgafi]	coffee
[s̪]	sugui	[s̪ʌgʌi]	dried
[z]	ze	[ze]	only
[s]	soo	[su]	very
[ɬ]	hubulh	[hʌbʌɬ]	with them
[ʃ]	shas	[ʃas]	grizzly bear
[ɣ̥]	ghusida	[ɣ̥ʌsida]	I married
[x]	khui	[xʌi]	winter
[w̥]	whusdli	[w̥ʌsdli]	It happened
[h]	hookw’elh’az	[huk^{w}’ɛɬʔaz]	afterwards

Liquids and Glides

[r]	lugarat	[lʌgarat]	carrot
[l]	lanezi	[lanezi]	10 (generic)
[j]	jun	[jʌn]	floor
[w]	wasi	[wasi]	lynx

Nasals

[m]	mai	[mai]	berry
[n]	nusiya	[nʌsiya]	I went
[ŋ]	anggwul	[aŋgʷʌl]	pine cone

Having introduced the consonants of Lheidli, I go on in the following sections to a discussion of those features of the inventory which are particularly striking when compared to other languages.

2.2.2 Properties of the phonemic inventory

In this section I outline some of the properties of the phonemic inventory which distinguish it from that of other languages. Topics covered are gaps in the system (2.2.2.1), non-native sounds (2.2.2.2), false geminates (2.2.2.3) and allophonic variation among nasals (2.2.2.4).

2.2.2.1 Gaps in the system

Although the consonant system in Lheidli is very rich, there are two gaps worth mentioning. First, like other dialects of Dakelh, Lheidli does not have the bilabial ejective stop /p'/ (Walker, 1979, Poser, 2001). Furthermore, the bilabial voiceless aspirated stop /p^h/ is marginal. Second, Lheidli is missing the voiced palatal fricative [ʒ]. These gaps are not surprising, given typological facts on the distribution of sounds (Maddieson, 1984, Ohala, 1995, Pulleyblank, 1997, Ladefoged and Maddieson, 1999). Indeed, bilabial voiceless stops are the most marked of the voiceless stops - if a language is missing one of the voiceless stops, it is most likely to be a labial (Maddieson, 1984, Ohala, 1995). As for [ʒ], this sound is also relatively marked (Maddieson, 1984). English is another language in which this sound is missing in all but a few words, even though its voiceless counterpart occurs frequently.

2.2.2.2 Non-native sounds

The phonemes /r/, /f/, and /p^h/ are not native to Lheidli, but do occur in a few borrowed words, mainly from Canadian French and English. For example:

(12) Non-native sounds in Lheidli

Lheidli	*IPA*	*French*	*English*
lugarat	[lʌgarat]	la carrotte	(carrot)
lugafi	[lʌgafi]	le café	(coffee)
pupur	[p^hʌp^hʌr]	--	pepper

The phoneme /m/ is another sound which occurs primarily in words borrowed from French such as *lumes* from 'la messe' (Mass), *luminis* from 'le ministre' (minister) and *musi* from 'merci' (thank you). However, the distribution of /m/ is a bit broader than /r/, /f/, and /p^h/. Whereas the latter sounds occur exclusively in borrowed words, /m/ does occur in native Lheidli words. An example of this is the [m] in *mai* 'berries'.

2.2.2.3 False geminates

Lheidli does not have contrastive geminate consonants[7]. However, in certain cases it does have derived sequences of two identical consonants as a result of morphological concatenation. The only consonants this happens with are [ss], from the combination of /s-ts/, and [ɬɬ] from the combination of /ɬ-tl'/.

[7] See section Chapter 5 for detailed discussion of gemination in Lheidli.

(13) Geminate consonants

	Lheidli	*IPA*	*English*
a.	nk'essi'	[ŋk'essiʔ]	I love you
	n-k'e-s-ts-i'		
	you - incorporated postposition - I - valence marker - love		
b.	telhlhoh	[tɛɬɬoh]	He is breaking
	t-e-lh-tloh		(lit. he has started to get mushy)
	inceptive - perfective - valence marker - be mushy		

In *nk'essui'*, the geminate [ss] results from the simplification of the cluster /s-ts/, where /s/ is the first person singular marker and /ts/ is the first consonant of the verb stem (Poser, 2001). In *telhlhoh*, [ɬɬ] results from the simplification of the cluster /ɬ-tl/, where /ɬ/ is the valence marker and /tl/ is the first consonant of the verb stem. Note that cases of truly identical consonants concatenating do not seem to exist.

2.2.2.4 Allophonic variation among nasals

I mentioned earlier that the phoneme /m/ occurred primarily in borrowed words (section 2.2.2.2). However, this sound also occurs as an allophone of the phoneme /n/. Underlying /n/ surfaces as /m/ before bilabial stops, as in *mbat* ('your mitts' - from /n/ 'your' + /bat/ 'mitts'). The velar nasal [ŋ] also surfaces as an allophone of /n/ preceding velar consonants, as in *anggwul* ('pinecone'). This may in fact be the only context in which [ŋ] surfaces, in which case it should not be considered a phoneme at all. A more thorough investigation of the occurrence of [ŋ] is required to verify this.

2.2.4 Conclusion on the consonant inventory

In this section, I have provided the reader with an overview of the consonant inventory of Lheidli, including its interesting gaps. Obviously, some areas require much more thorough an exploration than I have provided here. It is my hope that this work will trigger further exploration into Lheidli's consonant inventory. In the following section, I move to a discussion of syllable structure in Lheidli.

2.3 Syllable structure: a first pass

In this section, I introduce the basic syllable structure for Lheidli. We shall see in Chapter 5 that the facts are more complicated than they appear from the brief introduction presented below. This section is included because it represents the facts as they are generally accepted in the Athapaskan literature. It provides the background necessary for the discussion in Chapter 5, in which we see that - assuming that Lheidli is representative of Athapaskan languages in general - descriptions of syllable structure in these languages must involve mention of ambisyllabicity and gemination, something that has not yet been done.

Lheidli is characteristic of the Athapaskan language family with respect to syllable structure (Morice, 1932, Poser, 2001) (Sapir and Hoijer, 1967, Walker, 1979, Young and Morgan, 1987). In general, syllables are relatively restricted in terms of the number of segments they may contain. In the literature on Dakelh (including the Lheidli dialect), the syllables in (14) are considered acceptable (Morice, 1932, Walker, 1979, Poser, 2001). If the given word contains more than one syllable, the relevant syllable is underlined.

(14) Allowable syllables in Dakelh

	Syllable	*Example*	*IPA*	*English gloss*
a.	C[8]	mbat	[mbat]	your mitten(s)
b.	CV	too	[tʰu]	water
c.	CVC	andit	[andɪt]	now
d.	V	a	[a]	yes
e.	VC	usyi	[ʌsyi]	I am eating (specified object)
f.	CCV	sloo	[slu]	my mother
g.	CCVC	stl'esja	[stl'ɛsdʒa]	I quit

Of these syllable types, not all occur with the same frequency in different positions of the word. Furthermore, not all consonants may fill each of the syllable positions. The three most general restrictions on syllable structure are outlined here. First, onsetless syllables (V, VC) occur by and large word-initially. Examples (15)a and (15)c illustrate the syllable types V and VC respectively. They are contrasted with (15)b and (15)d, which

[8] It is debatable whether this syllable type actually occurs; see discussion below.

have word-initial onsets:

(15) Word-initial vowels

	Lheidli	*IPA*	*English gloss*
a.	a	[a]	yes
b.	'a	[ʔa]	fog
c.	usyi	[ʌs.yi]	I am eating (specified object)
d.	'usyi	[ʔʌ.syi]	I am eating (unspecified object)

There is disagreement among researchers as to whether onsetless syllables may occur word-medially (Morice, 1932, Walker, 1979). If there are such syllables in the language, they are uncommon[9].

The second restriction involves consonant clusters. Although coda consonants occur frequently, leading to word-medial *consonant-consonant* sequences, tautosyllabic clusters are for the most part disallowed in the language. As Poser (2001) mentions, the only clusters are in onset position, mostly word-initially. Furthermore, the first consonant of the cluster is always [s] or [ɬ], as in the examples given in (16) below[10].

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[9] One such case is the word *yeinyol* ('he is blowing into it'), which was syllabified *ye.in.yol* by the Lheidli subject whose data was analyzed for this work.

[10] Syllabification is somewhat simplified here. Each of these cases may involve ambisyllabicity word-medially. What is important here is the syllabification of the word-initial consonants.

(16) Word-initial clusters

	Lheidli	*IPA*	*English gloss*
a.	schaikeh	[stʃai.kɛh]	my grandchild
b.	sbaiyaz	[sbai.yaz]	little lamb
c.	lhk'utaneh	[ɬk'u.ta.nɛh]	six

Evidence for the fact that these words are syllabified with word-initial clusters - [stʃai.kɛh] - rather than with an initial syllabic consonant - *[s.tʃai.kɛh] - comes from native speaker syllabification intuitions. While onset clusters do exist word-initially, it is sometimes the case that speakers insert an epenthetic [ʌ] word-initially. For example, the word *sloo* ('my mother') is sometimes pronounced [ʌs.lu]. In this case, the cluster is avoided, as the [s] takes on the role of coda consonant to the preceding syllable[11]. Epenthesis is particularly common with [ɬ]-initial words. The example given in (16)c is often pronounced [ʌɬ.k'u.ta.nɛh]. Cases of epenthesis show that, even word-initially, consonant clusters are disfavored. Note that I am assuming these are cases of epenthesis and not elision, based on the fact that the relevant vowel is always [ʌ], which is the default epenthetic vowel in other contexts as well.

The final restriction discussed here involves syllabic consonants. Poser (2001) argues that /m/ and /n/ are the only syllabic consonants, and their distribution is limited to

[11] Note that I am assuming here that the epenthetic vowel serves as a syllable nucleus. See Warner et al. (2001) for a discussion of whether epenthetic vowels actually insert a syllable or not.

word-initial position and between two consonants. The examples in (17) illustrate the occurrence of /m/ and /n/ word-initially. Poser does not cite any examples of their occurrence between two consonants.

(17) Word-initial syllabic consonants

	Lheidli	*IPA*	*English gloss*
a.	mbat	[m.bat]	your mits
b.	nloo	[n.lu]	your mother

It is not clear from Poser's discussion what evidence there is that /s/ and /ɬ/ form clusters with the following consonant whereas /m/ and /n/ do not. Based on native speaker intuitions (see chapter 5, section 5.3), /s/ and /ɬ/ do not differ from /m/ and /n/. None of these consonants are interpreted as syllabic. Whether the distinction between these two sets of sounds can be motivated or not - phonetically or phonologically - one thing is clear: their distribution is by and large limited to word-onset position. Word-internally, tautosyllabic clusters such as these are very rare.

From this brief introduction to Lheidli syllables, it seems that syllables are for the most part relatively simple. What complexities do exist are limited to word-initial position. Word medially, syllables are basically either CV or CVC. The simplicity of the syllable structure is reflected by the fact that the writing system originally designed for Lheidli (and Dakelh in general) was syllabic. Indeed, the *Dené Syllabics*, as they are called, were an obvious way of writing the language, given the simplicity of its syllables[12].

2.4 Stress in Lheidli

Having introduced the sounds and syllables of Lheidli, I turn in this section to a presentation of the stress facts. This section serves as background for Chapter 5 (section 5.4), on the relationship between intervocalic consonant duration and stress placement. It also sheds valuable light on the question of stress in Athapaskan languages in general, something that is still little understood. I begin here by introducing the literature on stress in Dakelh and other Athapaskan languages (2.4.1). I then go on to present results from a pilot study on stress placement in Lheidli (2.4.2).

2.4.1 Stress in the Dakelh and Athapaskan literature

Athapaskan languages are notoriously difficult to classify in terms of their stress patterns. In Dakelh alone, there has been much disagreement as to whether or not stress exists. In his grammar of Dakelh, Morice (1932) suggests that Dakelh does not have stress. He notes:

[12] The syllabic system was designed and introduced by Father Adrien-Gabriel Morice in 1885, but fell out of use in favor of an alphabetic system.

> "(...) there is no prosodic or stress accent in Carrier, unless we consider as such some kind of a slight rest on the last syllable of each word, which recalls that of the French language" (Morice, 1932: 7)

Walker (1979) seems to agree with Morice's claim:

> "Stress is not significant on the word level. Preliminary analysis of higher level phonology, however, indicates that stress is significant in phonological pause groups." (Walker, 1979) (p. 102).

Contrary to Morice and Walker, Story (1984) asserts "Carrier is a 'stress-timed' language" (p.102). Since stresses are necessary for stress-timing, Story's claim implies that Dakelh must have stress. However, Story's description of the acoustic facts seems at odds with her characterization of Dakelh stress. In her discussion of nouns, Story claims that nouns have high tone on one of their syllables, although the pitch of the high-toned syllable is not necessarily higher than the pitch of the preceding syllables. According to Story, there are two kinds of words: (1) those with high tone on a non-final syllable ($\acute{\sigma}\breve{\sigma}]_{wd}$), and (2) those with high tone on the final syllable ($\breve{\sigma}\acute{\sigma}]_{wd}$). If the high tone is on a non-final syllable, there is a relatively sharp drop in pitch between the high-toned syllable and the following syllable. If the high tone is on the final syllable, the pitch is relatively flat within the word itself. However, words with final high tone fall into two classes: (2)a those in which the pitch lowers into the first syllable of the following word, and (2)b those in which the pitch does not lower into the first syllable of the following word.

Table 2.2 Story's description of pitch in Dakelh

	High tone placement	*Pitch contour*
(1)	Non-final syllable	Sharp drop in pitch following the high-toned syllable
(2)a	Final syllable	Drop in pitch between the word-final high-toned syllable and the initial syllable of the following word
(2)b	Final syllable	No drop in pitch between the word-final high-toned syllable and the initial syllable of the following word

Story's description of the Dakelh pitch patterns is reminiscent of pitch-accent languages. Crucially, words which have a 'high tone' on their final syllable but in which the pitch does not lower into the following word ((2)b) resemble words which have no high-toned syllable at all. If the high tone discussed by Story corresponded to the phonetic realization of stress, one would expect all words to have at least one high tone. Indeed, in languages with stress, all words (at least content words such as nouns) have a primary stress. The fact that words like (2)b exist - in which there is arguably no stress (no high tone) - is at odds with an analysis of Dakelh as having stress.

From only three accounts of Dakelh, several different analyses emerge: Morice and Walker assume that Dakelh does not have stress; Story claims that it is a stress-timed language, yet her description of the facts (in disagreement with her claim) suggests that Dakelh is actually a pitch-accent language, with no stress at the word level. The disparity among analyses of stress in Dakelh is reflected in analyses of Athapaskan languages in general. One might expect Athapaskan languages to share their stress system, since they are all related. However, researchers working on Athapaskan languages have proposed a wide range of analyses of stress and, more generally, of rhythmic structure. Sapir, reporting on Sarcee, states the following:

> "In pronouncing Sarcee, or any Athabaskan language, it is important to give each syllable its due weight ... the syllables of a word do not generally differ greatly in stress" (Sapir, 1925)(p. 191)

From this comment, Sapir seems to interpret Sarcee as resembling French in having no lexical stress. Haile has a similar view of Navajo, as illustrated in the following comment:

> "In Navaho the syllable is not regularly stressed as is done in English words ... one is often at a loss whether to use stress accent at all, because rising and falling inflection of the voice more frequently accentuate a syllable." (Haile, 1926, p. 7)

In contrast to Sapir and Haile's research, recent work on Babine Witsuwit'en and Fort Ware Sekani (Hargus, to appear) and Apache (Tuttle, to appear) suggests that at least these three languages have alternating stresses[13]. Hargus (to appear) provides data from both Babine Witsuwit'en and Fort Ware Sekani which exhibit an alternating stress pattern, although she argues that stress placement depends on several factors, including morphology, vowel quality (peripheral vs. central and long vs. short), position of syllable in the word (left edge vs. word-medial), syllable type (open vs. closed - Babine Witsuwit'en only), and tone (Fort Ware Sekani only). The acoustic factors contributing to stress were found to be increased amplitude, duration, and pitch in Babine Witsuwit'en, and increased duration and amplitude (to a lesser degree) in Fort Ware Sekani.

Tuttle, in work on Tanana, found that this language too had alternating stress (Tuttle, 1998). Tuttle (to appear) has also looked at Jacarilla Apache in terms of its rhythmic structure as a whole (including stress). Based on Grabe and Low's (in press) work on durational correlates to rhythm, Tuttle used a translation of the fable "The North Wind and the Sun" to calculate the durational variability across syllables in Jacarilla Apache. She compared her results to results taken from French and English translations of the same text, and found that Jacarilla Apache fell between English (stress-timed) and French (syllable-timed) in terms of its rhythm. Jacarilla Apache does have stress, although Tuttle does not mention whether or not it has alternating stresses.

Finally, McDonough's work on Navajo is in line with Story's description of Dakelh facts: in her work on tone and accent in Navajo, McDonough has argued that Navajo is a pitch-accent language (McDonough, 1989, McDonough, 1999).

[13] Babine Wistuwit'en and Fort Ware Sekani are northern Athapaskan languages, closely related to Dakelh. Apache is a southern Athapaskan language, closely related to Navajo. Tanana, mentioned below, is another northern Athapaskan language.

From the literature presented above, it is clear that Athapaskan languages - including Dakelh - have been treated very differently by different researchers. These languages are sometimes analyzed as having stress, other times not. In cases where they are assumed to have stress, they are most often analyzed as having alternating stress. Pitch-accent has also been used - rather than stress- to describe these languages by various researchers. The following table summarizes the different analyses presented above of stress (and rhythm) in Athapaskan languages:

Table 2.3 Research on stress and rhythm in Athapaskan languages

Language	*Stress*	*Source*
Dakelh (Central Carrier)	No word-level stress	Morice (1932)
Dakelh (Central Carrier)	No word-level stress	Walker (1979)
Dakelh (Central Carrier)	'Stress-timed': implies word-level stress (Pitch accent)	Story (1984)
Sarcee	No word-level stress	Sapir (1925)
Navajo	No word-level stress	Haile (1926)
Navajo	Pitch-accent	McDonough (1999)
Babine Witsuwit'en	Alternating stresses	Hargus (to appear)
Fort Ware Sekani	Alternating stresses	Hargus (to appear)
Tanana	Alternating stresses	Tuttle (1998)
Jacarilla Apache	Word-level stress Falls between syllable-timed and stress-timed extremes (in terms of rhythm)	Tuttle (to appear)

The wide range of analyses presented here indicates one of two things: either Athapaskan languages vary a lot in terms of stress, or they do not vary much, but their stress system has not yet been fully understood. In the following section I turn to a pilot study on stress in Lheidli, which will provide additional experimental data on the matter, and consequently enrich our understanding of stress in Athapaskan languages.

2.4.2 Stress in Lheidli

In this section I present the results of a pilot study conducted to investigate stress in bisyllabic words. We shall see that bisyllabic words fall in two classes, reflected by their pitch and amplitude contours: Class I words have a decrease in pitch and amplitude between the first and second syllables, which is taken to indicate first syllable stress. Class II words have an increase in pitch and amplitude between the first and second syllables, which is taken to indicate second syllable stress.

2.4.2.1 Research design and acoustic measurements

In total, 121 words were analyzed for this study, which constitutes pilot work for a more in-depth investigation of Lheidli's stress system. The words analyzed formed a subset of those collected and analyzed in other studies reported in this dissertation (see General Methodology, section 1.4). Of these words, 76 were of the form CVCV(C), and 45 were of the form CVCCV(C)[14].

For each syllable, pitch and amplitude were measured using the Praat speech software. Amplitude was measured from the 'intensity curve' function (not from the waveform), and pitch was measured from the 'pitch contour' function. Since all words

[14] See Appendix C for the complete word list used for this study.

measured were bisyllabic, in total 4 measurements were taken for each word: pitch and amplitude of the first syllable, and pitch and amplitude of the second syllable. Both pitch and amplitude measurements were taken in one of two ways depending on the nature of the contour. If there was a clear peak during the vocalic portion of the syllable, the measurement was taken at the peak. Given that pitch peaks and amplitude peaks did not always correspond, pitch and amplitude were sometimes measured at different points. In some cases, there was a pitch or amplitude peak at the onset or offset of the vowel. This was not taken as the peak of the vowel. It was assumed to be an effect of the transition between the vowel and the preceding or following consonant. If there was no clear peak, the measurement was taken at the middle point of the vowel. If the voicing was amodal at the vowel onset or offset (as a result of creaky voicing), the measurement was taken at the mid point of the modal voice portion of the vowel.

Stress was calculated as follows: the pitch and amplitude values for the first syllable were subtracted from those of the second syllable. If the differences were positive (i.e. the values were greater in the second syllable), stress was considered to be on the second syllable. If the differences were negative (i.e. the values were greater in the first syllable), stress was considered to be on the first syllable. Note that the data was not calibrated for amplitude, and consequently the amplitude measures did not correspond to absolute dB values. Since the amplitude measure used was relative (amplitude of first syllable compared to that of second syllable), calibrating the data was not necessary.

Take for example the word *'andit* ('now'), illustrated in Figure 2.1. The pitch and amplitude values for the first syllable are 174 Hz and 81 dB respectively. The values for the second syllable are 217 Hz and 84 dB. The difference in pitch between the first and second syllable is: (217-174) = 43 Hz. That this result is positive means that pitch is higher in the second syllable, a first indication that stress is on the second syllable. The difference in amplitude between the first and second syllable is: (84-81) = 3 dB. Again, the positive result means that amplitude is higher in the second syllable, providing further evidence that this word has second syllable stress.

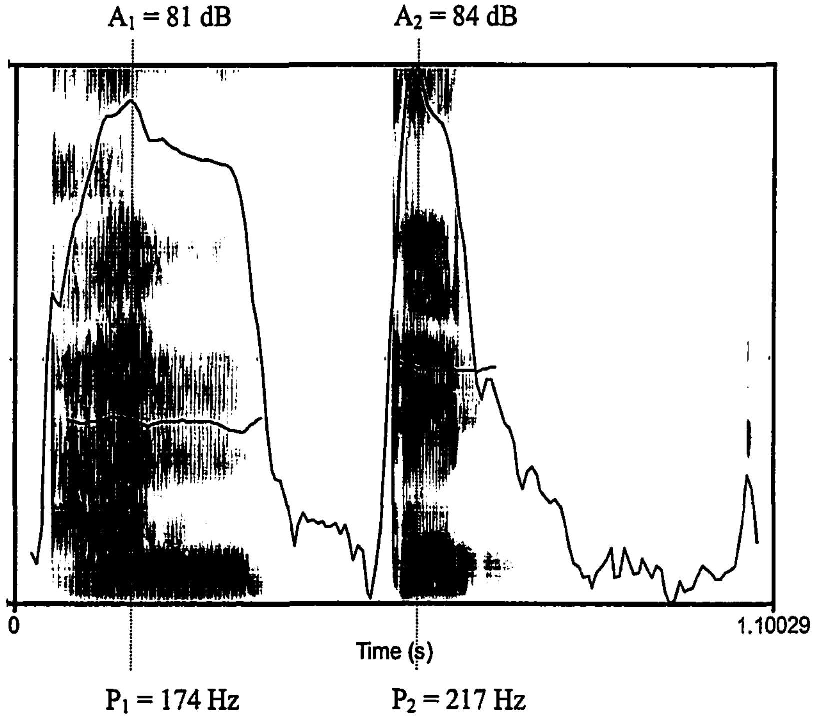

Figure 2.1 Spectrogram, pitch and intensity measurements in *'andit* [andɪt] ('day'). Vertical dotted lines mark the pitch and amplitude peaks in the first and second syllables.

In some cases the pitch and amplitude values disagreed. If the pitch was very similar across syllables, then the syllable with highest amplitude was taken to be the stressed one. Similarly, if the amplitude was very similar across syllables, the syllable with the highest pitch was taken to be the stressed one. Quantitatively, cases in which the pitch or amplitude differences across syllables were smaller than four were considered "very similar"[15]. For example, take a hypothetical word with the following values: P1 = 190 Hz, P2 = 189 Hz, A1 = 75 dB, A2 = 95 dB. The following pitch and amplitude differences result: (P2 – P1) = -1 and (A2 – A1) = 20 dB. In such a case, the pitch is taken to be "very similar" across syllables (because (P2 – P1) < 4); therefore, stress is placed on the second syllable, based on the amplitude difference between syllables. Cases in which pitch and amplitude disagreed, and neither pitch nor amplitude was similar across syllables, were discarded. Similarly, cases in which pitch and amplitude disagreed, and both pitch and amplitude were very similar across syllables, were discarded. Of the 121 words analyzed, 10 words were discarded for the above-mentioned reasons. In total, stress placement values were obtained from 111 words, 68 of which had a single intervocalic consonant (CVCV(C)).

2.4.2.2 Results

Two patterns were observed with respect to pitch and amplitude measurements. The first pattern is illustrated in Figure 2.2. The pitch decreases from the first syllable to

[15] Note that the number 'four' was chosen somewhat arbitrarily as a preliminary cut-off point for 'very similar' judgments. It is not meant to imply that steps in pitch are equivalent to steps in amplitude, perceptually. Determining how to compare perceptual steps in Hz to perceptual steps in dB will have to await further research.

the second: the peak pitch of the first syllable (P_1) is 239 Hz, and the peak pitch of the second syllable (P_2) is 164 Hz. The amplitude also decreases from the first syllable to the second: the peak amplitude of the first syllable (A_1) is 82 dB, and the peak amplitude of the second syllable (A_2) is 78 dB. Notice that in the second syllable, the pitch and amplitude were not measured at the onset of the sonorant interval. The word measured was *sulhwus* [sʌɬwʌs] ('foam'), with the second syllable beginning with [w]. Pitch and amplitude measurements were taken after the [w-ʌ] transition.

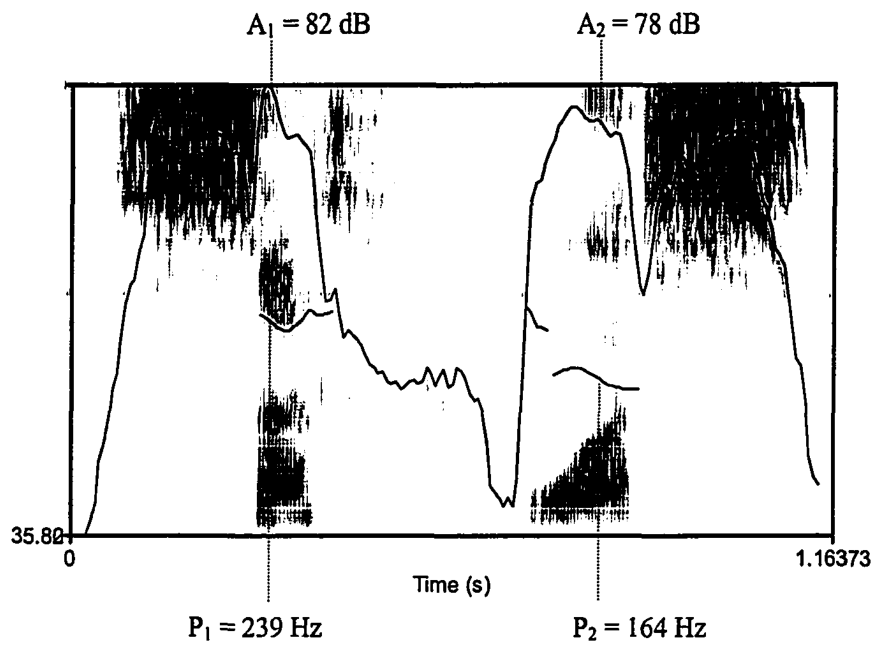

Figure 2.2 Formal representation of *sulhwus* [sʌɬwʌs] ('foam').
Vertical dotted lines mark the pitch and amplitude peaks
in the first and second syllables.

The second pattern is illustrated in Figure 2.1 above. As already mentioned, in this case the pitch increases from the first syllable to the second (P_1 = 174 Hz, P_2 = 217 Hz). The amplitude also increases from the first syllable to the second, although not by very much (A_1 = 81 dB, A_2 = 84 dB).

The two patterns illustrated in Figures 2.1 and 2.2 were interpreted as reflecting second syllable and first syllable stress respectively. Table 2.4 provides the mean pitch and amplitude values for both syllables of words with first and second syllable stress, as well as the differences in pitch and amplitude between the two syllables.

Table 2.4 Pitch and amplitude in first and second syllables of Lheidli words

Pitch and amplitude		*First syllable stress*		*Second syllable stress*	
		Mean	*(st. dev.)*	*Mean*	*(st.dev.)*
P_1	(first syllable)	210	(20)	184	(8)
P_2	(second syllable)	180	(20)	207	(15)
P_2-P_1		-31	(17)	22	(12)
A_1	(first syllable)	80	(2)	79	(2)
A_2	(second syllable)	78	(2)	80	(2)
A_2-A_1		-2	(2)	1	(2)

A single-factor ANOVA (stress: unstressed vs. stress) showed that the different in pitch between stressed and unstressed vowels was significant in both words with first syllable stress ($F(1,156) = 89.26$, $p < 0.0001$) and in words with second syllable stress ($F(1,62) = 53.70$, $p < 0.0001$). A second single-factor ANOVA showed that the difference in amplitude between stressed and unstressed vowels was also significant in words with first syllable stress ($F(1,156) = 18.16$, $p < 0.001$) and in words with second syllable stress ($F(1,62) = 4.99$, $p < 0.05$)[16].

Of the 111 words evaluated as to stress placement, 79 had first syllable stress and 32 had second syllable stress. Considering only words with single intervocalic consonants (CVCV(C)), of the 68 words evaluated for stress, 46 had first syllable stress and 22 had second syllable stress. These results are summarized in the following table:

Table 2.5 Stress in Lheidli bisyllabic words

Word type	*1st syllable stress*	*2nd syllable stress*	*Proportion of 1st syllable stress*	*Total*
CVCV(C)	46	22	68%	68
CVCCV(C)	33	10	78%	43
Total	79	32	71%	111

The numbers listed in Table 2.5 show that bisyllabic words in Lheidli are most often stressed on the first syllable (71% of the time). A Chi Square test of goodness of fit showed that the number of words with first syllable stress differed significantly from that predicted by chance ($X^2(1, n = 111) = 19.9$, $p < 0.001$). The proportion of words with first syllable stress is also slightly higher for words with medial clusters (78%) than for words with single intervocalic consonants (68%). However, a Chi Square test of Independence showed that this result was not significant ($X^2(1, n = 111) = 1.06$, $p > 0.05$).

A Pearson correlation showed that there was no correlation between stress placement and the duration of the vowel in the first syllable ($r = -1.48$, $p > 0.05$). That is,

[16] Note however that a statistically significant difference does not necessarily imply an audible difference.

the first vowel was not longer in words with first syllable stress than in words with second syllable stress. A second Pearson correlation showed that there was also no correlation between stress placement and the duration of the vowel in the second syllable ($r = -0.026$, $p > 0.05$). That is, the vowel in the second syllable was not longer in words with second syllable stress than in words with first syllable stress. These findings indicate that duration is not a correlate of stress in Lheidli.

Another Pearson correlation performed on only CVCV(C) words showed that there was no correlation between the duration of the intervocalic consonant and stress placement ($r = 0.085$, $p > 0.05$). Finally, a fourth Pearson correlation performed on only CVCCV(C) words showed that there was also no correlation between the duration of the word-medial consonant cluster and stress placement ($r = 0.008$, $p > 0.05$).

For words with single intervocalic consonants, stress placement was explored as a function of the voicing, place of articulation, and manner of articulation of the intervocalic stop. A series of Chi Square tests for Independence showed that there was no significant effect of voicing on stress placement ($X^2(2, n = 68) = 0.87$, $p > 0.05$), no significant effect of place of articulation ($X^2(6, n = 68) = 9.38$, $p > 0.05$), and no significant effect of manner of articulation ($X^2(5, n = 68) = 5.97$, $p > 0.05$).

Finally, stress placement was investigated as a function of vowel quality. Two Chi Square tests for Independence showed that stress was neither a function of the preceding vowel ($X^2(6, n = 111) = 11.13$, $p > 0.05$), nor a function of the following vowel ($X^2(7, n = 68) = 11.64$, $p > 0.05$).

2.4.2.3 Discussion

Although pitch and amplitude measurements are taken to reflect stress in Lheidli, whether stress actually exists in the language is worth some discussion here. It has been said of other Athapaskan languages that they have no stress, but are pitch accent languages (McDonough, 1989). Even Dakelh (dialects other than Lheidli) has been described as having pitch-accent, or a combination of stress and pitch-accent (Gessner, 2002).

Based on the facts obtained here, it is not possible to argue for Lheidli being a pitch-accent language such as Japanese (Beckman and Pierrehumbert, 1986, Pierrehumbert and Beckman, 1988). As mentioned above, stress does not seem to be correlated with duration: the first vowel of bisyllabic words is not longer in words first syllable stress than in words with second syllable stress, and the second vowel is not longer for words with second syllable stress than for words with first syllable stress. However, it is possible that the apparent lack of correlation between duration and prominence found in this study results from word-final lengthening. As we shall see in Chapter 5, vowels are lengthened word-finally, even when they occur in closed syllables. Given that only bisyllabic word were analyzed, word-final lengthening affected the second syllable vowels, perhaps obscuring the durational differences between first and second syllable vowels in words with different stress patterns.

In preliminary work on prosody in Dakelh, Gessner (2002) found some evidence for duration being a correlate of stress, with high-pitched vowels being longer than low-pitched ones. Further investigation is required in order to determine whether or not duration is a correlate of prominence in Lheidli. Even if stress is not correlated with duration, it is correlated with amplitude. If prominence in Lheidli were achieved solely through manipulations in pitch, then Lheidli would perhaps best be characterized as having pitch-accent rather than stress. However, given that prominence is also correlated with increased amplitude, and given that the role of duration is unclear, the data do not provide conclusive evidence for Lheidli having pitch-accent. For this reason, I assume here that Lheidli is a stress language.

Another finding of Gessner's (2002) work worth mentioning here involves the number of pitch patterns found in bisyllabic words. Gessner proposes that the possible pitch patterns in bisyllabic words are HL, LH, and HH. In the study presented above, I reported only HL (first syllable stress) and LH (second syllable stress) words. However, words in which the pitch difference between the first and second syllables was smaller than 4 Hz were classified according to the amplitude difference between the two syllables if the difference was greater than 4 dB, or were discarded if the amplitude also did not vary across syllables (section 2.4.2.1). In the data set, there were 6 of words in which the pitch did not vary across syllables, 5 of which were discarded because the amplitude was also constant across syllables. It seems likely that these 6 words in fact exhibit the HH pitch pattern observed by Gessner (2002). The average pitch of both first and second syllable vowels across these words is 194 Hz. This frequency is not as high as the average pitch of stressed syllables (210 Hz for words with first syllable stress and 207 Hz for words with second syllable stress). However, it is higher than the average pitch for unstressed syllables (180 Hz for words with first syllable stress and 184 for words with second syllable stress). These words could be classified either HH or as LL.

Whether the 6 words mentioned above are best characterized as HH or LL, or as simply unclear, is left unresolved here. The reason for presenting the stress facts of Lheidli here is so that the duration of intervocalic consonants can be investigated as a function of stress placement (see Chapter 5). The words of interest for this investigation are those which are clearly stressed on either the first or second syllable. For this reason, no further mention will be made here of the possible HH or LL words mentioned above. A final point worth noting here is that I have not found any minimal pairs in Lheidli, which are distinguished solely by stress placement.

2.4.3 Conclusion on stress

In Lheidli bisyllabic words, prominence can fall either on the first syllable or on the second, and is correlated with an increase in pitch and amplitude. A more thorough investigation is necessary to understand whether duration plays a role in prominence or not, and to determine whether Lheidli is best characterized as having stress or a pitch-accent.

2.5 Conclusion

The goal of chapter 2 was to provide the reader with an understanding of Lheidli sounds, syllables, and stress. In the following chapters I turn to a discussion of one specific set of sounds in Lheidli: intervocalic consonants. These sounds are unusually long for consonants. This fact has been noted in the literature on Athapaskan languages, but its implications for the phonetic and phonological structure of Lheidli have not yet been investigated in any depth. Chapter 2 has served as background to this topic, which is taken up in the remainder of the dissertation.

CHAPTER 3 THE NATURE OF INTERVOCALIC CONSONANTS

Having provided an overview of Lheidli's phonological system (Chapter 2), we now turn to the focus of this dissertation: Lheidli's intervocalic consonants. While the remarkable length of (intervocalic) consonants has been noted in the Athapaskan literature, neither the phonetic nature of these sounds nor their phonological role has been studied in any detail. In the remainder of this dissertation, I present the results of several studies on the nature of intervocalic consonants in Lheidli, and on their phonetic and phonological implications for the language. Chapter 3 begins this investigation by looking at duration, comparing intervocalic consonants to consonants and vowels in other positions within Lheidli, as well as intervocalic consonants in other languages. I start by presenting an overview of previous research on intervocalic consonants in Athapaskan languages (3.1), and go on to discuss their durational properties in Lheidli (3.2 - 3.4).

We shall see that intervocalic consonants are substantially longer in duration than consonants in any other position (3.2), than the surrounding vowels (3.3), and than intervocalic consonants in other languages (3.4). Within the set of Lheidli intervocalic consonants, duration varies depending on place of articulation, manner of articulation, and voicing (3.5). Based on the findings presented in this chapter, I argue that Lheidli intervocalic consonants are geminates (in the descriptive sense), since their duration is much longer than that of any other consonants found both within Lheidli and cross-linguistically. Furthermore, these consonants provide evidence supporting the view taken by several researchers recently that language-specific phonetics exists, and must be encoded in the grammar (Keating, 1985, Kingston and Diehl, 1994, Cohn, 1998, etc.). Indeed, because the duration of Lheidli intervocalic consonants is unique to Lheidli, and consequently differentiates Lheidli from other languages, this duration must be encoded in the grammar as part of the phonetic knowledge of Lheidli speakers. The effect of Lheidli intervocalic consonants on the phonetic timing (rhythm) and phonological timing (syllabification) of Lheidli are investigated in Chapters 4 and 5. Their implications for the phonetics-phonology interface are taken up in Chapter 6.

3.1 Intervocalic consonants in the Athapaskan literature

It has been noted in the literature that intervocalic consonants in Athapaskan languages are unusually long (Sapir and Hoijer, 1967, Young and Morgan, 1987, McDonough and Ladefoged, 1993, Tuttle, to appear). Sapir and Hoijer claim of intervocalic consonants in Navajo,

> "When an initial or medial Cv precedes another syllable that begins with a consonant, the consonant of the second syllable is mechanically lengthened. Since long consonants do not occur elsewhere, this lengthening is taken as phonetic evidence of a preceding Cv syllable." (Sapir and Hoijer, 1967: 3).

In discussing the syllabification of intervocalic consonants, Sapir and Hoijer distinguish between *phonological* syllable breaks and *phonetic* syllable breaks. This distinction is illustrated in the following examples, taken from Sapir and Hoijer (1967); syllable breaks are marked with periods. Note that Sapir and Hoijer provide no examples of this phenomenon with either stops or nasals (I have included here all of the examples they cite).

(1) Phonological vs. phonetic syllabification of Navajo words[1]

	Phonological breaks	*Phonetic breaks*	*English gloss*
a.	di.ʃááh	[diʃ.ʃááh]	I start to go
b.	tą́.ʒii	[txą́ʒ.ʒiih]	turkey
c.	ní.yol	[níy.yol]	wind

Sapir and Hoijer imply ambisyllabicity in their phonetic syllabification. Furthermore, they imply gemination in their description of the phenomenon ('the consonant of the second syllable is mechanically lengthened'). However, they do not explicitly discuss either ambisyllabicity or gemination - probably because these terms were not yet in use at the time they were conducting their research. Similarly, Young and Morgan mention the "doubling of consonants", as they call it:

[1] To make the data easier to read, I use IPA here, instead of Sapir and Hoijer's orthography. One exception is the cedilla, used to indicate nasalization (this is consistent with current Navajo orthography and is used here to avoid having two diacritics above high toned nasalized vowels).

> "The consonants tend to be doubled when they occur intervocalically -- that is, the consonant that begins a syllable tends to also close a preceding open syllable" (Young and Morgan, 1987: xv).

Young and Morgan cite several examples of this consonant doubling, including the following:

(2) Syllabification of intervocalic consonants

	Navajo word	*Syllabification*	*English Gloss*
a.	'ádin	['ád.din]	none
b.	bíla'	[bíl.la']	his hand
c.	bíká	[bík.ká]	after him

Young and Morgan further claim that in the case of intervocalic affricates, or consonants involving a secondary release (glottalized and labialized consonants), only the first portion of the consonant is "doubled":

(3) Syllabification of intervocalic consonants with secondary release

	Navajo word	*Syllabification*	*English Gloss*
a.	bits'ilí	[bit.tsilí]	his bone
b.	bich'ah	[bit.tʃ'ah]	his hat

c.	dékwi	[dék.kwi]	I vomited
d.	bik'is	[bik.k'is]	his brother

As did Sapir and Hoijer, Young and Morgan imply ambisyllabicity through the syllabification of the forms they cite, and gemination through their description of the facts ('consonant doubling'). However, they also do not explicitly discuss these terms, nor do they discuss the *phonological* role of these unusually long intervocalic consonants. Furthermore, neither Sapir and Hoijer, nor Young and Morgan provide any sort of phonetic or phonological evidence to support their choice in syllabification. What phonetic evidence is there for claiming that these consonants get lengthened? And what phonological evidence is there for ambisyllabicity and/or gemination? In sections 3.2 through 3.5 I provide the answer to the former question. The latter question constitutes the topic of Chapter 5.

3.2 Intervocalic consonants compared to other consonants in Lheidli

Most of the preceding discussion of the unusual length of (intervocalic) consonants has focused on Navajo (Sapir and Hoijer, 1967, Young and Morgan, 1987, McDonough and Ladefoged, 1993). In this section I show that similar facts are found in Lheidli. Evidence is based on a series of studies designed to compare the duration of intervocalic consonants to other segments within Lheidli, as well as across languages.

3.2.1 Study I: The effect of syllable position and finality on consonant duration

The goal of the first study is to gain a general understanding of the duration of consonants depending on their position in the word. Through this understanding, it will be possible to evaluate the behavior of intervocalic consonants and answer the following questions: Do intervocalic consonants pattern with onsets or with codas? How do they compare with onsets and codas in different positions in the word? Two factors were considered here: syllable position (onset vs. coda) and finality (non-final vs. final position). The hypotheses tested were as follows:

Hypothesis I

Consonants are longer in coda position than in onset position.

Hypothesis II

Consonants are longer in the last syllable of the word than in the preceding syllables.

Hypothesis I is based on the fact that, cross-linguistically, coda consonants can bear phonological weight whereas onset consonants never do (Hayes, 1989, Goedemans, 1998). The reasoning behind this hypothesis is that phonological weight should be mirrored by phonetic duration[2]. Hypothesis II is based on word-final and utterance-final lengthening effects found cross-linguistically (Klatt, 1979, Lehiste, 1980, Nooteboom &

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[2] Note that Goedemans (1998) did not find that onsets were shorter than coda consonants, although he did find that they were more variant in duration than codas (and more invariant perceptually).

Doodeman, 1980, Kaiki and Sagisaka, 1990, Campbell, 1992, Sagisaka, 1992, Gerfen, 1996, Tuttle, to appear).

3.2.1.1 Design of the study

Four conditions were compared in this study: non-final syllable onset[3], non-final syllable coda, final syllable onset, and final syllable coda. The data used were a set of 342 bisyllabic words, as discussed in the section on General Methodology (1.4.3). In total, 786 consonants were used[4]. Table 3.1 illustrates the experimental design used. Non-final onset consonants were onsets in the first syllable: #_V(C).CV(C). Final onset consonants were onsets in the second syllable: (C)VC._V(C). Non-final codas were word-medial codas: (C)V_.CV(C). Final codas occurred word-finally: (C)V(C).CV_#. In Table 3.1, the numbers in parentheses indicate the number of items in each condition.

Table 3.1 Experimental design of Study I

Syllable structure	*Finality*	
	Non-final syllable	*Final syllable*
Onset	$\underline{C}$V(C).CV(C) (309)	(C)VC.$\underline{C}$V(C) (130)
Coda	(C)V$\underline{C}$.CV(C) (130)	CV(C).CV$\underline{C}$ (217)

Notice that this design excludes single intervocalic consonants. Indeed, one would expect that final onset condition would include the following: (C)V.$\underline{C}$V(C). As mentioned above, intervocalic consonants are unusually long, and as a result it is unclear what their

[3] Since the data consists of bisyllabic words, 'non-final' corresponds to 'initial' here. See section 3.2.3 for a further discussion of the conditions used.
[4] See Appendix A for the complete word list used.

role in the syllable is. Because of their mysterious phonological status, they were excluded from Study I and investigated separately in Study II.

3.2.1.2 Results

Results are discussed in two parts. I begin by presenting an overview of the results using raw durations. I then introduce the notion of z-scores (Campbell, 1992), and provide a statistical analysis of the results using z-scores where appropriate.

Let us first look at the raw durational data, plotted in Figure 3.1. Values are averaged across all consonant types (durations are in seconds).

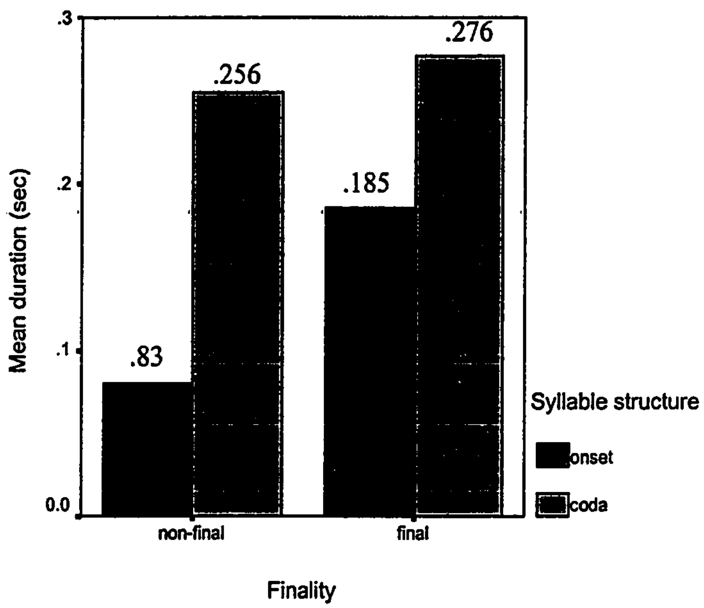

Figure 3.1 Mean duration of consonants in onset vs. coda position in final vs. non-final syllables

Two points are worth noting regarding these data. First, codas are longer than onsets, supporting Hypothesis I, and contrary to Goedemans (1998): consonants are longer in coda position than in onset position. Second, consonants in final syllables are longer than those in non-final syllables, regardless of whether these consonants are onsets or codas, supporting Hypothesis II: consonants are longer in the last syllable of the word than in the preceding ones.

Let us now look at the data in a more detailed fashion. To compare consonant durations across positions, a two-factor between-items ANOVA was used. The two factors were 1) finality (final vs. non-final) and 2) position (onset vs. coda). The design chosen was a *between-items* comparison[5]. Comparisons are by items rather than by subjects because only one subject is used. The decision to run a *between-items* comparison rather than *within-items* one deserves some discussion here. In a *within-items* design, the same items are used in each condition. In a *between-items* design, different items are used for different conditions. In the study reported here, the items do not neatly fit either of these designs. Some words are used to measure several consonants, in onset and coda position (within-items design). Other words are used to measure only one consonant (between-items design). Take for example a word of the shape $C_1VC_2.C_3V$. In this study on the effect of syllable position on consonant duration, this one item is used in two conditions: C_2 is used in the *coda* condition; C_1 and C_3 are used in the *onset* condition. Another word of the shape $C_1V.C_2V$ is only used in one condition (there are no codas - only C_1 is used, in the onset condition). Using a *within-items* design would be

[5] The term 'between-items' means the same as 'non-repeated-measures'.

relatively complex in that it would require determining which items to use for each specific comparison. It would also greatly restrict the amount of useable data. In this study on the effect of syllable position on consonant duration, it would cut down the useable data to CVCCVC words only. This would reduce the data to 73 words, rather than the 342 actually used. In order to avoid the problem of design complexity and small sample size, a *between-items* design was chosen.

In testing for significant differences in consonant durations, z-scores were used rather than raw durations, following Campbell (1992). Z-scores transform absolute values into relative values, thus providing a means of comparing different types of items. In the present study - and in subsequent ones - the values we wish to compare are durations, and the different types of items are different consonants.

Consonants differ in their inherent duration. For example in American English, Crystal and House (1988) found that stops differ in duration as a function of voicing and manner of articulation. Voiced stops are shorted than voiceless stops; bilabial stops are shorter than alveolar stops, which are in turn shorter than velar stops. Crystal and House (1988) give the following mean durations for bilabial, alveolar, and velar stops.

Table 3.2 Mean duration of bilabial, alveolar and velar stops in American English (Crystal and House, 1988)

Place of articulation	*Mean duration (ms)*	*Standard deviation (ms)*
bilabial	77	30
alveolar	80	27
velar	103	34

Take a hypothetical instance of /p/ - p1 - and an instance of /k/ - k1 - both of which measure 150 ms in duration. According to Table 3.2, the duration of p1 is almost twice as long as the average duration of /p/ (150 ms vs. 77 ms). The duration of k1 is only one and a half times as long as the average duration of /k/ (150 ms vs. 103 ms). P1 is longer relative to /p/ than k1 is relative to /k/. For this reason, it is impossible to compare the raw durations of p1 and k1.

Because consonants differ in inherent duration, it is necessary to normalize for this inherent duration when comparing durations of consonants as a whole in different positions (e.g. when comparing consonants in final vs. non-final position). This is important because phonemes do not all occur in each position with equal frequency. If the consonants that can occur in coda position happen to be those which are inherently short, for example, this will throw off the results taken from raw durations: it will appear that the coda position is associated with shorter consonants than any other position. This is misleading since the short duration is not an effect of the coda position per se, but rather of the consonants which can fill this position.

In order to normalize for inherent consonant durations, the first step is to calculate z-scores for each token of a particular consonant. Take t1, a particular token of /t/. The z-score of t1 will tell us how the duration of t1 compares to the mean duration of /t/ across positions. The formula for calculating a z-score is given in (4) below (Campbell, 1992, Gravetter and Wallnau, 1999), and an example using t1 is given in (5). X refers to the value for a particular item; in (5), X refers to the duration of t1: 139 ms. The letter μ refers to the mean value for that item across conditions; in (5), μ refers to the mean duration of /t/ across positions: 222 ms. Finally, σ refers to the standard deviation among values for that item; in (5) σ refers to the standard deviation in duration across all tokens of /t/: 176ms.

(4) Formula for calculating z-scores

$$z = \frac{X - \mu}{\sigma}$$

(5) Example z-score calculation (for p1, a token of /p/)

$$z\,(t1) = \frac{139 - 222}{176} = \frac{-83}{176} = -0.47$$

In this example, the z-score for t1 is -0.47. That the z-score is negative indicates that the duration of t1 is shorter than the average duration of /t/.

Having calculated the z-score for each token of a particular consonant, we can then calculate the mean z-score for all tokens of that consonant in a particular position. For example, the mean z-score for all word-final tokens of /t/ will tell us whether or not, in general, the duration of word-final /t/ is longer than the mean duration of /t/ across positions. In order to calculate mean z-scores, one simply adds up the z-scores for all the relevant tokens, and divides by the number of tokens used. Table 3.3 provides an example of z-scores for four tokens each of two phonemes (/t/: t1 through t4, and /n/: n1 through n4) across four positions (non-final onset, non-final coda, final onset, and final coda)[6]. Table 3.4 illustrates how z-scores are used for comparing consonants in different positions positions.

Table 3.3 Z-scores for /t/ and /k/ in different positions

/p/ token	*Duration (ms)*	*Mean duration (st.dev.)*	*Z-score*	*Position*
t1	186	222 (176)	-0.21	Non-final onset
t2	372	222 (176)	0.85	Non-final coda
t3	139	222 (176)	-0.47	Final onset
t4	408	222 (176)	1.06	Final coda
n1	62	214 (111)	-1.37	Non-final onset
n2	273	214 (111)	0.21	Non-final coda
n3	159	214 (111)	-0.49	Final onset
n4	283	214 (111)	0.63	Final coda

Table 3.4 Mean z-scores across positions

Position	*Mean z-score*	
Non-final onset	-0.79	((-0.21-1.37)/2)
Non-final coda	0.53	((0.85+0.21)/2)
Final onset	-0.48	((-0.47-0.49)/2)
Final coda	0.84	((1.06+0.63)/2)

From Table 3.4, we can see that consonants (merged across tokens of /t/ and /n/) are longer in word-final coda position than in any other position, since the mean z-score for this position is higher than for other positions (0.84). That the z-score is positive indicates that the duration of consonants in word-final coda position is greater than the mean duration of consonants across positions. Table 3.4 also tells us that consonants are shortest in non-final onset position, since the mean z-score is the smallest in this position

[6] The z-scores are taken from the data used in Study I.

(-0.79). That the z-score in non-final onset position is negative indicates that in this position consonants are shorter than the average across positions.

As illustrated in Tables 3.3 and 3.4, one can calculate mean z-scores across phonemes. Study I involved comparing the duration of consonants as a whole in final vs. non-final position, and in onset vs. coda position. To do this, mean z-scores across all phonemes were calculated for each of the four conditions outlined in Table 3.4: non-final onset, non-final coda, final onset, and final coda. The mean z-scores were used to determine whether there were significant durational difference between consonants in these four conditions. As mentioned above, using z-scores rather than raw durations allowed for comparing the relative duration of consonants in different positions, without running into the problem of comparing consonants with inherently different durations.

Figure 3.2 provides the z-scores for each condition mentioned above: non-final onset, non-final coda, final onset and final coda. The way to read this graph is as follows: The value 0.0 on the vertical axis indicates the mean duration of consonants across all positions. Values above 0.0 represent durations that are above the average duration across positions, i.e lengthened. Similarly, values below 0.0 represent durations that are below the average duration across positions, i.e shortened. For example, consonants in word-final open coda position have approximately z = +.4 (this value is averaged across consonants). This means that the duration of consonants in word-final coda position is well above the mean duration of consonants across all positions.

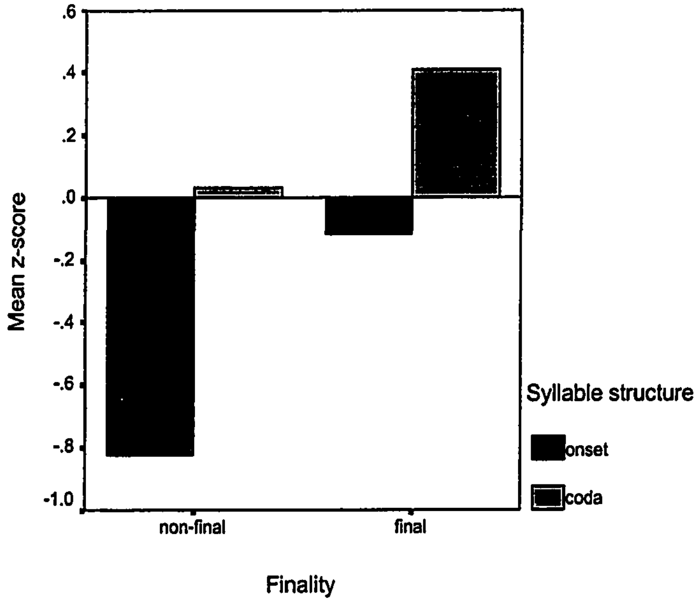

Figure 3.2 Mean z-scores for final and non-final consonants in onset and in coda position

Figure 3.2 shows that the mean duration for non-final onset consonants is substantially below the average duration of consonants across positions in the word. On the other hand, the average duration of final coda consonants is well above the average duration of consonants across positions. Non-final coda consonants are just above average in duration, and final onset consonants are just below average.

Both main effects and the interaction were significant (finality: $F(1,782) = 97.34$, $p < 0.001$; syllable structure: $F(1,782) = 158.46$, $p < 0.001$; finality by syllable structure interaction: $F(1,782) = 9.21$, $p < 0.005$). Analysis of simple effects revealed that the effect of finality was significant for onset consonants ($F(1,437) = 178.69$, $p < 0.001$), with onsets in the final syllable of the word being longer (or less shortened) than those in non-final syllables. The effect of finality was also significant for coda consonants ($F(1,345) = 13.435$, $p < 0.001$). In general, the longest consonants were codas in final syllables. The shortest consonants were onsets in non-final syllables. Finally, from the graph one can see that codas in non-final syllables were slightly longer than onsets in final syllables.

From these results, what can one say about Hypotheses I and II given above? Hypothesis I (that consonants are longer in coda position than in onset position) was supported both word-finally and in preceding syllables. Hypothesis II (that consonants in final syllables are longer than those in non-final syllables) was also supported, both in open and in closed syllables. This means that consonants are affected both by their role in the syllable (onset vs. coda) and by their position in the word. Furthermore, these two effects interact in an interesting manner: indeed, the effect of syllable structure is stronger in non-final position than in final position.

3.2.1.3 Discussion

It is interesting that finality has an effect on the duration of onset consonants as well as coda consonants. Indeed, final-syllable onsets are much longer than non-final-syllable onsets. Furthermore, Figure 3.2 shows a considerably bigger difference between final and non-final onsets than between final and non-final codas. It seems that the effect of final lengthening is even stronger for final onsets than for final codas. This is very surprising, since normally final lengthening affects the last segment of the domain most (Klatt, 1979, Kaiki and Sagisaka, 1990, Sagisaka, 1992). Two factors help explain this result. First, final lengthening appears to affect the entire final syllable in Lheidli rather than simply the last segment, such that final-syllable onsets are lengthened as well as final-syllable codas. Second, given that onsets are so short in non-final position (compared to codas), final lengthening has a proportionally larger effect on final onsets than on final codas. This accounts for the smaller difference in duration between onsets and codas in final syllables, compared to the difference between onsets and codas in non-final syllables.

It is worth noting here that, even if word-final lengthening affects the whole syllable, there are no compensatory effects such that onset consonants are longer in final open syllables than in final closed syllables. Figure 3.3 compares the duration of onsets in final open vs. final closed syllables. Data comes from dividing the set of 130 words with word-medial clusters used previously into two groups: (a) those with final open syllables (50) and (b) those with final closed syllables (80).

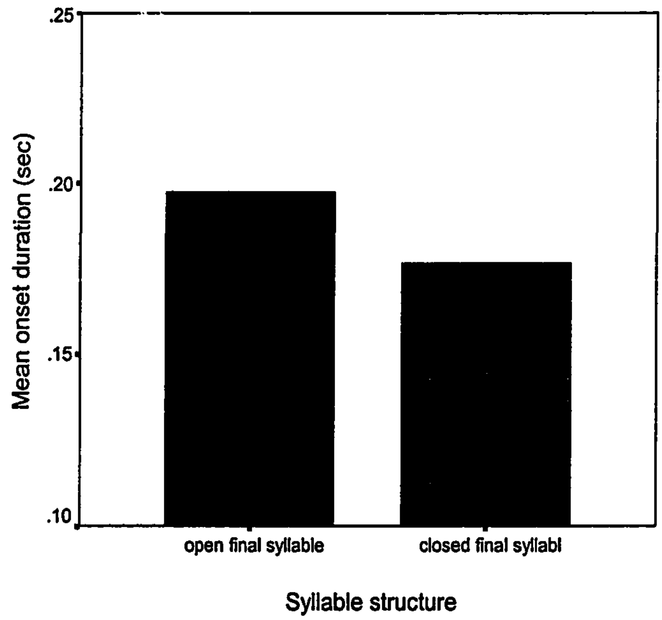

Figure 3.3 Duration of final onset in open vs. closed final syllables

Although Figure 3.3 shows a slight tendency towards longer onsets in open syllables, a single factor ANOVA (with syllable structure as the factor) shows that this tendency is not significant ($F(1,128) = 2.35$, $p > 0.05$).

As we shall see in Chapter 5, the effect of syllable structure on vowel duration is significant word-finally but not word-medially, providing further evidence for final lengthening affecting the whole syllable. Determining what the domain is for word-final lengthening is an interesting question. There is some evidence that in Japanese, this domain is the final mora (Kaiki, 1990, Sagisaka, 1992). The Lheidli data show that the domain can also be the final syllable.

Aside from word-final lengthening effects, Study I has shown that coda consonants are longer than onsets. This finding will allow us to determine whether intervocalic consonants pattern with codas or with onsets, or with neither, based on their duration.

3.2.2 Study II: The nature of intervocalic consonants

We have just seen that onsets behave differently than codas in terms of their duration. What about intervocalic consonants? The following bar graph compares mean durations of word-medial onsets (VC$\underline{\text{C}}$V), word-medial codas (V$\underline{\text{C}}$CV), intervocalic consonants (V$\underline{\text{C}}$V), and word-medial clusters (V$\underline{\text{CC}}$V). Note that I am comparing raw durations rather than z-scores in this figure. Z-scores are used for removing inherent durational differences between consonants when comparing duration in different positions, across consonants. Consonant clusters do not involve the same consonant occurring in different positions; they are always in the same position (word-medially) and consist of two different consonants. For this reason, z-scores are not an appropriate measure for clusters.

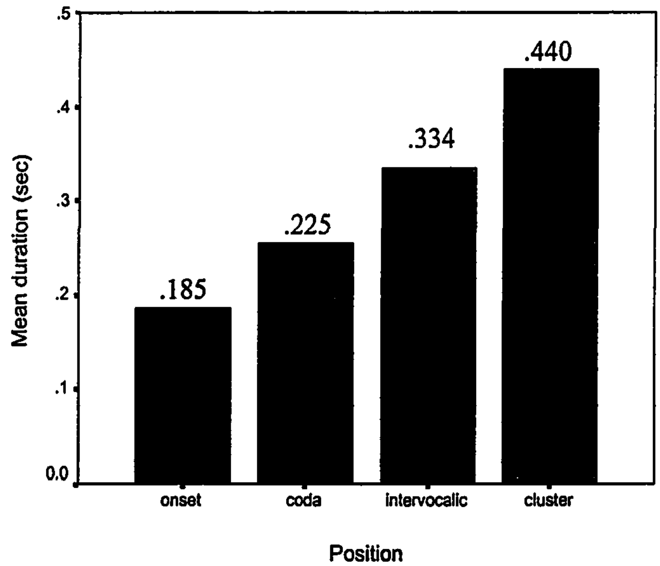

Figure 3.4 Mean durations for onset consonants, coda consonants, intervocalic consonants, and consonant clusters

Figure 3.4 shows a very even increase in duration for different consonantal categories. Note that the 'cluster' category used to compute cluster duration corresponds simply to the 'onset' duration added to the preceding 'coda' duration (within each word). Onset consonants have the shortest durations, and clusters have the longest durations. Between the two are coda consonants (shorter) and intervocalic consonants (longer). This graph shows clearly that intervocalic consonants are long compared to codas as well as to onsets.

The phonological role of length in intervocalic consonants is discussed in Chapter 5. Study II explores the phonetic quality of intervocalic consonants through two comparisons, the first involving onsets and codas (Comparison A) and the second involving clusters (Comparison B).

3.2.2.1 Design of the study

Comparison A compared the duration of intervocalic consonants to that of plain onsets and codas. Comparison B compared the duration of intervocalic consonants to that of consonant clusters. In both comparisons, the data used consisted of the same set of 342 words used throughout this dissertation[7]. All words had the form (C)VCV(C) or (C)VCCV(C). The consonants used in comparison A were (a) intervocalic consonants: (C)VCV(C), word-medial onsets: (C)VCCV(C), and (c) word-medial codas: (C)VCCV(C). The consonants used in comparison B were (a) intervocalic consonants: (C)VCV(C), and (b) word-medial clusters: (C)VCCV(C). The clusters in comparison B were formed from the onsets and codas used in comparison A. This made the data more easily comparable. Tables 3.5 and 3.6 summarize these research designs. The number of consonants used in each condition is included in parentheses in each cell of the tables.

Table 3.5 Experimental design of Comparison A

Onset	*Coda*	*Intervocalic*
(C)VCCV(C) (130)	(C)VCCV(C) (130)	(C)VCV(C) (212)

Table 3.6 Experimental design of Comparison B

Cluster	*Intervocalic*
(C)VCCV(C) (130)	(C)VCV(C) (212)

In Comparison A, z-scores were used to remove inherent durational differences between

[7] See Appendix A for the complete word list used.

consonants. In Comparison B, raw durations were used because the comparison was across two different categories (intervocalic consonants vs. clusters) rather than across different instances (onset, coda, intervocalic) of a single category (a given consonant). Since z-scores are used to standardize across instances only (not across categories), they would not be appropriate in Comparison B.

3.2.2.2 Results

The following bar graph illustrates the differences in z-scores between onsets, codas, and intervocalic consonants (Comparison A).

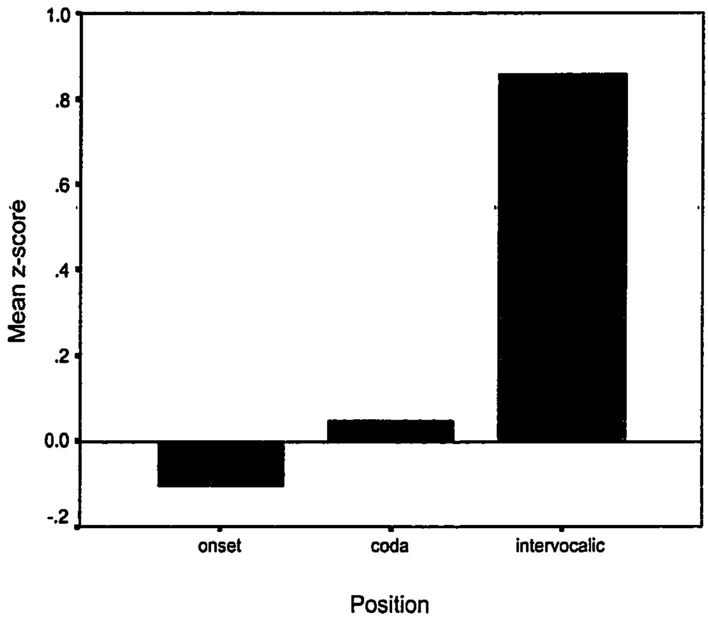

Figure 3.5 Mean z-scores for onset consonants, coda consonants, and intervocalic consonants

From Figure 3.5, it is clear that intervocalic consonants are much longer than either onsets or codas. The data was analyzed with a single-factor between-items ANOVA, the factor being position (onset, coda, intervocalic). The effect of position was significant ($F(1,469) = 79.66$, $p < 0.001$). Onsets are the shortest, falling below the average duration of consonants across positions. Codas are slightly above average. The duration of intervocalic consonants is much higher than average. A post-hoc comparison of intervocalic consonants and coda consonants showed that the difference in mean z-score between consonants in these two positions was significant ($t(469) = 9.56$, $p < 0.001$). The mean z-score for intervocalic consonants is significantly higher than that for codas. This means that consonants in intervocalic position are significantly longer than consonants in coda position. Given that the mean z-score for onsets is even smaller than is the one for codas, this finding implies that intervocalic consonants are also significantly longer than onset consonants. A second post-hoc comparison of onsets and codas showed that the difference in z-score between consonants in these two positions was not significant ($t(469) = 1.52$, $p > 0.05$).

The following bar graph illustrates the results of Comparison B; it is a simplified version of Figure 3.4 - only the results for intervocalic consonants and clusters are shown here:

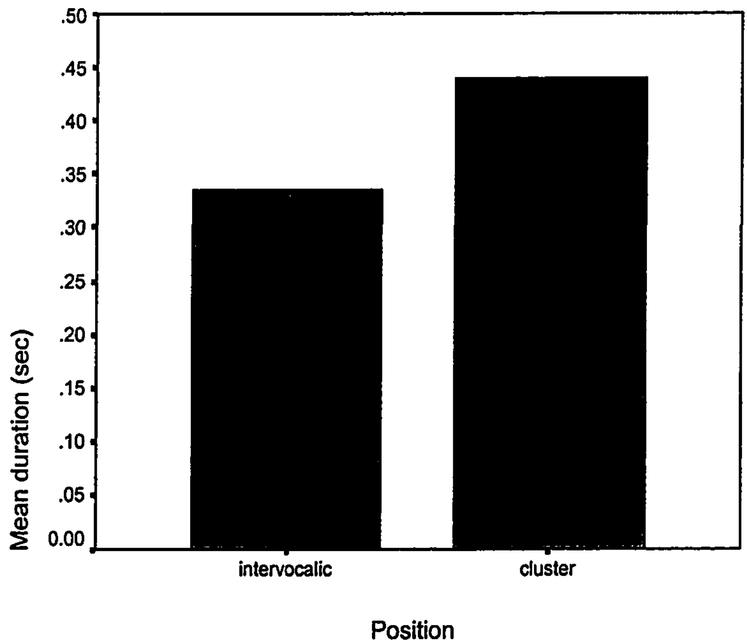

Figure 3.6 Mean durations (in seconds) for intervocalic consonants and consonant clusters

Again, the data was analyzed with a single-factor between-items ANOVA, the factor being complexity (intervocalic consonant, cluster). Results show that although intervocalic consonants are much longer than both onsets and codas separately, they are shorter than the consonant clusters created by combining these onsets and codas. This effect is significant ($F(1,340) = 88.55$, $p < 0.001$).

3.2.2.3 Discussion

Results from Comparison A indicate that, at least from a phonetic point of view, intervocalic consonants act neither as onsets - yielding the syllable structure CV.CV(C), nor as coda consonants - yielding the syllable structure CVC.VC(C). Looking back at Figure 3.4, intervocalic consonants are approximately 3 times as long as onsets, and almost twice as long as word-medial codas. These data provide the first indication that intervocalic consonants must affect both the rhythmic structure and the syllable structure of Lheidli in a special way, discussed in Chapters 4 and 5 respectively.

Comparison B shows that the duration of intervocalic consonants is smaller than that of *coda* + *onset* consonant clusters. Ideally, in order to argue that intervocalic consonants behave as both onsets and codas, one would have liked their duration to be equivalent to that of heterosyllabic consonant clusters. However, differences in duration between geminates and clusters could simply be due to the articulatory and aerodynamic requirements associated with producing one continuous sound vs. a sequence of two sounds. The fact that intervocalic consonants in Lheidli are shorter than *coda* + *onset* clusters does not disprove the idea that they geminate to fill requirements of syllabification and stress assignment.

3.2.3 Conclusion on consonant durations

Study I showed that there was a significant difference in duration between onset and coda consonants. Study II showed that, in terms of duration, intervocalic consonants behaved neither as onsets nor as codas, being significantly longer than consonants in either of these positions. Intervocalic consonants also differed from clusters in duration, although as mentioned in section 3.2.2.3, this finding can perhaps be explained through articulatory and aerodynamic requirements involved in the production of a single sound (intervocalic consonants) vs. two sounds (clusters).

In the studies presented in this section, I used the terms 'final' and 'non-final' in comparing the duration of consonants across positions in the word. I continue using these terms in studies reported in subsequent sections (in Chapter 5). Given that the data used in these studies consists exclusively of bisyllabic words, the 'non-final' condition corresponds to the 'initial' position. It is possible that word-medial onsets and codas behave differently from those in the first and last syllables of words. For this reason, it would be useful to compare the results presented here with results obtained from analyzing longer words. This comparison will be undertaken in future research.

3.3 Intervocalic consonants vs. the surrounding vowels

That intervocalic consonants are unusually long in duration can further be seen by comparing their duration to that of the surrounding vowels. It has often been found in the literature that vowels are longer than their surrounding consonants (Lahiri and Hankamer, 1988, Giovanardi et al. 1998). This finding supports the idea that vowels carry the melody of the language, put forth by researchers such as Fowler (1983), Pérez (1997) and Grabe (1999). Indeed, the salience of vowels is increased by their relative duration. As a result their ability to 'carry the melody of the language' is clearer than if they were shorter and less salient that the surrounding consonants[8].

---

[8] Note though that duration does not necessarily correspond to salience. See Warner (1998) for a discussion of length and salience.

In the paragraphs below, I show that intervocalic consonants are for the most part substantially longer than their surrounding vowels. This provides another indication that they are indeed unusually long, and that their duration will affect both the phonetic timing (rhythm) and phonological timing (syllabification) of Lheidli.

Let us first look at intervocalic consonants compared to the vowels that precede them. In a set of 212 words of the form (C)VCV(C), the duration ratio between the intervocalic consonant and the preceding vowel was calculated. Figure 3.7 provides this ratio for each vowel. The ratio is averaged across consonants. For example, intervocalic consonants are on average just over twice as long as the vowel /a/, and almost 5 times as long as the vowel /ʌ/ (labeled 'u')[9].

[9] In Figures 3.7 and 3.8, /u/ is labeled 'oo', /ʌ/ is labelled 'u', and /ʌi/ is labelled 'ui' (following the Lheidli practical orthography.

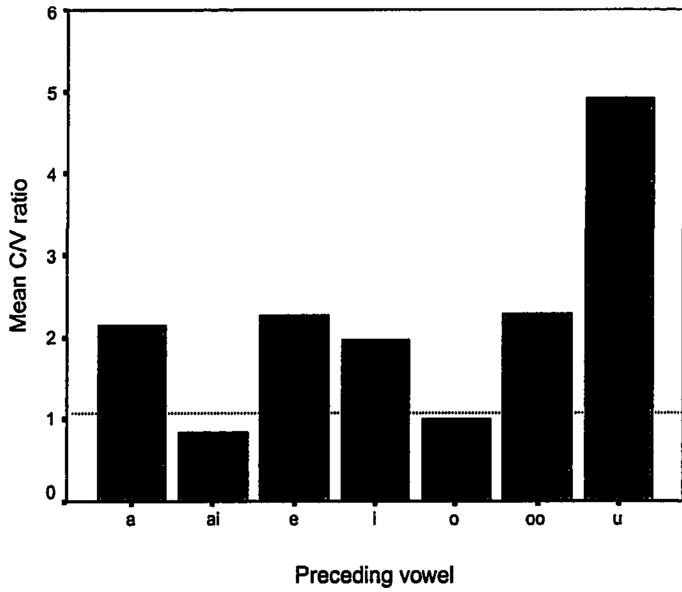

Figure 3.7 Mean ratio of the duration of intervocalic consonants to the duration of the preceding vowel

Figure 3.7 shows that the C/V ratios are for the most part greater than one. Indeed, on average, the duration of the intervocalic consonant was 3.28 times longer than the duration of the preceding vowel. The mean duration of intervocalic consonants was 334 ms and the mean duration of the preceding vowel was 135 ms. A single factor within-items ANOVA (the factor is segment type; the two levels are intervocalic consonant and preceding vowel) showed that this difference in duration was significant($F(1,211) = 275.31$, $p < 0.001$): intervocalic consonants were indeed significantly longer than the preceding vowel.

Note that in Figure 3.7, only the vowels /ai/ and /o/ are longer than the following intervocalic consonant - with the C/V ratio just below one. That /ai/ is longer than the following consonant is not surprising, since it is a diphthong. It seems odd that /o/ is longer than the preceding consonant. However, there are only 4 tokens of /o/ (out of a total of 212 vowels) - its unusual behavior is perhaps an artifact of the small sample size. Finally, the extremely high ratio of intervocalic consonant to preceding /ʌ/ results from /ʌ/ being a very short vowel (as mentioned in Chapter 2, section 2.1.4 and Chapter 5, sections 5.3.1.2 and 5.3.2.2).

Let us now turn to a comparison of intervocalic consonants with the following vowels. Using the same set of 212 words, the duration ratio between the intervocalic consonant and the following vowel was calculated. Figure 3.8 gives the duration ratio of intervocalic consonant to following vowel. In this case the ratio is given for each vowel in 2 positions: word-final (V#) and followed by a consonant (VC#). This is done so as to make explicit the effect of final lengthening on the vowel. Again, the average ratio is averaged across consonants. Notice that the diphthong /ʌi/ is represented here whereas it was absent from Figure 3.7. This is because it only occurred in the second syllable. Notice also that there are no cases of non-final /ʌi/ (VC#), and no cases of word-final /ʌ/ (V#). This last fact is discussed further in Chapter 5, section 5.1.3, on vowel distributions.

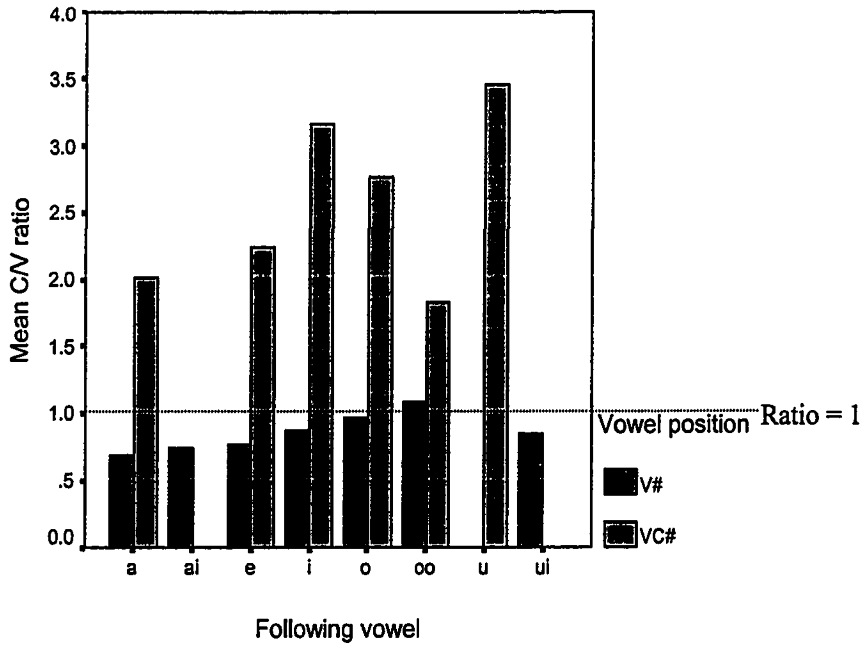

Figure 3.8 Mean ratio of the duration of intervocalic consonants to the duration of the following vowel

Word-finally, all vowels except [u] ('oo' in Figure 3.8) are longer than the preceding consonant, with a mean C/V ratio of 0.31. This results from word-final lengthening. When followed by a coda consonant, vowels are generally shorter than their preceding consonant, with a ratio of 2.70. As mentioned above, the mean duration of intervocalic consonants is 334 ms. The mean duration of following vowels in open syllables (V#) is 440 ms and the mean duration of following vowels in closed syllables (VC#) is 149 ms. A two-factor ANOVA (with the factors being final vowel position: V# or VC# and segment type: intervocalic consonant or following vowel) showed that both main effects and the interaction were significant (final vowel position: $F(1,420) = 13.24$,

$p < 0.001$; segment type: $F(1,420) = 224.81$, $p < 0.001$; interaction: $F(1,420) = 161.98$, $p < 0.001$). Analysis of simple effects showed that the effect of segment type (C vs. V) was significant both in CV# contexts ($F(1,148) = 19.07$, $p < 0.001$) and in CVC# contexts ($F(1,272) = 299.36$, $p < 0.001$). Intervocalic consonants are significantly longer than the following vowel in a closed syllable (VC#), and significantly shorter than the following vowel in an open syllable (V#).

In summary, Lheidli intervocalic consonants are significantly longer than (a) the preceding and (b) the following vowels when they are not word-final (and subject to word-final lengthening). The high ratio in duration between intervocalic consonants and their surrounding vowels is unusual cross-linguistically (Lahiri and Hankamer, 1988, Campbell, 1992, Giovanardi and Di Beneditto, 1998). Table 3.7 compares Italian, Turkish, and Lheidli in terms of the ratio *intervocalic consonant/preceding vowel.* From this table it is clear that this ratio is much higher in Lheidli than in Italian and Turkish, even when Lheidli consonants are compared to geminates in the other languages.

Table 3.7 C/V1 ratio in V1CV2 sequences

Language	Ratio		Source
Italian	*Singletons:* *Geminates:*	0.80 1.97	Giovanardi and Di Beneditto (1998)
Turkish	*Singletons:* *Geminates:*	0.94 1.81	Lahiri and Hankamer (1988)
Lheidli	?	3.38	Bird (current work)

In Chapter 4, I present data on the ratio of consonantal material to vocalic material in words and utterances, and on the variability in duration across consonantal intervals.

These are two of the measures which are used to compute the rhythm of a language (Ramus et al., 1999). The data presented in Chapter 4 further support findings presented here on the remarkable length of intervocalic consonants: Lheidli has a much higher proportion of consonantal material in its words than do other languages.

3.4 Intervocalic consonants in Lheidli vs. in other languages

We have just seen that intervocalic consonants are substantially longer than consonants in other positions, as well as longer than the surrounding vowels (provided they are not word-final). The duration of intervocalic consonants becomes even more surprising when compared to that of consonants in other languages. Several researchers have explored (a) the duration of consonants compared to those of vowels, and (b) the duration of singleton vs. geminates in languages which have both (Homma, 1981, Crystal and House, 1988, Lahiri and Hankamer, 1988, Campbell, 1992, Nagano-Madson, 1992, Giovanardi and Di Benedetto, 1998, Pickett et al., 1999, Aoyama, 2000, Kraehenmann, 2001). Tables 3.8 through 3.10 compare consonant durations cross-linguistically. Since the methodological details vary from study to study, these comparisons should be taken simply as a broad, approximate indication of consonantal length in Lheidli compared to that in other languages. Durations are those found in the original papers - hence different levels of preciseness. Standard deviations are included when available from the original sources. Table 3.8 provides durations of singleton and geminate consonants across different languages. Note that the standard deviation in Lheidli is much higher than in the other languages. This results from the nature of the Lheidli data. It was collected from one elderly speaker, in the field. Speech elicited in such fieldwork is inevitably more variable than laboratory speech, since it is not possible to control the environment in which speech is elicited in the same way as it is possible in a laboratory setting.

Table 3.8 Mean duration of singleton and geminate (where available) consonants cross-linguistically[10]

Reference	*Language*	*Sound*	*Duration (ms)*
Homma (1981)	Japanese	Voiceless singleton stops Voiceless geminate stops	83 193
		Voiced singleton stops Voiced geminate stops	44 157
Aoyama (2000)	Japanese	Singleton /n/ Geminate /n/	68 172
Aoyama (2000)	Finnish	Singleton /n/ Geminate /n/	62 178
Giovanardi and Di Benedetto (2001)	Italian	Singleton fricatives Geminate fricatives	134.9 (37.6) 233.25 (45.07)
Lahiri and Hankamer (1988)	Turkish	Voiceless singleton stops Voiceless geminate stops	105 210
Kraehenmann (2001)	Swiss German	Singleton stops Geminate stops	68.6 171.9
Campbell (1992)	Japanese	/k/	60.04 (28.41)
		/s/	89.05 (18.55)
		/t/	75.32 (51.91)
		/n/	41.38 (12.24)
		/h/	66.71 (21.19)
		/m/	45.98 (11.35)
		/y/	56.24 (14.61)
		/w/	42.84 (11.39)
Bird (current work)	Lheidli	Intervocalic consonants	334.25 (105)

[10] With the exception of Campbell (1992), the consonants measured in all studies were in intervocalic position.

Based on Table 3.8, one can calculate average durations of singleton and geminate consonants across languages. Doing this allows us to see how Lheidli intervocalic consonants pattern with respect to singletons and geminates. This is done in Table 3.9:

Table 3.9 Mean duration of Lheidli intervocalic consonants compared to singletons and geminates cross-linguistically

Consonant type	*Duration (ms)*
Singletons (averaged across languages other than Lheidli)	70
Geminates (averaged across languages other than Lheidli)	188
Lheidli intervocalic consonants	334

From Tables 3.8 and 3.9, it is clear that Lheidli intervocalic consonants are remarkably long compared to consonants in other languages. In fact, from the figures given here, it seems that they are too long even to be geminates. This may be partially due to the effect of speech rate, which is not comparable across the studies included in the Tables above. However, if the difference in duration between Lheidli intervocalic consonants and those in other languages were entirely an effect of speech rate, one would expect Lheidli vowels to be lengthened by the same proportion, such that the ratio between the intervocalic consonant and the preceding vowel would be the same in all languages. This is not the case: Table 3.7 (above) shows that in Italian and Turkish, the ratio of intervocalic consonant to preceding vowel never exceeds 2/1 even for geminates. In Lheidli, this ratio is on average well over 3/1. The fact that intervocalic consonants are so long relative to onset and coda consonants within Lheidli further indicates that the duration of Lheidli intervocalic consonants is not solely an effect of speech rate.

Table 3.10 reports on studies which were conducted on the duration of segments depending on speech rate. The numbers in parentheses (in the last column) refer to standard deviations.

Table 3.10 Mean duration of consonants depending on speech rate

Reference	*Language*	*Speech*	*Duration (ms)*
Crystal and House (1987)	English	Slow speech	75 (37)
		Fast speech	64 (30)
		All speech rates	70 (34)
Pickett (1999)	Italian (singletons)	Isolated form	117
		Slow speech	98
		Fast speech	75
Pickett (1999)	Italian (geminates)	Isolated form	276
		Slow speech	208
		Fast speech	136
Bird (in preparation)	Lheidli	Isolated forms	334 (105)

From this table, it seems that Lheidli's intervocalic consonants most resemble Italian geminates, spoken in isolation and in slow speech (Pickett, 1999). It is worth pointing out here that the Lheidli data used for analysis is based on words spoken in isolation. Since Italian data (Pickett, 1999) show that forms in isolation are substantially longer than words spoken in context, it seems probably that some of the length of Lheidli consonants is due to the manner in which words were elicited. Further research will involve measuring segments in words spoken in continuous speech.

In summary, even if one considers the longest consonants discussed in other languages, Lheidli intervocalic consonants still seem unusually long. In languages which have the geminate/singleton distinction, Lheidli intervocalic consonants are certainly closer in duration to the geminates. However, they are longer even than geminates (notably compared to Italian geminates, which has the longest consonants reported in the literature covered in this section).

3.5 Duration as a function of place of articulation, manner of articulation, and voicing

Although intervocalic consonants in Lheidli are generally long, their duration does differ depending on their nature. I conclude this section with an investigation of duration as a function of place of articulation, manner of articulation, and voicing.

Figure 3.9 illustrates the duration of intervocalic consonants based on manner of articulation. In general, the less sonorant sounds are the longest. Affricates are longest, followed by fricatives and stops. Then, in decreasing order of duration come liquids, nasals, and finally glides - the shortest sounds.

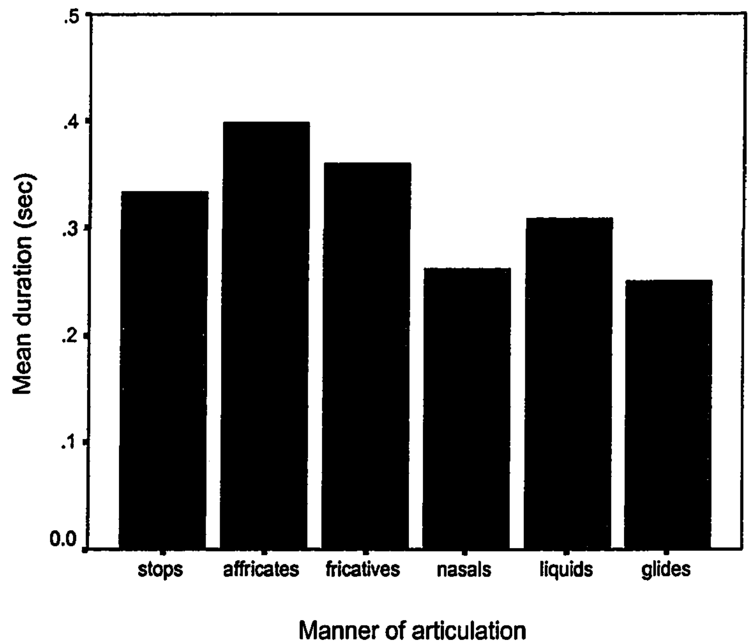

Figure 3.9 Duration of intervocalic consonants
as a function of manner of articulation

The distribution of duration as a function of manner of articulation shown in Figure 3.9 is, for the most part, supported by Crystal and House's (1987) work on English. Although the durations of Lheidli sounds are much longer than those reported by Crystal and House, the durations across manners of articulation pattern similarly in both cases. The only difference is in the nasals. Crystal and House (1987) found that they were the same length as oral stops in English. In Lheidli, they are much shorter than oral stops.

Table 3.11 Consonant duration by manner of articulation in English and Lheidli

English (Crystal and House, 1987)		Lheidli (current work)	
Manner of articulation	*Mean duration (st.dev.)*	*Manner of articulation*	*Mean duration (st.dev.)*
Affricates	123 (42)	Affricates	396 (98)
Fricatives	80 (42)	Fricatives	359 (76)
Stops	76 (36)	Stops	333 (103)
Nasals	76 (33)	Liquids	307 (108)
Liquids	72 (29)	Nasals	261 (85)
Glides	63 (29)	Glides	249 (105)

The Lheidli findings illustrated in Figure 3.9 are also supported by data from Welsh (Viheman, 2002), in which intervocalic stops and fricatives are particularly subject to lengthening by children (compared to other manners of articulation)[11].

Figure 3.10 illustrates the duration of intervocalic consonants as a function of place of articulation. In general, the more 'front' the place of articulation is, the longer the consonant is.

[11] Welsh has affricates as well (/tʃ/ and /dʒ/), but they are rare, and result exclusively from borrowing (Kibre, 1997).

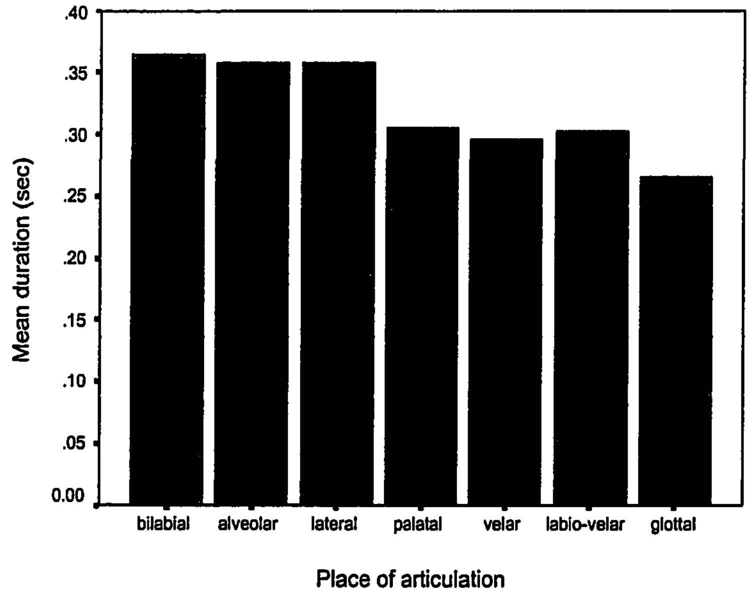

Figure 3.10 Duration of intervocalic consonants
as a function of place of articulation

This finding is supported by Byrd (1993), but contrary to Crystal and House's (1997, 1988) finding that the more 'front' the place of articulation is, the shorter the consonant is. Crystal and House looked only at labial, alveolar and velar sounds, and only at stop consonants. Figure 3.11 illustrates bilabial, alveolar, and velar stops only, thus providing data comparable to Crystal and House. This figure shows that the different durational distributions in the current work vs. Crystal and House's work are not simply an effect of the different manners of articulation considered. Looking at Figure 3.11, the distribution follows the same pattern as in Figure 3.10: the more front the articulation is in Lheidli, the longer the stops are.

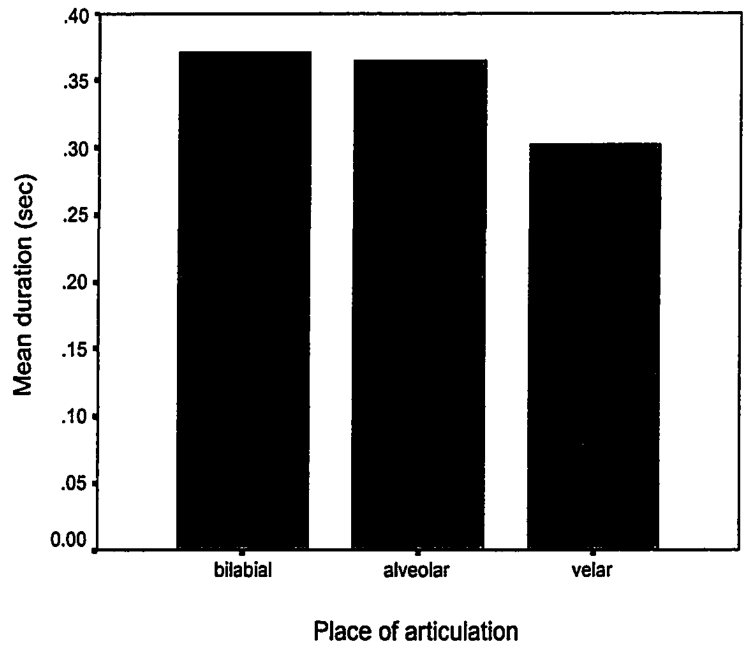

Figure 3.11 Duration of intervocalic stop consonants as a function of place of articulation

A single factor ANOVA (place of articulation) showed that the difference in duration between places of articulation was significant ($F(2,74) = 4.07$, $p < 0.05$). Based on this finding, two planned comparisons were done to determine the source of the significant differences in duration. The first found that there is a significant difference between bilabial and alveolar stops on one hand, and velar stops on the other ($t(74) = 2.78$, $p < 0.01$). The second comparison found that there was no significant difference in duration between bilabial and alveolar stops ($t(74) = 0.20$, $p > 0.05$). In summary, the pattern observed in Lheidli differs from that observed in English by Crystal and House, at least to the extent that in Lheidli, velar stops are shorter than stops at other places of articulation.

Finally, the duration of intervocalic consonants varies as a function of voicing, as illustrated in Figures 3.12 and 3.13. Nasals, liquids, and glides were excluded from these figures because they are always voiced. Figure 3.12 provides the mean durations for stops and affricates, as a function of voicing (voiceless unaspirated, voiceless aspirated, and ejective).

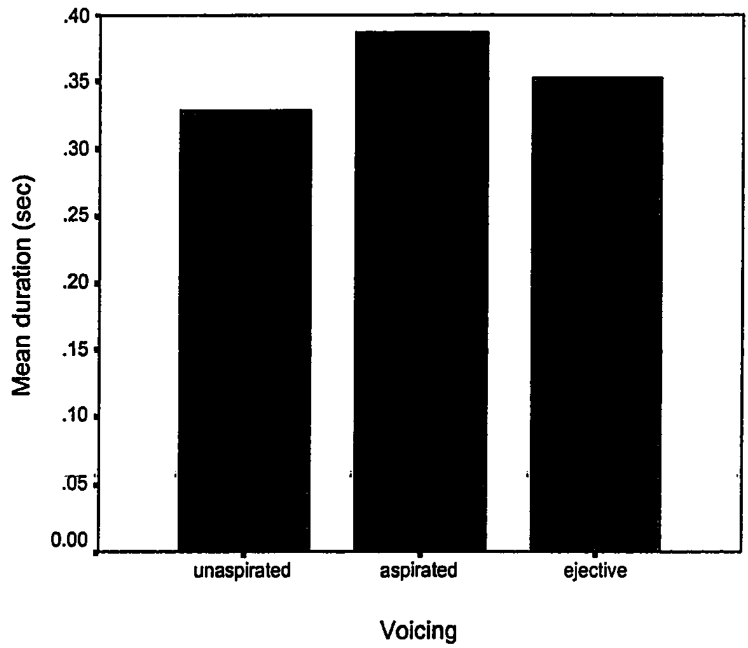

Figure 3.12 Duration of intervocalic stops and affricates
as a function of voicing

A single factor ANOVA (voicing) showed that the durational differences between unaspirated, aspirated, and ejective stops were significant ($F(2,119) = 3.58$, $p < 0.05$). Based on this finding, three planned comparisons were done, which showed that the only significant difference in duration was between unaspirated and aspirated stops ($t(119) =$

2.68, $p < 0.01$). The durational difference between unaspirated and ejective stops was not significant ($t(119) = 1.04$, $p > 0.05$), and neither was the difference between aspirated and ejective stops ($t(119) = 1.36$, $p > 0.05$).

Recall from chapter 2 that Lheidli has both weak and strong ejectives. In Figure 3.12 ejectives are considered as one group. The prediction is that if they were split into two categories, weak ejectives would be similar in duration to voiceless unaspirated sounds, whereas strong ejectives would be even longer than voiceless aspirated sounds.

Figure 3.13 provides the mean duration as a function of voicing for fricatives (voiced vs. voiceless).

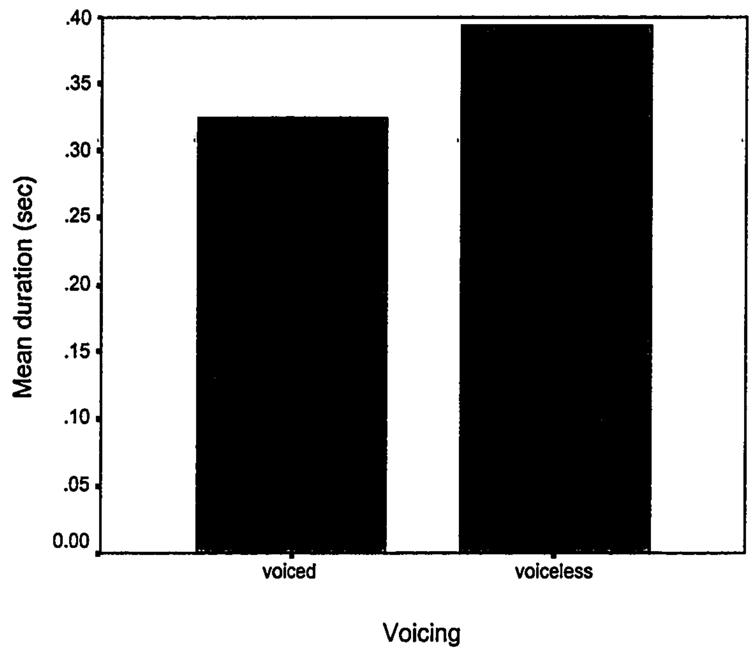

Figure 3.13 Duration of intervocalic fricatives
as a function of voicing

A single factor ANOVA (voicing) showed that voiced fricatives were significantly shorter than voiceless fricatives ($F(1,41) = 11.07, p < 0.01$). This finding is supported by Crystal and House's (1987, 1988) finding that voiced stop consonants are shorter than voiceless ones in English.

In summary, the duration of intervocalic consonants generally patterns in the predicted ways (based on Crystal and House's work) with respect to manner of articulation and voicing: the more sonorous consonants are, the shorter they are (with the exception of nasals in Lheidli); voiceless unaspirated stops and affricates are shorter than voiceless unaspirated ones and voiced fricatives are shorter than voiceless ones. With respect to place of articulation, Lheidli does not pattern like English: Crystal and House (1988) found that the more front the place of articulation was, the shorter the consonant was. The Lheidli data show the opposite distribution; the more front the place of articulation is, the longer the consonant is.

3.6 Conclusion

Chapter 3 has provided a phonetic analysis of the durational properties of intervocalic consonants in Lheidli, which is representative of other Athapaskan languages discussed in the literature. Studies reported in this Chapter reveal that (a) intervocalic consonants are substantially longer than consonants in other positions within the language, (b) intervocalic consonants are for the most part longer than surrounding vowels in the language, and (c) intervocalic consonants are longer than consonants found in other non-Athapaskan languages. Together, these results provide robust evidence that

Lheidli intervocalic consonants exhibit unique durational properties: they are indeed unusually long and for this reason should be considered geminates, in the descriptive sense. Furthermore, intervocalic consonants support the view that language-specific phonetics exists (Keating, 1985, Kingston and Diehl, 1994, Cohn, 1998, Tsuchida, 1998, etc.). Indeed, that intervocalic consonants in Lheidli are so much longer than those in other languages must be encoded in the grammar, since their duration is an important factor in making Lheidli (and other Athapaskan languages) sound so different from other, more extensively studied languages. How to encode this Lheidli-specific phonetic information, and how it interacts with the phonology of Lheidli, is taken up in detail in Chapter 6.

Based on the findings reported in Chapter 3, the question that arises is: what role do intervocalic consonants play in the structure of the language? This question can be approached from two perspectives, one phonetic and the other phonological. First, it is possible to approach the unusual length of Lheidli's intervocalic consonants as a purely phonetic property. In this case, its role can be said to involve the rhythmic structure of language. Second, it is possible to approach the length of these consonants as the phonetic manifestation of a phonological property. If this is the case, then the role of duration in intervocalic consonants can be said to involve the syllabification requirements of the language.

The phonetic approach is taken up in Chapter 4, in which I propose that rhythm in language is a function of a combination of phonetic and phonological facts, where the phonetic facts include segmental duration. The phonological approach is taken up in

Chapter 5, in which I present the results of a series of studies showing that intervocalic consonants in Lheidli are non-contrastive geminates (in the formal sense), acting as codas to the preceding syllable as well as an onsets to the following syllable. Chapter 6 concludes by proposing a unified explanation of the length of intervocalic consonants, in which phonetic duration is directly correlated with phonological weight.

CHAPTER 4 THE PHONETIC ROLE OF INTERVOCALIC CONSONANTS: SEGMENTAL DURATION AND RHYTHM

Having established in Chapter 3 that intervocalic consonants are remarkably long in Lheidli, I now turn to an exploration of the role of these intervocalic consonants in Lheidli. In this chapter, I consider their role from a purely phonetic perspective, focusing on the effect of their duration on the rhythmic structure of the language. Chapter 5 goes on to discuss their formal representation and their phonological role with respect to syllable structure. Finally, chapter 6 concludes by integrating the phonetic and phonological roles of intervocalic consonants in Lheidli.

Discussion in this chapter is based on the recent literature on rhythm classes, and begins with an in-depth discussion of this literature. Rhythm in language is still very little understood, and for this reason it is worth spending a fair amount of time on the research that has been done on the topic and the conclusions that have been drawn so far. Based on this literature, I provide a new model of rhythm, which allows languages to fall along a continuum with respect to rhythm. I also argue that Lheidli intervocalic consonants provide evidence for a correlate of rhythm not yet considered in the literature: inherent segmental (consonantal) duration.

The chapter is structured as follows: section 4.1 provides an overview of the literature on rhythm. Section 4.2 provides a discussion of the importance of segmental duration in establishing the rhythmic structure of language. This section is based Ramus et al.'s (1999) approach to rhythm, and on the phonetic nature of Lheidli intervocalic consonants (established previously in Chapter 3). Section 4.3 proposes a new model of rhythm based on primary and secondary correlates to rhythm. Section 4.4 illustrates how this model captures the facts of Lheidli. Finally, I conclude by raising some issues that have yet to be addressed in the rhythm literature.

4.1 Rhythm and rhythm classes

What is rhythm in language? With respect to music, rhythm is defined by the Webster's Third New International Dictionary of the English Language as the "forward movement of music", which is created in part by the presence of "an underlying steady and persisting succession of beats" (p. 1950). With respect to language, this question - what is rhythm? - has proven much more difficult to answer, primarily because very little acoustic evidence for an "underlying steady and persisting succession of beats" has been found in natural language.

In his Dictionary of Linguistics and Phonetics, Crystal provides the following definition for rhythm (Crystal, 1997):

> "an application of the general sense of this term in phonology, to refer to the perceived regularity of PROMINENT UNITS in speech. These regularities may be stated in terms of patterns of STRESSED vs. unstressed SYLLABLES, syllable LENGTH (long vs. short) or PITCH (high vs. low) - or some combination of these variables. Maximally regular patterns, such as are encountered in many kinds of poetry, are referred to as 'metrical." (p. 334)

There are two key components to Crystal's definition: (a) perceived regularity, and (b) prominent units. In the discussion below, I argue that rhythm in language is similar to rhythm in music: it is the "forward movement" of speech. Where language and music differ is in terms of the two components mentioned by Crystal: perceived regularity and prominent units. In music, the 'prominent unit' is the beat, for example the quarter note in the time signature 4/4. The regularity with which it recurs is physical, objective, and quantifiable. Indeed, it is possible to measure the time that elapses between beats in a piece of music. As long as the tempo is kept constant, the interval between beats remains the same[1].

In language, on the other hand, the prominent unit can vary. In the traditional view of rhythm, the unit can be the stressed syllable (in stress-timed languages), the syllable (in syllable-timed languages), or the mora (in mora-timed languages). However, there is disagreement as to whether these units should really be used to classify languages into rhythm classes (Dauer, 1987, Nespor, 1990, Ramus et al., 1999, Grabe and Low, in press). Crystal himself states that the prominent units can also involve length and pitch. Furthermore, many researchers now believe that the regularity with which these units recur is not physical[2], but rather is perceptual[3]. The degree to which speech units are perceived as recurring regularly is a function of several phonetic and phonological factors in the language in question.

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[1] Or at least that is the goal.
[2] At least not in natural speech. In poetry for example, beats do occur regularly.
[3] Though Scott and Isard (1985) argue that even perceptual isochrony does not exist.

In this section, I start here by presenting an overview of the literature on rhythm, beginning with Pike (1945) and Abercrombie (1965, 1967), and ending with Grabe and Low (in press) and Ramus (1999). This overview serves as background for sections 4.2 and 4.3, in which I propose a new theory of rhythm based in part on what has already been found in the literature.

4.1.1 The traditional view of rhythm

The traditional classification of languages in terms of their rhythmic structure is based on isochronous units of speech, 'isochronous' meaning 'recurring regularly' (Pike, 1945, Abercrombie, 1965, 1967). In *stress-timed* languages like English, the isochronous unit is the foot. In *syllable-timed* languages like French, it is the syllable. Finally, in *mora-timed* languages like Japanese, the isochronous unit is the mora.

There are two problems with this classification. The first is that it simply stipulates that a particular unit recurs (relatively) regularly in a particular language, and this is not related to any other phonological factors of the language. However, there is very little evidence in speech for any regularly recurring interval, be it a syllable, foot, or mora[4]. Several researchers, beginning with Classe (1939) have measured interstress intervals in English, and all have show that they increase as the number of syllables increase (Shen and Peterson, 1962, Bolinger, 1965, O'Connor, 1965, Lea, 1974). Dauer (1983) provided further support for this finding in her work on English (stress-

[4] There is research on speech segmentation which suggests that syllables, feet, and morae are perceived differently in different languages (Cutler, et al., 1991). See section 4.1.2 for a discussion of this literature.

timed), and Spanish, Italian, and Greek (syllable-timed). She found that in all languages, the duration of interstress intervals is a function of the number of syllables, and that interstress intervals are not any more regular in English than in other languages. Wenk and Wiolland (1982) found that syllables were not isochronous in French. Borzone de Manrique and Signorini (1983) found that Spanish syllables varied in duration, and that interstress intervals tend to cluster around an average duration. Finally, Roach (1982) compared the variability in the duration of syllables and interstress intervals in stress-timed languages (English, Russian, and Arabic) and in syllable-timed languages (French, Telegu, and Yoruba). He found that the duration of syllables was no more variable in stress-timed languages than in syllable-timed languages. Furthermore, the duration of interstress intervals was no more variable in syllable-timed languages than in stress-timed languages. In summary, the notion 'isochronous units' has not found much support in experimental work.

The second problem with the traditional rhythm classification is that it forces languages into discrete categories. Some languages (including Athabaskan languages) share properties of both stress-timed and syllable-timed languages; such languages do not fit nicely into this classification system. These two problems are in fact directly related. Because rhythm is said to be solely a function of a regularly recurring unit, it follows naturally that languages fall into discrete categories. For example, either syllables recur regularly in a language or they do not; either the language is syllable- timed or it is not, there is no place for ambiguity, at least following the most conservative definition of rhythm classes.

4.1.2 Do rhythm classes exist at all?

Given that (a) little evidence has been found for isochronous units in natural language and (b) languages have been found which cannot be easily placed in a particular rhythm class, the question arises as to whether it is appropriate at all to talk about rhythm classes in the sense of Pike (1945) and Abercrombie (1964, 1967). Do these classes truly exist? Can languages be classified according to their rhythmic structure? I argue here that rhythm classes do exist, in that they form a useful tool for categorizing languages. However, the distinction between language classes is often fuzzy, and cannot be reduced to a simple distinction as to which unit recurs regularly.

The first argument for the existence of rhythm classes is based on intuitive impressions regarding rhythm in different languages. Let us compare, for example, English and French. In English, there is an alternation between strong (stressed) and weak (unstressed) syllables. Alternating stress is particularly easy to hear in long words such as *hamamelidanthemum*, pronounced [hˈaməmˌɛlɪdˈanthəməm]. The alternation between stressed and unstressed syllables creates a very characteristic rhythm in English. In contrast to this, French exhibits no such alternating stress pattern, at least not word-internally[5]. For example in a word such as *anticonstitutionellement* [ã.ti.kõs.ti.ty.siɔ.nɛl.mã] ('anticonstitutionally'), for the most part syllables carry equal stress. Although it has been said that French words have final-syllable stress, native

[5] Dell (1984) proposes an analysis of French involving the alternation between strong and weak syllables, but the data he uses does not include cases in which alternating stress would occur word-internally.

speaker intuitions sometimes do not support this analysis[6]. The difference in rhythm between English and French made Lloyd James (1940) compare the sound of languages like English to that of morse-code and the sound of languages like French to the sound of a machine gun. That languages such as English and French are so different in rhythm suggests that it is indeed appropriate to talk about rhythm classes, with English falling into one class (stress-timed) and French falling into another (syllable-timed).

The second piece of evidence for rhythm classes comes from data on speech segmentation. In a study comparing French and English subjects, Cutler et al. found evidence that the unit used in speech segmentation differed in French and English (Cutler et al., 1992). French subjects used syllables in segmenting speech whereas English subjects did not. Cutler et al.'s study does not provide support for classes based specifically on rhythm. Indeed, the unit used in speech segmentation does not necessarily play a role in establishing rhythm. However, their study does show that English and French differ in speech segmentation along the same lines as they do in rhythm. Once again, this suggests that a classification system which distinguishes between these two languages is appropriate.

Another argument for rhythm classes is that they provide a useful tool for explaining language acquisition data. For example, Nazzi et al. (1998) found that French newborns can discriminate between English and Japanese sentences, but not between English and Dutch ones. Furthermore, newborns can abstract away from particular

[6] I am a native speaker of Canadian French. Before I had read any of the literature on stress in French, I was asked about stress in the language by a fellow graduate student. It wasn't until she told me that French was said to have final-syllable stress that I "heard" it.

languages: they can discriminate between a set of sentences from English and Dutch (both stress-timed) and a set from Spanish and Italian (both syllable-timed). However, they cannot discriminate between a set of English and Spanish sentences and a set of Dutch and Italian ones. These results show that rhythm classes play an important role even in infant's perception of speech.

Finally, rhythm classes may also be supported by other types of evidence, for example from writing systems or language games. The original writing system for Lheidli was a syllabary, which captured the language quite elegantly because its syllables are fairly simple. Japanese also has a relatively simple syllable structure, and has a syllabary. It would be interesting to see whether any stress-timed languages, which usually have much more complex syllables, have a syllabary. Perhaps there one could establish a correlation between rhythm type and writing system, for example.

In summary, although very little evidence has been found for isochrony in speech (Roach, 1982, Dauer, 1983 and 1987, Miller, 1984, Ramus et al., 1999, Grabe and Low, in press), there *is* something to rhythm classes[7]. Indeed, their existence is supported by intuitions on rhythm across languages, speech segmentation and language acquisition data. The question is then, what is it that differentiates between languages like French and those like English, if isochrony is not involved? In recent years, several researchers have

[7] One might expect isochrony given that different language classes are based on the notion of isochronous units (syllables, feet, or morae).

sought an answer to this question. Their findings are summarized in the following section.

4.1.3 Recent literature on rhythm

Given that there is neither acoustic nor perceptual evidence for isochrony in speech, what is it that creates the impression of different rhythm types in language? Researchers who have worked on this problem in recent years (Dauer, 1983, 1987, Ramus et al., 1999, Grabe and Low, in press) do not deny the importance of units like the mora, syllable, and stress, but they claim that having rhythm based on one of these units does not mean that it repeats regularly. Instead, they argue that the rhythm of a language results from a combination of phonetic and phonological properties, and that languages can be more or less stress-timed or syllable-timed depending on which properties they exhibit. Research has in recent years has focused on discovering exactly what these properties. It has taken various directions, summarized below.

Dauer was among the first to consider the notion that the rhythm of a language results from its other properties (1983, 1987). She argues that languages fall along a continuum based on the number of phonological properties they have associated with each of the rhythm classes. Relevant properties include (a) durational differences in accented and unaccented syllables, (b) syllable structure (complex vs. simple), (c) presence vs. absence of contrastive duration (in accented vs. unaccented syllables), (d) patterns of intonation and tone, (e) presence vs. absence of vowel and consonant reduction (as a function of accent), (f) presence vs. absence of lexical stress, (g) number of syllables between stresses, and (h) effects of stress on the phonological system. Dauer associates the properties above with phonological features, each of which can take on the value +, ∅, or –, depending on the extent to which a language exhibits the feature (property) in question. Take (a), durational differences in accented vs. unaccented syllables. Languages with a + value for this feature, termed *duration* by Dauer, are those in which accented syllables are regularly longer than unaccented ones. Examples she provides are English and Serbo-Croatian. Languages with a ∅ value for *duration* are those in which accented syllables are only slightly longer than unaccented ones, such as Spanish and Greek. Finally, languages with a – value for *duration* are those in which accent does not affect the duration of syllables, such as Japanese and Yoruba. Dauer suggests that by calculating the sum of +, ∅, and – values for the set of features (a) - (h), one can come up with a rhythm "score" for each language. The more +'s a language has, the more likely it is to be stress-timed.

Ramus et al. (1999) and Grabe and Low (in press) have approached rhythm from the perspective of quantifiable differences in the acoustic signal between languages of different classes. Both have measured vocalic and intervocalic intervals, and conducted various comparisons among these intervals in order to determine what durational measures best capture the established rhythm classes. Their goal is to abstract away from phonological units in specific languages, such as the syllable or the foot, and determine whether rhythm classes can be defined through durational measurements alone. We shall return to the work of Ramus et al. in section 4.2 below, since it forms the basis of the work reported in this chapter on Lheidli.

Beckman (1992) also considers durational intervals, although different ones from those considered by Grabe and Low and Ramus et al. Based on the production and perception literature on rhythm, Beckman (1992) argues that rhythm classes are related to other durational properties such as the duration of interstress intervals (based on Dauer, 1983), which are longer in syllable-timed languages like French than in stress-timed languages like English. Beckman also considers the ratio of stressed syllables to unstressed syllables as an important factor in establishing rhythm. This ratio is smaller in syllable timed languages than in stress-timed languages. Indeed, in stress-timed languages like English the ratio is quite large, since for every stressed syllable there will be at most 2 unstressed syllables, leading to a ratio of stressed to unstressed syllables of 1/1 or 1/2. In French, the ratio is much smaller since for every stressed syllable, there can be several unstressed syllables. For example in *anticonstitutionellement*, there are 8 syllables ([ã.ti.kõs.ti.ty.siɔ.nɛl.mã]). Assuming that there is stress on the last syllable (see section 4.1.2), the ratio of stressed to unstressed syllables is 1/8 in this word.

In other phonetic work, Galves et al. (2002) have explored sonority as an acoustic correlate of rhythm. They classified languages in terms of fluctuations in sonority, and obtained the same categories as Ramus et al. did using durational measurements. This result is particularly interesting because unlike durational measurements, sonority measurements can be taken automatically rather than manually. This avoids many hours of manual labor on the part of the researcher, and also avoids the inevitable inconsistencies involved in taking hand measurements.

As already mentioned, Cutler et al. (1992) have approached the question of rhythm classes (stress-timed vs. syllable-timed) from the perspective of speech segmentation, investigating the units listeners use in segmenting speech in different rhythm classes. Their results agree with the established classification of languages in distinguishing between English and French. One reason they cite for this classification is ambisyllabicity, which occurs in English but not in French. The idea is that ambisyllabicity causes fuzzy boundaries between syllables, which makes them difficult to segment into discrete units. In a language where syllable boundaries are not clear, the units used in speech segmentation are less likely to be syllables, and more likely to be stresses. In more recent work, Cutler and Otake (1994) found that Japanese listeners use the mora to locate word boundaries in connected speech, thus providing evidence for a third rhythm category: mora-timed.

Cummins (2002) uses a metronome task to capture distinctions between syllable-timed and stress-timed languages. In his task, subjects are asked to pronounce utterances, producing the stressed syllables on the metronome beats. Speakers of English[8] (stress-timed) had no problem with the task, whereas speakers of Spanish (syllable-timed) could not successfully accomplish it. These results indicate a clear difference between stress-timed and syllable-timed languages in speech production. Whereas stressed syllables naturally fall on beats in stress-timed languages, this is not the case in syllable-timed languages.

[8] Cummins does not specify what dialect of English his subjects spoke.

Smith (1995) argues that languages can be grouped together based on articulatory data: vowel-vowel coordination (corresponding to mora-timed languages) vs. vowel-consonant coordination (corresponding to syllable- and stress-timed languages). She compares the articulation of singletons and geminates in Japanese (mora-timed) and in Italian (syllable-timed), in VCV sequences. She finds that in Japanese the beginning and end of the vowel articulations are the same with singleton and geminate consonants. Geminates simply overlap with more of the vowels than do singletons. Smith interprets this as a reflection of Japanese's vowel-to-vowel coordination. In Italian, the beginning and end of the vowel articulations are *not* the same for singletons and geminates: the onset of the second vowel comes later following geminates than following singletons. This is taken to reflect vowel-to-consonant coordination in Italian.

Finally, there are several researchers whose work bears indirectly on rhythm typology. For example, Fowler (1983) and Pérez (1997) both discuss rhythm in terms of the segments that carry it. Fowler argues that vowels carry the rhythm of the language; the consonants are superimposed on the vowels. Furthermore, the perceived timing of syllables is based on the perceived timing of vowels. Her proposal is based on both production and perception data. Pérez (1997), based on the P-center literature (Morton et al., 1976) focuses on perception data, and argues that isochrony exists between perceptual centers, where each syllable has one perceptual center. Table 4.1 summarizes the phonetic and phonological factors which have been associated with rhythm in language.

Table 4.1 Correlates of rhythm

Correlate	*Type of correlate*	*Reference*
o vowel and consonant reduction (and centralization) o contrastive duration o syllable structure o number of syllables between stresses o presence/absence of lexical stress o patterns of intonation and tone	Phonological (correlates are based on phonological facts of the language)	Dauer (1983, 1987)
o variability among vocalic intervals, and among intervocalic intervals o proportion of consonantal material vs. vocalic material	Phonetic (correlates are based on physical (durational) measurements)	Ramus et al. (1999)
o variability between consecutive vocalic intervals, and between consecutive intervocalic intervals	Phonetic (as in Ramus et al.)	Grabe and Low (in press)
o sonority	Phonetic (correlate is based on sonority - a physical measurement)	Galves et al. (2002)
o unit used in speech segmentation o (ambisyllabicity)	Speech segmentation (correlate is based on the unit used in speech segmentation)	Cutler et al. (1992)
o duration of inter-stress intervals o ratio of stressed to unstressed syllables	Speech production and perception (correlates are based on speech production and perception data)	Beckman (1992)
o vowel-vowel vs. vowel-consonant coordination	Articulation (correlate is based on articulatory data)	Smith (1995)

Table 4.1 Correlates of rhythm - *Continued*

Correlate	*Type of correlate*	*Reference*
o speech unit that fits between two metronome beats	Rhythmic speech production (correlate is based on speech production data)	Cummins (2002)
o vowel to vowel coordination (isochrony among vowels)	Speech production (articulation) and perception	Fowler (1983)
o intervals between P-centers	Speech perception	Pérez (1997)

The properties associated with stress-timed and syllable-timed languages are summarized in Table 4.2. These are based on the research cited above. I do not consider mora-timed languages in this discussion, since the research outlined above has focused primarily on stress-timed and syllable-timed languages (with the exception of Smith).

Table 4.2 Phonetic and phonological correlates of rhythm

Syllable-timed languages	*Stress-timed languages*
Phonetic correlates o long interstress intervals (measured in ms) o high proportion of vocalic material o low variability in the duration of consonantal intervals	Phonetic correlates o short interstress intervals o low proportion of vocalic material o high variability in the duration of consonantal intervals
Phonological correlates o absence of vowel reduction o simple syllables o many syllables between stresses (measured in number of syllables) o low ratio of stressed syllables to unstressed syllables	Phonological correlates o presence of vowel reduction o complex syllables o not many syllables between stresses o high ratio of stressed syllables to unstressed syllables o ambisyllabicity

It is important to note here that the phonetic correlates listed in Table 4.2 can be viewed not as correlates themselves, but simply as measurable results of phonological correlates. For example, the proportion of vocalic material (%V) and the durational variability in consonantal intervals (ΔC) considered by Ramus et al. (1999) can be seen as merely a reflection of syllable structure, where syllable structure is the 'true' correlate of rhythm. This is approach is implied in Ramus et al., although they call %V and ΔC 'correlates' of rhythm.

The broad range of research outlined in this section reflects the fact that finding invariant features corresponding to the three traditional rhythm classes is no easy task. In the following section, I move to a more detailed discussion of one approach to rhythm:

that of Ramus et al. (1999). We shall see that this model wrongly predicts that Lheidli should fall at the extreme stress-timed end of the rhythm continuum. In section 4.3, I propose an alternative model of rhythm, the Enhancement/Inhibition model, which encompasses findings from the research outlined above as well as findings based on the Lheidli data presented below.

4.2 The Ramus et al. (1999) approach to rhythm

Having introduced the literature on rhythm, I turn now to one particular approach to rhythm: that of Ramus et al. (1999). I show that Ramus et al.'s model of rhythm cannot capture the facts of languages like Lheidli adequately. This finding provides the basis for proposing a new model of rhythm - the Enhancement/Inhibition model (section 4.3).

Ramus et al. propose that languages cluster into rhythm classes based on two measures: %V (the proportion of vocalic material in an utterance) and ΔC (the amount of variability among consonantal intervals). These durational measures are taken as reflections of the complexity of syllable structure, which predicts rhythm. The reasoning is as follows: languages with a low %V are those which allow large proportions of consonantal material, i.e. syllables with complex onsets and codas. Furthermore, languages with high ΔC are those in which consonantal intervals vary a lot within utterances. Again, this is taken as a reflection of syllable complexity. In languages with only CV syllables, the intervocalic intervals will always be of approximately the same length (the length of one consonant). However, in languages with syllables such as CV vs. CCVCC, the consonantal intervals will vary greatly in duration, since they are composed of anywhere from one (VCV) to four (VCC.CCV) consonants.

In Ramus et al.'s analysis, languages with high %V and low ΔC are those with simple syllable structure: mora-timed. Languages with low %V and high ΔC are those with complex syllable structure: stress-timed. Syllable-timed languages fall between these two extremes. Using %V and ΔC, Ramus et al. find that languages fall along a 'rhythm continuum', clustering around the traditional rhythm classes: stress-timed, syllable-timed, and mora-timed (see Figure 4.1 below).

In a study based on Ramus et al. (1999), Bird (2001) found that Lheidli fell at the extreme stress-timed end of the language spectrum. Table 4.3 and Figure 4.1 are taken from Bird (2001). They place Lheidli and Navajo (another Athapaskan language) within the rhythm continuum, comparing them to other languages studied by Ramus et al. In Table 4.3, languages are listed in increasing order for %V, following Ramus et al.'s (1999) original Table 1. In this table (according to Ramus et al.), the cut-off between stress-timed and syllable-timed languages falls between Dutch and French, and the cut-off between syllable-timed and mora-timed languages falls between Catalan and Japanese.

Table 4.3 Ramus et al.'s results (p. 272) + Lheidli and Navajo

Language	*Vocalic intervals*	*Consonantal intervals*	*%V (SD)*	*ΔV (SD) (*100)*	*ΔC (SD) (*100)*
Lheidli	183	185	37.7 (4.5)	9.75 (5.17)	13.96 (3.60)
English	307	320	40.1 (5.4)	4.64 (1.25)	5.35 (1.63)
Polish	334	333	41.0 (3.4)	2.51 (0.67)	5.14 (1.18)
Dutch	320	329	42.3 (4.2)	4.23 (0.93)	5.33 (1.50)
French	328	330	43.6 (4.5)	3.78 (1.21)	4.39 (0.74)
Spanish	320	317	43.8 (4.0)	3.32 (1.00)	4.74 (0.85)
Navajo	409	422	44.3 (5.8)	7.30 (4.00)	7.04 (2.00)
Italian	326	317	45.2 (3.9)	4.00 (1.05)	4.81 (0.89)
Catalan	332	329	45.6 (5.4)	3.68 (1.44)	4.52 (0.86)
Japanese	336	334	53.1 (3.4)	4.02 (0.58)	3.56 (0.74)

From Table 4.3, one can see that Lheidli falls at the extreme stress-timed end of the rhythm spectrum, whereas Navajo falls within the syllable-timed range. Figure 4.1 illustrates this distribution in the form of a graph. From this figure, it seems that Lheidli is on its own, rhythmically speaking, whereas Navajo falls among other more commonly studied languages. Note that if Lheidli were not plotted, thus expanding the y-axis, Navajo would look like an outlier as well in terms of ΔC.

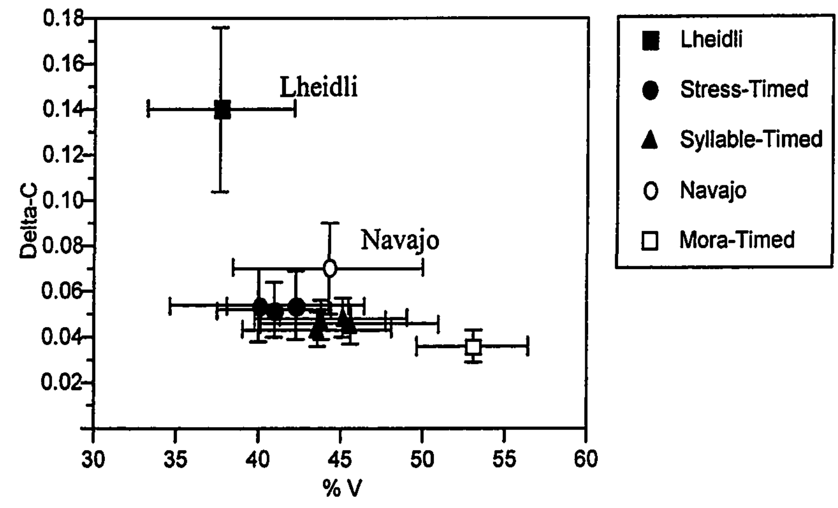

Figure 4.1 Distribution of languages over the (%V, ΔC) plane.
Data points for all languages except Lheidli and Navajo
are taken from Ramus et al. (1999).

Figure 4.1 shows that Lheidli has a very low value for %V and an extremely high value for ΔC. The low %V value is a result of the high proportion of consonantal material. Because intervocalic consonants are so long, they contribute to increasing the proportion of consonantal material in an utterance and thereby decreasing the proportion of vocalic material (%V). This effect is amplified by the fact that Lheidli does not have very long vowels (unlike Japanese, for example, which has long vowels as well as long consonants). The high ΔC value is a result of the variability in the duration of consonants. Whereas intervocalic consonants regularly exceed 300 ms in duration, word-initial onsets can be very short, particularly word-initial glottal stops. The differences in duration among these consonants lead to an extremely high value for ΔC. Note that in Bird (2001) only VOT was measured for word-initial stops (as closure duration is unavailable in this position). In contrast to this, both VOT and closure duration were measured for word-medial stops. This difference in measurements contributed to increasing ΔC. Ramus et al. do not mention this issue. I therefore assume that they measured stops in the same way as in Bird (2001), and that for this reason ΔC is comparable in both studies.

Although the Lheidli results are interpretable within Ramus et al.'s analysis, they are not in fact caused by the phonological properties that Ramus et al. assume. As mentioned above, Ramus et al. assume that ΔC and %V are phonetic reflections of syllable structure, a phonological property of language. According to this view, Lheidli's extremely high ΔC and low %V should mean that it has very complex syllables, allowing far bigger and more variable clusters than in English, for example. Recall from Chapter 2 though that Lheidli syllable structure is relatively simple. In this case, what leads to such a high ΔC and low %V is *not* the occurrence of complex syllables, it is the inherent duration of certain segments - namely intervocalic consonants. Lheidli therefore shows that ΔC and %V need not be a reflection of syllable complexity, they can be a reflection of inherent segmental duration[9].

The finding that %V and ΔC are a function of phonetic and phonological facts other than those considered by Ramus et al. does not in itself warrant rejecting their method of quantifying rhythm classes. However, a more serious problem involves the placement of Lheidli in Ramus et al.'s rhythm continuum. Given where Lheidli falls on the rhythm continuum (Figure 4.1), one would expect it to have all the properties listed in

[9] Note that %V and ΔC can also be a reflection of phonological processes like flapping, which create very short consonants, thus leading to high %V, and potentially higher ΔC as well (Mark Liberman, p.c.).

Table 4.2 for stress-timed languages (at least those languages considered by Ramus et al). However, Lheidli has neither vowel reduction nor complex syllables. Furthermore, it is not clear that Lheidli has alternating stress - as do all stress-timed languages considered by Ramus et al. Although the bisyllabic words considered in this dissertation are too short to determine whether or not Lheidli has alternating stress, none of the previous analyses posit this feature (see Chapter 2, section 2.4). For these reasons, it seems unlikely that Lheidli would fall at the extreme stress-timed end of the rhythm continuum. In order to solve this problem, I propose in the following section a new model of rhythm - the Enhancement/Inhibition model. This model allows for factors such as inherent segmental duration to have a direct effect on rhythm, and also solves the problem of Ramus et al.'s model in the placement of Lheidli along the rhythm continuum.

Before moving on to the Enhancement/Inhibition model, I briefly consider here the distance between Lheidli and Navajo in Figure 4.1. Since both are Athapaskan languages, and both have unusually long consonants, one might expect them to be close together on the continuum. There are several reasons why Navajo is not at the extreme stress-timed end of the spectrum, as is Lheidli. First, Navajo has both long and short vowels, unlike Lheidli. The existence of long vowels in the language explains why its %V value is higher than in Navajo: longer vowels mean more vocalic material in utterances. As for ΔC, it is less clear why it should be so much higher for Lheidli than for Navajo. One possibility is that Navajo consonants are simply never as long as Lheidli's, and also never as short.

Another factor that may be influencing the results involves speech rate. The Lheidli speech used for analysis was generally slower, and more variable in speech rate (even within an utterance) than the Navajo speech. This was a result of the speakers as well as the recording environment: the Lheidli speaker was elderly, and was recorded in the field. The Navajo speakers (three of them) were much younger, and were recorded in a laboratory setting. It is possible that the higher overall variability in the Lheidli speech was manifested most in variations in consonant length, rather than vowel length, thereby exaggerating the differences in durations between consonants in various positions[10]. Since the Navajo speech was overall less variable than the Lheidli speech, this might have lead to less variability in the duration of consonantal intervals. Although the differences in ΔC between Navajo and Lheidli are worth exploring further, the basic finding - that Athapaskan languages have a high ΔC relative to other languages - holds for both Navajo and Lheidli (as shown in Table 4.3 and Figure 4.1). It is this finding that is important for the current work.

4.3 Rhythm in language: the Enhancement/Inhibition model

Recall from section 4.1 above that where Ramus et al.'s model runs into trouble is in basing rhythm classes solely on two variables: %V and ΔC. These measures wrongly predict that Lheidli should fall at the extreme stress-timed end of the rhythm continuum. In other words, in attempting to define rhythm based solely on acoustic measurements,

[10] This idea is supported by the finding that in Dogrib, another Northern Athapaskan language, story tellers lengthen consonants rather than vowels to create emphasis (Leslie Saxon, p.c.).

Ramus et al. missed some other important correlates of rhythm. In order to understand the perceived differences in rhythm between various languages, it is necessary to consider *all* of the correlates of rhythm (summarized in Table 4.2 above). In this section, I propose the Enhancement/Inhibition model of rhythm, whereby there is a primary correlate of rhythm, which is enhanced or inhibited by a set of secondary correlates - leading to a particular rhythmic structure for each language. The notions of enhancement and inhibition are based on Stevens et al.'s (1986) notion of feature enhancement. Within this model, Lheidli falls somewhere between syllable-timed and stress-timed languages (see section 4.4).

4.3.1 Primary and secondary correlates of rhythm

As expressed in the literature outlined in 4.1 above, rhythm is correlated with several phonetic and phonological factors of language. The most recent literature has focused on phonetic correlates to rhythm, i.e. correlates which are measurable quantitatively. For example, Ramus et al. (1999) and Grabe and Low (in press) have looked at durational characteristics of speech, and Galves et al. (2002) have looked at sonority.

While these phonetic correlates of rhythm are important, as are phonological correlates such as syllable structure, I propose here that the role they play in establishing the rhythm of a language is secondary. Indeed, alternating stresses (in stress-timed languages) and syllables (in syllable-timed languages) play the primary role in establishing the rhythm of a language. They are the units which are most prominent, perceived as recurring in a rhythmic fashion. Note that this does not mean that these units actually repeat regularly; they do not have to be physically isochronous to be perceived as creating the 'beat' of a language by speakers[11]. These primary correlates serve to establish the perceived rhythm of the language.

Phonetic correlates of rhythm, such as those studied by Ramus et al. (1999), Galves et al. (2002), and Grabe and Low (in press) are secondary in that they serve to enhance or inhibit the role of alternating stresses in stress-timed languages, or the role of syllables in syllable-timed languages. Note that under this view, the phonetic properties themselves are considered correlates of rhythm. This differs from Ramus et al.'s approach (as well as Grabe and Low's), in which phonetic properties result from phonological properties - the actual correlates of rhythm - and simply provide a useful means of measuring rhythm quantitatively.

The following table summarizes the primary and secondary correlates of rhythm in the Enhancement/Inhibition model. These correlates are discussed further below. I have not included Ramus et al.'s %V and ΔC in this table, because they are not correlates themselves, but rather results of phonological correlates such as syllable structure and phonetic correlates such as segmental duration.

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[11] In fact, these units do not even have to be perceptually isochronous for them to be perceived as creating the beat of the language. See Scott et al. (1985) for a discussion of perceptual isochrony.

Table 4.4 Primary and secondary correlates of rhythm

Primary correlate	o alternating stresses, *or* o syllables (in languages with no alternating stresses)	
Secondary correlates	*Phonological correlates* o (segmental duration) o lexical stress o syllable complexity o ambisyllabicity o vowel reduction o contrastive duration o ratio of stressed to unstressed syllables	*Phonetic correlates* o (segmental duration) o amplitude o pitch o sonority o vowel and consonant qualities o duration of vocalic and intervocalic intervals o duration of interstress intervals

Note that *ambisyllabicity* is included among the phonological correlates of rhythm. Ambisyllabicity does not necessarily affect the timing among consonants and vowels (the timing of a VCV string can be the same whether it is syllabified V.CV or V(C)V). However, it does affect how easy it is to separate syllables into discrete, recurring units. Ambisyllabicity inhibits the salience of syllables as the primary correlate of rhythm because it prevents syllables from being segmented into discrete units. Also note that 'segmental duration' is included in both phonological and phonetic correlates of rhythm. This is because segmental duration varies across languages in whether or not it has a phonological role. In Lheidli, I argue that segmental duration is phonological, since it interacts with other properties of the language (e.g. syllabification, discussed in Chapter 5). However, one could imagine a language with inherently long segments, but which do not interact with other phonological properties. In such languages, segmental duration would be phonetic, but not phonological.

As an example of how primary and secondary correlates interact, take English and Polish. The alternating stress pattern in English is its most salient cue to rhythm, and clearly classifies it as a stress-timed language. The reason alternating stress is so clear in English is that there are other correlates of rhythm which enhance the salience of alternating stress. For example, it has vowel reduction in unstressed syllables. Reduced unstressed vowels are not only shorter than stressed vowels, they are also lower in pitch and in amplitude. This increases the relative salience of stressed vowels in words and utterances, and as a result makes the alternation between stressed and unstressed vowels more apparent perceptually. This (in part) leads to the perception of English as a stress-timed language. In contrast to this, Polish is not as 'good' a stress-timed language as English. Although Polish has alternating stress (Nespor, 1990), it does not have vowel reduction. As a result, the salience of the alternating stress pattern is decreased, and Polish does not sound as stress-timed as English (Nespor, 1990). In sum, both these languages have alternating stress as the primary cue to rhythm. However, in English this cue is enhanced by the presence of vowel reduction, whereas in Polish it is inhibited by the lack of vowel reduction.

Figures 4.2 through 4.4 illustrate the contribution of primary and secondary correlates of rhythm. In each figure, the small inner circle represents languages with alternating stress. The large outer circle represents languages with syllables. These figures show that the set of languages with alternating stress (one of the primary correlates of rhythm) is a subset of the set of languages with syllables (the other primary correlate of rhythm). The syllable is, in a sense, the default primary correlate of stress, in that all languages have syllables. If a language does not have alternating stress, its primary correlate of rhythm is the syllable[12]. In order to keep the figures simple, I have included only two secondary correlates to rhythm: presence vs. absence of vowel reduction and syllable structure (simple vs. complex)[13].

Vowel reduction enhances the salience of alternating stresses, since it increases the salience of stressed vowels, compared to unstressed (reduced) ones. Syllable structure also affects the salience of the primary rhythm correlate. Simple syllable structure enhances the salience of the syllable as the rhythmic unit. This is because if the syllables are all of roughly the same shape (CV), it will be easier to identify them as all corresponding to the same unit. Take the two hypothetical strings of syllables in (1). The first string (a) is composed of simple CV syllables, whereas the second (b) is composed of a variety of syllable types. In reading these strings aloud, the first string should seem more obviously composed of similar units than the second.

(1) Hypothetical strings of syllables

a. ba.ki.te.do.sa.mi.da.re.bo.fi

b. ba.kit.ste.ralk.kloft.o.akt.skeh.alp.stsisk

[12] Note that I am considering only stress-timed and syllable-timed languages, since they are the ones on which most of the recent literature on rhythm has focused. However, see Warner and Arai (2001a, 2001b) on mora-timed languages.

[13] The secondary correlate 'syllable structure' is discussed further below, as it has interesting implications for the model.

If all syllables are simple and similar in form, they will be perceived as recurring regularly, rhythmically, as in (1)a. In contrast to this, complex syllable structure enhances the salience of stresses by decreasing the salience of individual syllables, as in (1)b. The less salient the syllables are as recurring units, the more likely stress is to be perceived as the regular, rhythmic unit in speech. In the following figures, arrows pointing towards the primary correlate represent enhancement. Arrows pointing away from the primary correlate represent inhibition.

In English, there is alternating stress. Furthermore, both the presence of vowel reduction and complex syllables enhance the salience of alternating stress. As a result, English is a 'good' stress-timed language.

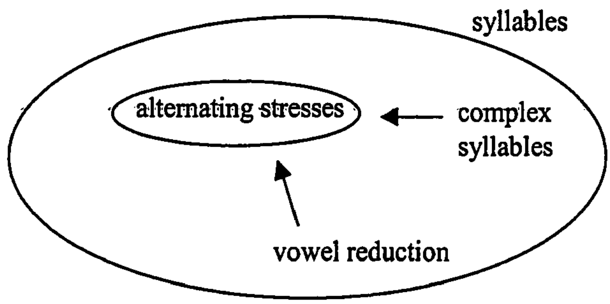

Figure 4.2 Primary and secondary correlates of rhythm in English (stress-timed)

In French, there is no alternating stress, which means that the primary correlate of rhythm is the syllable. French has relatively simple syllables, and also has vowel reduction, although it does have vowel deletion - typical of syllable-timed languages (Nespor, 1990)

- which arguably is an extreme case of vowel reduction[14]. Simple syllables and lack of vowel reduction enhance the salience of syllables in French, making it a 'good' syllable-timed language.

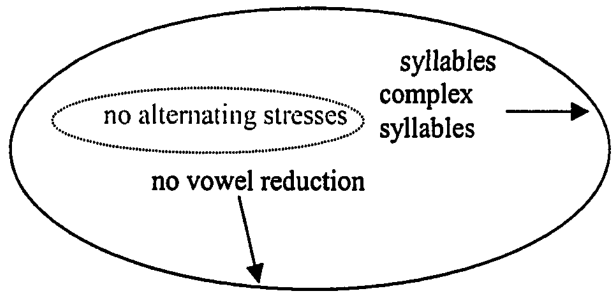

Figure 4.3 Primary and secondary correlates of rhythm in French (syllable-timed)

Finally, Polish is a language which has been classified both as syllable-timed and as stress-timed (Nespor, 1990). It has alternating stress, and therefore under the current analysis should be classified as stress-timed. The salience of alternating stress is enhanced by complex syllables, which Polish also has. However, it is inhibited by the lack of vowel reduction. Because of this inhibiting secondary correlate, Polish sounds less like a stress-timed language than does English (Nespor, 1990).

[14] An example of vowel deletion is [ʃtœ d^{z}i] for *je te dis* [jœ tœ d^{z}i] in Canadian French. Note that vowel deletion, although typical of syllable-timed languages, actually inhibits the salience of syllables by creating complex syllables, as in [ʃtœ] instead of [jœ tœ].

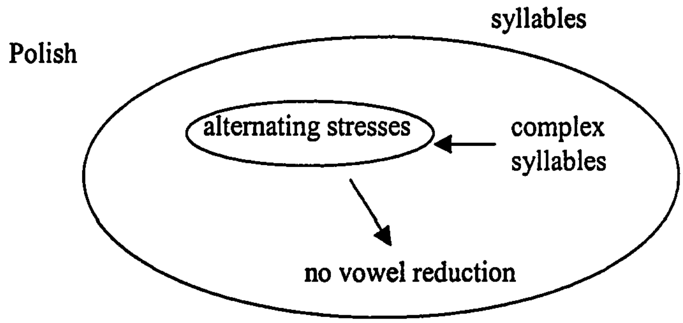

Figure 4.4 Primary and secondary correlates of rhythm in Polish (mixed)

In sum, correlates of rhythm can be divided into two groups, one of which consists of a single member: (a) the primary correlate (alternating stresses in stress-timed languages and syllables in syllable-timed languages), and (b) the secondary correlates: vowel reduction, syllable structure, durational properties, sonority, etc. If a language has alternating stress, then the primary correlate of rhythm is stress. If it does not, then the primary correlate is the syllable. Secondary correlates either enhance the primary correlate or inhibit it. The following table illustrates the enhancing and inhibiting secondary correlates of rhythm for stress-timed and syllable-timed languages.

Table 4.5 Enhancing and inhibiting secondary correlates of rhythm

	Stress-timing	*Syllable-timing*
Enhancing correlates	*Phonological properties* o lexical stress o complex syllables o ambisyllabicity o vowel reduction o contrastive duration o low ratio of stressed to unstressed syllables *Phonetic properties* o long consonants o changes in pitch, amplitude, duration to indicate prominence o tense/lax vowel distinction o short interstress intervals	*Phonological properties* o no lexical stress o simple syllables o no ambisyllabicity o no vowel reduction o no contrastive duration o high ratio of stressed to unstressed syllables *Phonetic properties* o short consonants o no changes in pitch, amplitude, duration to indicate prominence o no tense/lax vowel distinction o long interstress intervals
Inhibiting correlates	Same as enhancing correlates for syllable-timed languages	Same as enhancing correlates for stress-timed languages

Note that Table 4.5 is somewhat simplified in that it assumes that all languages which are not syllable-timed are stress-timed, which is not the case. It is true that the set of correlates that inhibit stress-timing corresponds exactly to the set of correlates that enhance syllable-timing. However, the reverse is not true: not all correlates which inhibit syllable-timing enhance stress-timing. This results from the asymmetry involved in the two primary correlates of rhythm, stresses and syllables. All languages have syllables, such that correlates which inhibit stress-timing in languages with alternating stresses necessarily enhance syllable-timing as well. For example in Polish, the lack of vowel reduction inhibits stress-timing, and at the same time enhances syllable timing. However, in languages without alternating stresses, correlates which inhibit syllable-timing cannot enhance stress-timing, since there is no primary correlate (alternating stresses) to enhance. The implication here is that the rhythm continuum consists of a two-dimensional space, containing 4 types of languages: (a) stress-timed languages, (b) syllable-timed languages, (c) languages between stress-timed and syllable-timed: those with alternating stresses, combined with correlates inhibiting stress-timing, and (d) other languages: those with no alternating stresses combined with correlates inhibiting syllable-timing. We shall see that Lheidli is among this last type of language, as are arguably mora-timed languages[15]. The following figure illustrates the rhythm space predicted by the Enhancement/Inhibition model:

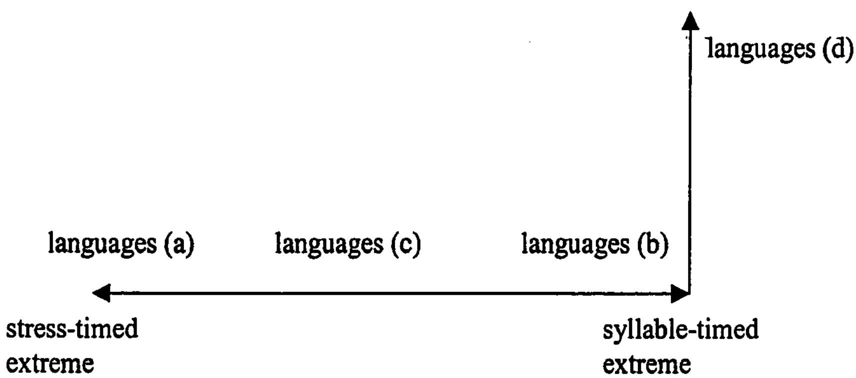

Figure 4.5 Rhythm space predicted by the Enhancement/Inhibition model

[15] Lheidli may in fact be best characterized as mora-timed. Future research will investigate this possibility.

The existence of primary and secondary correlates of rhythm has interesting implications for the issue of discrete classes vs. a continuum in rhythm. Recent literature has argued that languages fall along a continuum with respect to rhythm, although they tend to cluster at certain points (Dauer, 1987, Nespor, 1990, Ramus et al., 1999, Grabe and Low, to appear). This argument is based on the fact that some languages, such as Catalan and Polish, seem to fall between categories (Nespor, 1990). Indeed, we have already see that Polish has alternating stresses, but lacks vowel reduction, such that it falls between stress-timed and syllable-timed languages. Catalan lacks alternating stresses, has no tendency for stress to fall on heavy or long syllables, and

> "has a rule that deletes one of two adjacent vowels under certain conditions (cf. Mascaró, 1989), a rule typical of "syllable-timed" languages, according to Dauer (1983)" (Nespor, 1990, p. 164).

However, Catalan has relatively complex syllables and vowel reduction (Nespor, 1990). Catalan is therefore another language which sounds neither stress-timed nor syllable-timed.

Under the model proposed here, it is the secondary correlates which allow languages to fall along a continuum with respect to rhythm. For example, a language like Polish with alternating stress, but with correlates inhibiting the salience of stress will fall somewhere between the stress-timed and syllable-timed extremes on the rhythm continuum. In Figure 4.5, Polish falls among languages of type (c). A language such as

Catalan, which has no alternating stress combined with factors inhibiting the salience of syllables (complex syllables and vowel reduction), falls among languages of type (d). An interesting direction to pursue within this model involves the relative weight of various secondary correlates. It is likely that secondary correlates do not all have the same weight when it comes to enhancing or inhibiting the primary correlate, i.e. that they do not all influence the perception of stress to the same degree.

The crucial difference between the Enhancement/Inhibition model and previous models of rhythm (Dauer, 1983, 1987, Ramus et al., 1999, Grabe and Low, in press) involves hierarchical structure. Previous models of rhythm have considered all correlates of rhythm to hold equal weight, in the sense that they all contribute equally to the perception of rhythm. The Enhancement/Inhibition model organizes correlates of rhythm hierarchically according to their contribution in creating the perception of rhythm. Indeed, the primary correlate - alternating stresses or syllables - is the main contributor to rhythmic structure. The idea is that alternating stress is such a salient cue to rhythm that if it is present in a language, it cannot be overridden by other factors in creating the perception of rhythm.

It is possible to determine whether it is appropriate to talk about hierarchical structure in rhythm through experimental research. A series of perception experiments can be conducted, for example, in which various correlates of rhythm are manipulated and subjects are asked to judge how rhythmic a language sounds. For example, an experiment on English would include (a) English - with alternating stress and vowel reduction, (b) English' - with alternating stress and no vowel reduction, (c) and English''

- with vowel reduction and no alternating stress. The prediction according to the Enhancement/Inhibition model is that English' will sounds more rhythmic (and more like English) than will English'' because English' has alternating stress whereas English'' does not. Such experiments will have to await future research.

Note that the idea of organizing correlates hierarchically is reminiscent of an Optimality Theoretic approach to rhythm (McCarthy and Prince, 1993, Prince and Smolensky, 1993). Within such an approach, correlates would be ranked according to their importance in creating the perception of rhythm. I return to this idea section 4.4 (conclusion).

One final property of the Enhancement/Inhibition model of rhythm that will be revisited below is that it assumes that rhythm is not a primitive feature of language. The grammar does not include a 'rhythm parameter' that is set at 'syllable-timed', 'stress-timed' or 'mora-timed'. Rather, rhythm is a secondary feature of language, which falls out from other properties of language: the primary and secondary correlates of rhythm. Furthermore, rhythm is a function of properties of the phonetic output of language, whether or not the source of this output is phonological. For example, rhythm is partly a function of the proportion of consonantal vs. vocalic material in an utterance (as in Ramus et al., 1999), regardless of whether this proportion results from syllable structure (phonological) or inherent segmental duration (which can be purely phonetic). In this sense, the phonological structure of language does not matter for rhythm, what matters is only the phonetic output.

4.3.2 Primary and secondary correlates: phonetic, grammatical, or phonological

Having introduced the Enhancement/Inhibition model, I turn now to a more detailed discussion of the primary and secondary correlates of rhythm. The first issue to consider is whether rhythm is a result of phonetic, grammatical, or phonological facts of the language. I propose that the primary correlate of rhythm (presence vs. absence of alternating stress) is phonological, and the secondary correlates consist of both phonetic (and grammatical) and phonological properties of the language in question. The reason that rhythm has so far been so difficult to pinpoint is that it is created by a combination of different types of correlates.

In the following sections, I consider first the primary correlate of rhythm (4.3.2.1) and then the secondary correlates (4.3.2.2). I discuss each correlate in terms of whether it is phonetic (and grammatical) or phonological in nature.

4.3.2.1 The primary correlate of rhythm

Languages differ in whether or not they have alternating stresses, and therefore the presence or absence of alternating stresses must be specified in the grammar. Furthermore, given that (alternating) stress interacts with other factors of the language - for example some languages require stressed syllables to be heavy (Prince (1992) - and that the placement of alternating stresses is principled, alternating stress also falls within the realm of phonology (see Chapter 1 for a discussion of the notions 'grammar' and 'phonology' in language). Therefore the primary correlate of rhythm is phonological.

In order to have alternating stress, a language must have stress. Stress itself must be encoded in the grammar (whether it is alternating or not), since languages differ in whether or not they make use of it (by attributing prominence to certain specified syllables). In languages in which stress placement is predictable, stress must also be encoded within the phonology - which provides the rules or constraints governing stress placement. If stress is lexically specified (not predictable), and does not interact with other properties of the language, it need not be encoded in the phonology. Note that for stress to affect rhythm, it need not be lexically distinctive, nor must it interact with other properties of the language. In Lheidli, for example, stress does not interact with vowel reduction, syllable weight, etc. It is also not contrastive[16]. However, its presence still inhibits salience of syllables as the primary correlates of rhythm.

Finally, the realization of stress is in the grammar, but not necessarily in the phonology. Stress is an abstract notion, which implies prominence of some sort: stressed syllables are made prominent compared to surrounding syllables. How stressed syllables are made prominent differs from language to language. Some use pitch, some use amplitude, some use duration, and some use a combination of the above. Because languages differ in the way stress is realized, this choice must also be encoded in the grammar. However, because the realization of stress does not necessarily interact with other phonological properties of the language, it is not necessarily part of the phonology. For example, languages in which duration is a cue to stress often also have vowel reduction, in order to increase the contrast in duration between stressed and unstressed

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[16] I have found no words which contrast only in stress placement.

syllables. In such languages (e.g. English), stress interacts with another phonological property of the language, vowel reduction, and therefore the realization of stress must fall within the realm of phonology. In languages where stress is manifested by pitch, for example, and pitch does not interact with other phonological phenomena of the language, the realization of stress need not be encoded in the phonology.

In summary, all components of alternating stress (the alternation, stress itself, and its phonetic manifestation) must be specified within the grammar of a given language. Furthermore, stress (alternating or not) is also necessarily encoded in the phonology. Of these three components, alternating stress alone constitutes the primary correlate of rhythm. The other two components (stress and its manifestation) are necessary in creating alternating stress, but are themselves secondary correlates of rhythm. This is discussed further below.

Table 4.6 Encoding the primary correlate of rhythm

Component	*Where it is encoded*
Alternating stress	Phonology (within the grammar)
Stress itself (abstract notion of prominence)	Phonology (if it is predictable and/or interacts with other phonological properties of language) Grammar (if it is lexical, and does not interact with other phonological properties of the language)
Phonetic realization of stress	Phonology (if it interacts with other phonological properties of the language) Grammar (if it does not interact with other phonological properties of the language)

4.3.2.2 The secondary correlates of rhythm

In the previous section I mentioned stress as a component of the primary correlate of rhythm. However, stress in language does not imply alternating stress. A language can have lexically specified stress without having an alternating pattern. One such language is Russian (Melvold, 1990, Halle, 1995). If a language has no stress, it has no alternating stress, and cannot therefore be categorized as a stress-timed language. However, if a language does have stress, even if it is not alternating, it contributes to the *perception* of alternating stress. Whether or not prominent syllables occur regularly, the fact that they do occur, and contrast with non-prominent syllables, gives the perception of a patterned, systematic distribution of prominence. This distribution enhances the perception of rhythmicity that is achieved through alternating stresses. In this sense, stress itself is a secondary correlate of rhythm. Note that if the language does not have alternating stress, then stress cannot have an enhancing effect, since there is nothing to enhance. Rather, it has an inhibitory effect on the perception of syllables as recurring regularly. In this case, stress makes a language sound more stress-timed by making it sound less syllable-timed.

The phonetic realization of stress is also a secondary correlate of rhythm. In English, for example, stress is realized through a combination of increased amplitude, increased pitch, and increased duration (Ladefoged, 1993)[17]. The combination of cues English uses to realize stress increases the salience of stresses, and consequently the

[17] Increased duration comes from both lengthening the stressed vowel, and reducing the surrounding unstressed vowels.

salience of the alternating stress pattern. English is a 'good' stress-timed language in part because it uses several cues to increase the prominence of its stressed syllables.

Contrast English to the hypothetical language English Prime (English'), in which stress is realized only through an increase in amplitude. Because English does not use as many ways to realize stress as English, the stressed syllables of English' are not as salient as the stressed syllables of English. As a result the alternating stress pattern of English' is not as salient as that of English: English' is not as 'good' a stress-timed language as English. With respect to stress then, the prediction is that the more ways in which prominence is achieved in a language, the more stress-timed a language will sound. This can be tested experimentally by manipulating speech so as to include more or less cues to stress, and having subjects judge whether a language is stress-timed or not. For example, this experiment could be done with infants, in a task requiring them to distinguish between French and English, and between French and English' (see Pegg and Werker (1997) for an example of the research design used with infants). The prediction is that newborns will have more difficulty distinguishing French from English' than from English.

One final point to consider with respect to stress and its realizations involves languages which use duration and pitch contrastively, but which are not said to have stress (for example Navajo). Duration and pitch are special in that they can be cues to stress, but they can also have a phonological role in the language unrelated to stress[18]. Duration is contrastive in languages which have both geminates and singletons. Similarly, pitch is contrastive in tone and pitch-accent languages. In Japanese, for example, duration is contrastive (it has singletons vs. geminates). Japanese also has pitch-accent, but no stress: changes in pitch do not alternate, and there can be long strings of morae with no sharp pitch change. Because Japanese has no alternating stress which can be enhanced through pitch and duration fluctuations, it cannot be said that pitch and duration enhance the salience of alternating stresses. However, they can inhibit the salience of syllables as the primary cue to rhythm. In general, whether or not duration and pitch are related to stress in a given language, they act as secondary correlates which enhance or inhibit the salience of the primary cue. Again, the fact that long segments alternate with short ones, or that high tones alternate with low tones, creates the perception of a patterned, systematic distribution of prominence, even if it is not isochronous, and even if the pattern is not called 'stress'.

Other than duration, pitch, and amplitude (and resulting stress), what can one say about the secondary correlates of rhythm? Many of these correlates are phonological: vowel quality (centralized vs. peripheral), vowel and consonant reduction, syllable complexity and ambisyllabicity. Languages differ in how they make use of these correlates, and for this reason these must be encoded in the grammar. Furthermore, because they play an active role within the phonology of a particular language, they must

[18] This is different from amplitude, which is not distinctive for segments (at least not systematically), and the sole phonological function of which involves stress.

be specified in the phonology. For example, whether or not a language has vowel reduction is included in the grammar. Because vowel reduction interacts with stress, for example, it must also be encoded in the phonology. Other correlates of rhythm are phonetic: sonority (Galves et al. 2002) and, in some cases, inherent segmental duration (discussed below). These correlates are encoded in the grammar, since they differ across languages. They are not in the phonology though, since they do not interact with other phonological properties of the language.

Whether phonological or phonetic, one interesting property of some of these correlates is that they are gradient by nature, and referring to them as 'enhancing' or 'inhibiting' requires replacing this gradience with a strict boundary. Take for example syllable complexity. The boundary between simple and complex syllables is not clear: is it the case that CV syllables are simple, and all other syllables are complex? Or are CV and CVC syllables simple, and all other syllables complex? Does sonority play a role, i.e. are CVV syllables simple whereas CVC syllables are complex? Does moraicity play a role? In order to determine whether the syllable structure of a particular language enhances or inhibits the primary rhythm correlate, it is crucial to know whether the syllable structure counts as simple (enhancing syllables as the primary correlate) or complex (enhancing alternating stresses as the primary correlate). The question of what exactly creates complexity (and how much) in syllable structure is certainly an area which needs attention. It seems most likely that simplicity is in fact a gradient property, and that as a result the degree of enhancement or inhibition related to syllable structure is also gradient. I will not go into this issue further here, but will explore it in future work.

In this section, we have seen that all correlates are encoded in the grammar but not necessarily in the phonology of the language. The primary correlate to rhythm is phonological, and the secondary correlates can be either phonological or phonetic. Table 4.7 summarizes the discussion above. Properties in parentheses are those that can be either encoded in the phonology or in the grammar (but not in the phonology), depending on how they are used within a specific language.

Table 4.7 Encoding the primary and secondary correlates of rhythm

Component	
Primary correlate (encoded in the phonology)	
o Presence/absence of alternating stress	
Phonological secondary correlates (encoded in the phonology)	
o Contrastive duration	o (Stress itself)
o Syllable complexity	o (Phonetic realization of stress)
o Vowel reduction	o (Segmental duration)
o Ambisyllabicity	
Phonetic secondary correlates (encoded in the grammar)	
o Sonority	
o (Stress itself)	
o (Phonetic realization of stress)	
o (Segmental duration)	

One thing to note here is that I have excluded several correlates mentioned above, such as %V, ΔC, duration of interstress intervals, ratio of stressed to unstressed syllables, etc. While these factors are indeed correlates of rhythm, and provide useful means of measuring rhythm quantitatively, they are excluded because they are not encoded in the grammar. Rather, they result from other correlates of rhythm. For example both %V and

ΔC fall out from syllable complexity (encoded in the phonology) and inherent segmental duration (encoded in the grammar and sometimes the phonology).

The question that remains to be answered is whether or not rhythm itself falls within the realm of phonology, or even within the grammar. This issue is introduced here and discussed further in Chapter 6. The perception of rhythm is created through manipulations of duration, pitch, amplitude, sonority, formant structure, etc. Whether these manipulations are rooted in phonological properties or not is irrelevant for rhythm per se. For example, suppose that a language has alternating stress, that stress is realized through an increase in pitch and duration, and that consequently, the language is perceived as stress-timed. All that matters from the perspective of rhythm is the alternating pattern of *high-low* pitch and *long-short* duration. It does not matter whether this pattern is created by the abstract notion 'stress' or not. In this sense, rhythm is outside the realm of phonology, even though many of its correlates are phonological. Furthermore, since rhythm is derived from other properties of the language, it does not even need to be encoded in the grammar.

Figure 4.6 illustrates the relationship between phonetics, phonology, and rhythm. Phonological factors and phonetic factors encoded in the grammar of a language affect its phonetic implementation. This implementation is what derives the perception of rhythm in language.

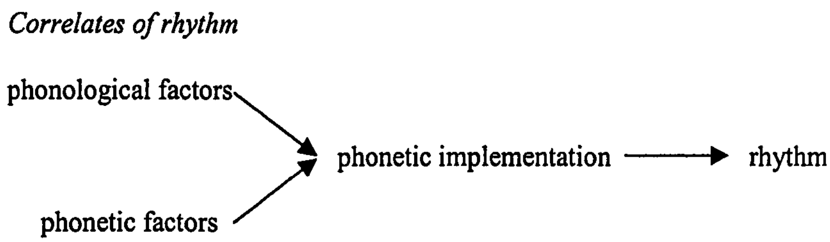

Figure 4.6 The effects of phonological and phonetic properties on rhythm

The correlates of rhythm discussed so far are to be taken as *sources* of rhythm, even though - in the case of phonological correlates - they do not directly affect rhythm (they do so through phonetic implementation). For example, syllable structure is a source of rhythm (and a secondary correlate), but its effect on rhythm is achieved through phonetic implementation, measurable in terms of %V and ΔC for example (discussed further below).

4.3.3 The nature of primary and secondary correlates: timing vs. rhythm

In this section, I make explicit the distinction between *timing* and *rhythm* in language, by discussing which correlates of rhythm are also elements of timing, and which are not. I propose that the only correlates of rhythm which are not also timing elements are (1) the primary correlate: alternating stresses or syllables, and (2) one of the secondary correlates: stress itself. All secondary correlates of rhythm other than stress and its phonetic manifestation can be interpreted as elements of timing in language. I start by outlining the difference between the concepts of timing and rhythm. I then go on to a discussion of the correlates of rhythm, with respect to these two concepts.

The relationship between timing and rhythm is illustrated in Figure 4.7. Rhythm refers to all factors which contribute to the 'forward movement' of language, whereas timing refers only to those factors which directly involve duration. In this sense, timing elements in the language form a subset of the set of rhythm elements.

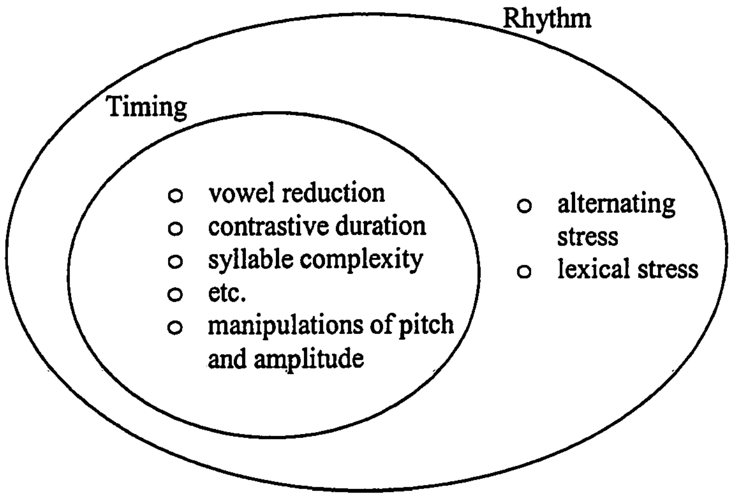

Figure 4.7 Venn diagram illustrating the relationship between rhythm and timing

The properties which affect rhythm and are measurable in terms of duration are elements of *timing*. Take for example vowel reduction. The effect of vowel reduction on rhythm is measurable quantitatively (by measuring the duration of reduced vs. full vowels). For this reason, vowel reduction is considered an element of timing. Similary, contrastive duration is an element of timing, since its effect on rhythm involves measurable differences in duration between singleton and geminate consonants, or between short and long vowels. Another - less obvious - example of a property involving timing is syllable complexity. The complexity of syllables determines the timing among consonants and vowels. In Ramus' terms, it affects %V (which is lower in languages allowing complex syllables) and ΔC (which is higher in languages allowing complex syllables). Both %V and ΔC are based on durational measurements, %V on the total durations of consonantal vs. vocalic material and ΔC on the variability in the duration of consonantal intervals. Because syllable structure affects %V and ΔC (based on durational measures), and because %V and ΔC affect rhythm in language, one can say that syllable structure is an element of timing. Other elements of timing include vowel and consonant qualities, and the fluctuations in sonority, pitch, and amplitude corresponding to the realization of stress[19].

While timing factors have a strong effect on the perception of rhythm, they are not alone in creating rhythm. I propose here that the most important contributing factor to rhythm - the primary correlate to rhythm - does not involve timing. Indeed, whether a language does or does not have alternating stress is not in itself related to timing, although the the realization of stress in languages that have it most often involves timing.

In summary, the only correlates of rhythm which are not also elements of timing are the abstract notions of stress and alternating stress. The phonetic realization of stress involves fluctuations of pitch and amplitude over time (as well as manipulations of duration). Any cue that involves fluctuation over time constitutes an element of timing.

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[19] Note that overall speech rate also has an effect on rhythm (Grabe and Low, in press).

Lexical stress aside then, the primary correlate of rhythm - alternating stresses or lack thereof - is the only correlate of rhythm that is purely "rhythmic" in nature, i.e. not also an element of timing. This correlate is enhanced or inhibited by the timing structure of the language, which is reflected by the secondary correlates. The rhythm continuum is created by the interplay between the rhythmic cue to rhythm, i.e syllables or alternating stresses (primary) and the timing features of the language (secondary). In Table 4.8, I summarize the correlates of rhythm which are and are not elements of timing.

Table 4.8 Phonetic and phonological correlates of rhythm

Primary correlate: element of rhythm	*Secondary correlates: elements of timing*
o alternating stresses o lexical stress	o amplitude fluctuations o pitch fluctuations o sonority fluctuations o vowel and consonant qualities o segmental duration o syllable complexity o vowel reduction o contrastive duration o duration of interstress intervals o ambisyllabicity (accompanied by a change in length)

One point worth discussing here involves the difference (in terms of phonetic implementation) between syllable complexity and segmental duration. As mentioned above, Ramus et al. (1999) use %V and ΔC to measure syllable structure quantitatively. In measuring the duration of consonantal intervals, it is assumed that longer intervals represent consonant clusters, whereas shorter intervals represent single consonants. In this way, the duration of consonantal intervals is taken as a direct reflection of the complexity of syllable structure - i.e. the presence vs. absence of clusters, etc.

One might be tempted to merge the correlates *syllable structure* and *segmental duration* into one correlate: *duration of consonantal intervals*, which is in fact what Ramus et al. (1999) do. The reason that syllable structure and segmental duration are considered separate correlates of rhythm is because their effects on rhythm differ. This can be seen in a language like Lheidli, which has simple syllable structure but long intervocalic consonants. In Lheidli, the salience of syllables as the primary correlates of rhythm is enhanced by simple syllable structure, but inhibited by long intervocalic consonants. Because syllable structure and segmental (consonantal) duration have opposing effects on the salience of the syllable, they are kept as distinct correlates.

4.3.4 Conclusion

In section 4.1, I presented the reader with an overview of the literature on rhythm. In section 4.2, I showed that Ramus et al.'s existing model of rhythm fails to capture the facts of all languages adequately. Based on the previous literature, and on findings from applying Ramus et al.'s methodology to Lheidli, in section 4.3 I proposed the Enhancement/Inhibition model of rhythm, whereby rhythm is created by the interplay between the primary and secondary correlates of rhythm. Each language has a particular rhythmic structure, created by the presence vs. absence of alternating stress (primary correlate). However, the salience of this rhythmic structure is strongly influenced by the timing features of the language (secondary correlates). It is the secondary correlates of rhythm which allow for languages to fall along a continuum in terms of rhythm, rather than falling into discrete classes[20]. In the following section, I show how Lheidli is accounted for within the Enhancement/Inhibition model of rhythm.

4.4 Lheidli within the Enhancement/Inhibition model

Recall from section 4.2 that Ramus et al.'s model of rhythm did not capture appropriately the facts of Lheidli. In this section, I account for Lheidli's rhythm within the Enhancement/Inhibition model of rhythm. I begin by presenting the primary and secondary correlates of rhythm in Lheidli (4.4.1) and go on to provide a representation of Lheidli within the Enhancement/Inhibition model (4.4.2).

4.4.1 Rhythm correlates in Lheidli

Lheidli is similar to Polish (mentioned in 4.2 above) in that it does not clearly fall into any one rhythm class. Lheidli has lexical stress (see Chapter 2, section 2.4). However, it does not have alternating stress (Morice, 1932, Walker, 1979, Story, 1984). Therefore, the primary correlate of rhythm in Lheidli should be the syllable, according to the Enhancement/Inhibition model of rhythm.

A number of its secondary correlates enhance this rhythm pattern: it does not have contrastive duration, either in the consonant system or the vowel system. It does not have stress-related vowel reduction, although it does have one vowel which is consistently

[20] For an alternative explanation of the continuum see Cummins (2002), who states that the rhythm continuum results from the coupling between nested prosodic units, which is gradient and depends on varying factors such as speech rate rather than on discrete factors such as syllables, morae, etc.

much shorter than the others - /ʌ/ - regardless of stress placement[21]. Finally, its syllable structure is relatively simple - tautosyllabic clusters are disallowed.

While the factors listed above enhance the syllable as the most salient recurring unit, they are not enough to place Lheidli clearly among syllable-timed languages. The most important inhibiting secondary correlate is segmental duration. Because intervocalic consonants are so long in Lheidli, the proportion of consonantal material is relatively high. A related factor is that, as we shall see in Chapter 5, these consonants are ambisyllabic (belonging to both the preceding and following syllables). This makes syllable boundaries difficult to establish, which results in the syllables being less clear as discrete, recurring units. Another result of long intervocalic consonants is that the variability across consonantal intervals is very high, since there are also very short intervals created by word-initial obstruents for example. Finally, Lheidli does have stress, although it is not alternating. Together, these correlates inhibit the syllable as the most salient recurring unit. Table 4.9 summarizes the enhancing and inhibiting correlates of rhythm in Lheidli. Note that the first enhancing correlate listed is predicted, since Lheidli lacks alternating stress. I have not yet measured interstress intervals or ratio of stressed to umstressed syllables quantitatively.

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[21] As mentioned in Chapter 2 (section 2.1.4), /ʌ/ is phonemic: it alternates with other vowels, can be stressed, and can be the only vowel in a (monosyllabic) word. Even when stressed it is very short (there is no significant difference in duration between stressed and unstressed /ʌ/).

Table 4.9 Enhancing and inhibiting correlates to syllable-timed rhythm in Lheidli

Enhancing correlates	*Inhibiting correlates*
o low ratio of stressed to unstressed syllables o no contrastive duration o simple syllable structure o no vowel reduction	o long segmental (consonantal) consonantal duration o ambisyllabicity o (high variability in consonantal intervals) o lexical stress (increased pitch and amplitude)

Although Lheidli does not have alternating stress, and should therefore be a syllable-timed language, there are a sufficient number of secondary correlates which inhibit this rhythm such that Lheidli is not clearly syllable-timed either. The interplay between primary and secondary correlates of rhythm indicates that Lheidli falls neither among stress-timed languages nor among syllable-timed languages on the rhythm continuum. Looking back at Figure 4.5, Lheidli falls among languages of type (d).

4.4.2 Lheidli and the Enhancement/Inhibition model of rhythm

I conclude this section by providing a representation of Lheidli within the Enhancement/Inhibition model of rhythm. Recapitulating, Lheidli has the following correlates of rhythm:

(2) Correlates of rhythm in Lheidli

a. no alternating stress

b. no contrastive duration

c. no vowel reduction

d. simple syllable structure

e. long intervocalic consonant duration = low %V (high %C) and high ΔC

f. ambisyllabicity

g. lexical stress (increased pitch and amplitude)

Lheidli has no alternating stress (a), and for this reason the primary correlate of rhythm is the syllable (like syllable-timed languages). Several facts enhance the salience of the syllable: no contrastive duration (b), no vowel reduction (c), and simple syllable structure (d). However, other correlates of rhythm (e-g) inhibit the salience of the syllable. Note that the correlates (e) and (f) are both related to the unusual duration of Lheidli intervocalic consonants: long segmental duration (low %V and high ΔC), as well as ambisyllabicity. The reason Lheidli falls at the stress-timed extreme in Ramus et al.'s classification is because his variables only capture secondary correlates. However, in the Enhancement/Inhibition model, Lheidli falls neither among stress-timed languages nor among syllable-timed languages because it lacks alternating stresses, and has several factors inhibiting the salience of the syllable as the primary correlate of rhythm.

Figure 4.8 illustrates Lheidli within the Enhancement/Inhibition model of rhythm. Arrows pointing towards the outer 'syllable' circle indicate correlates that enhance the salience of the syllable as the primary correlate of rhythm. Arrows pointing away from the outer 'syllable' circle indicate correlates that inhibit the salience of the syllable.

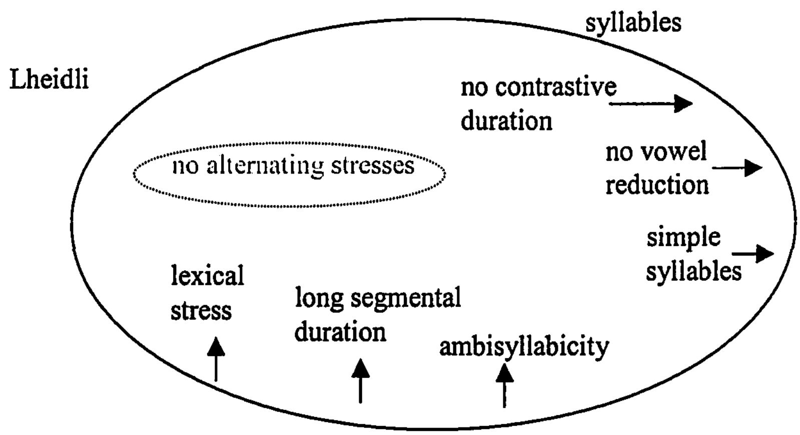

Figure 4.8 Primary and secondary correlates of rhythm in Lheidli (mixed)

Once again, the correlates affected by the duration of intervocalic stops are (a) long segmental duration, and (b) ambisyllabicity (as we shall see in Chapter 5). Combined with lexical stress, these three correlates have enough weight among them to prevent Lheidli from patterning with syllable-timed languages. Note that 'long segmental duration' and 'ambisyllabicity' are considered separate correlates of rhythm. This is because, cross-linguistically, these correlates are not necessarily related, even though they are in Lheidli (they are both properties of intervocalic consonants). Indeed, ambisyllabicity does not necessarily entail long segmental duration, and vice versa.

That Lheidli falls neither among stress-timed nor among syllable-timed languages is supported by data from another Athapaskan language: Jacarilla Apache. In a study on rhythm in this language, Tuttle (to appear) measured vocalic and intervocalic (consonantal) intervals, and computed the variability in durations across these intervals using the *Pairwise Variability Index* (PVI) (Grabe and Low, in press). This index places languages along a rhythm continuum based on the variability in duration across pairs of consecutive intervals (where the intervals are either both vocalic or both consonantal). Tuttle found that Jacarilla Apache fell between English (stress-timed) and French (syllable-timed) on the rhythm continuum, based on its PVIs.

4.5 Conclusion

The goal of this chapter was to provide a new understanding of how rhythm is achieved in language. This was accomplished through a discussion of the literature on rhythm, which led to the proposal of a new model of rhythm whereby rhythm is achieved through one primary cue (phonological and specific to rhythm) combined with a set of secondary cues (phonetic and phonological, all features of timing except lexical stress). In stress-timed languages, alternating stress forms the primary cue to rhythm; in languages without alternating stress, the primary cue to rhythm is the syllable. The salience of the primary cue is either enhanced or inhibited by secondary cues such as vowel reduction, syllable structure, pitch, amplitude, sonority, segmental duration, etc. Rather than being a primitive of language, rhythm falls out naturally from the primary and secondary correlates of rhythm. Furthermore, rhythm is a function of phonetic output, regardless of whether the source of this output is phonological or not.

The Lheidli data provided show that segmental duration is an important secondary cue to rhythm which has not yet been considered in the literature. Furthermore, it shows that Ramus et al.'s (1999) interpretation of consonantal intervals as reflecting complexity of syllable structure should be modified: consonantal intervals reflect segmental duration as much as complexity of syllable structure, and these two elements of rhythm must be considered distinct correlates, since they can have conflicting effects on rhythm.

One of the predictions of this model involves the interaction between stresses and strong beats in music and poetry. In stress-timed languages (with salient alternating stresses), the strong beats in music and poetry must respect the stressed syllables of the words involved. For example in English, stressed syllables must fall on strong beats in music and poetry. (3)a, an excerpt from the musical The Music Man, illustrates this. Its rhythm consists of alternations between strong (s) and weak (w) beats. Notice that all the lexical stresses (in the content words *bicker* and *talk*) coincide with the strong beats (s) of the music. Example (3)b shows that you could not have a similar rhyme, but with the strong beats on the unstressed syllables of the word *bicker*. Stressed syllables are indicated with acute accents, beats are indicated beneath the lines of the relevant syllables, "--" indicates a silent weak (w) beat.

(3) Stress in English music

a. … You can bícker bícker bícker you can tálk you can tálk …
s w s w s w s w s w s -- s w s --

b. *… bí.cker bí.cker …
w s w s

Examples (3)a and (3)b illustrate that in stress-timed languages like English, strong beats in music and poetry must respect (i.e. coincide with) the stresses in polysyllabic content words, as spoken naturally (Hammond, 1991, Hayes, 1995).

In syllable-timed languages, on the other hand, there is much more flexibility in music and poetry in terms of where the strong beats can go. Take for example French. The lines given in (4) come from a song by Daniel Bélanger (a musician from Quebec). This song involves a lot of syncopation, i.e. the strong beats are often silent and words are pronounced on the weak beats. Recall from section 4.1 that stress is generally said to fall on the last syllable of French words. What is important to notice here is that in both (4)a and (4)b a strong beat falls on the first syllable of the verb in italics, rather than on the second (and last). In (4)a, the first strong beat corresponds to the first syllable of the verb *j't'emprie*. In (4)b, the second strong beat falls on the first syllable of the verb *j'm'ennuie*. In both examples, the relevant verb is in italics. The stressed syllable is underlined, syllable breaks are indicated with periods, and "--" indicates a missing strong beat.

(4) Stress in French music[22]

a. *<u>J't'em</u>.prie* sèches tes pleurs
s w -- w -- w -- w
(I beg you, dry your tears)

b. Je l'aime et *j'm'e.<u>nnuie</u>*
w s w s w
(I love her and I miss her)

[22] *J't'emprie* is short for 'je t'emprie', and *j'm'ennuie* is short for 'je m'ennuie'.

These two examples show that in French, although it is generally accepted that stress falls on the last syllable of a word, this can change in music (and poetry as well). In both (4)a and (4)b, a strong beat falls on the first syllable of a bisyllabic verb, and as a result the first syllable is stressed, rather than the second.

The prediction then is that the stronger the perception of alternating stress is, the less you can alter the natural stress of words in music and poetry. This is why in strong stress-timed languages, stressed syllables must fall on the strong beats (Hammond, 1991, Hayes, 1995). This prediction can be tested by investigating music and poetry in languages which fall at the stress-timed and syllable-timed extremes of the rhythm continuum. If the prediction holds, then one can turn to music and poetry of less understood (rhythmically) languages, as a tool for placing them on the rhythm continuum. If in a language word stress can change depending on position (strong vs. weak beat), the language is more likely to be syllable-timed. Unfortunately, Lheidli elders (native speakers) have no knowledge of any poetry, songs, children's rhymes, etc. for this dialect of Dakelh (or for other any other dialects). Therefore, this prediction cannot be tested for Lheidli.

Another type of prediction within this model involves the specific secondary correlates involved. It should be possible to say that given the secondary correlate X, language Y should pattern within category Z in certain situations. An example prediction would be: given that Lheidli has ambisyllabicity (inhibiting syllable-timing), it should pattern with English in Cutler et al.'s (1992) study of speech segmentation. The difficulty with such predictions is that rhythm is a result of the interplay between several secondary correlates, as well as the primary correlate. Predicting how a language patterns with respect to one specific correlate requires understanding precisely how much weight this correlate has, i.e. how important it is as a cue to rhythm. As mentioned previously, an investigation of relative weights of various correlates has not yet been conducted. Therefore, making specific predictions about the effect of correlates on language patterns will have to await further research.

Having provided a model of rhythm and accounted for the Lheidli data within this model, I now turn to a number of issues which have yet to be explained. Perhaps most important is the question of position. Why is it the case that consonants are unusually long only intervocalically? One explanation of the limited distribution of long consonants (which does not necessarily involve phonology) has to do with perceptual salience (Liljencrants and Lindblom, 1972, Ohala, 1981, 1993, Flemming, 1995, Wright, 1996, Steriade, 1999, 2001, 2002, Hume and Johnson, to appear). Hume and Johnson (to appear) argue that certain patterns in language can be explained through perceptual salience. The idea is that perception influences phonological systems, in that "contrasts of weak perceptibility tend to be avoided in language" (p. 4). They illustrate their idea with an example from Maltese, which uses epenthesis to strengthen a length contrast among consonants:

> "In this process, the vowel [i] is epenthesized before a word-initial geminate consonant (...) Since the perceptual cues to word-initial

> geminates, stops especially, are relatively weak (see, e.g. Abramson, 1987; Muller, in prep.), insertion of a vowel before the geminate enhances the perceptibility of consonant length (...)" (p. 4)

It is possible that Lheidli consonants are lengthened intervocalically because, at least for stops, it is in this position that the additional length is most salient. The total duration of stops is only perceptible if the closure duration and release can be identified, i.e. intervocalically. Although perceptual salience is only an issue for the duration of stops, the resulting lengthening process (consonants are lengthened intervocalically) could have been phonologized (Hyman, 1976) at some point in time, thus lengthening *all* consonants intervocalically. Once the process became phonologized, even sounds such as fricatives, nasal, liquids, or glides were lengthened intervocalically, even though their duration is also perceptual in other positions (since their duration does not include a period of complete closure).

This explanation of the limited distribution of Lheidli long consonants based on perceptual salience runs into problems when one considers why duration should be perceptual salient. Duration is not contrastive in Lheidli, and there is therefore no reason - in terms of lexical distinctiveness - for duration to be salient. Given that lexical distinctiveness does not motivate the distribution of Lheidli's long consonants, what does? If rhythm were a primitive, and were influenced by %C, then one might expect consonants to be lengthened particularly in intervocalic position because it is in this position that their duration - and resulting effect on rhythm - is most salient. Indeed, if the rhythm of Lheidli required consonants to make up a large percentage of utterances, it would seem logical to lengthen them in a position where their duration is most salient. However, as mentioned in section 4.3.2.2 and discussed further in Chapter 6 (section 6.1.2), rhythm is not a primitive; rather, it falls out from other phonetic and phonological properties of language. Therefore, rhythm cannot 'require' consonants to be long in order to achieve a higher %C.

An explanation of the limited distribution of long consonants in Lheidli based on perceptual salience cannot appropriately capture the facts of the language, at least not within the Enhancement/Inhibition model of rhythm. As an alternative explanation, I propose in Chapter 5 that positional effects have to do with syllable structure - and consequently with the phonology of the language.

Another issue that should be addressed here involves the robustness of results obtained in conducting research on acoustic correlates to rhythm. This topic has been raised by several researchers, most recently Ramus (2002), who suggests it may not be possible, with current methodologies, to obtain data necessary to investigate rhythm in a systematic fashion. Particularly research involving durational measurements has certain shortcomings, the most important of which involves speech rate. Values obtained for variables which are correlated to rhythm (%V, ΔC, etc.) vary substantially based on speech rate, but controlling for this factor has proven very difficult (Ramus, 2002). Researchers studying widely accessible languages such as English and French have been able to record data in very controlled settings, and still face problems when it comes to consistency of the data. How then can it be possible to apply the established methodologies in studying the rhythm of Lheidli, and other endangered languages? Only two speakers are able to work on Lheidli, both are elderly, and bilingual. They differ in degree of literacy, and in frequency with which they use the language. Put bluntly, how can we hope to obtain any meaningful results from such a (necessarily) uncontrolled procedure? I have two comments on this issue. The first is that, for languages on the verge of extinction, it is better to study them using a methodology that is not as rigorous as one would like, than not to study them at all. In the case of Lheidli, it is crucial to 'take what we've got' and study the rhythmic structure now, while there are still speakers, albeit only two of them.

My second comment on this issue involves the specific phenomenon studied in this dissertation: the length of intervocalic consonants. The basic fact - that intervocalic consonants are remarkably long - is found across Athapaskan languages, and has been noted previously by other researchers (Sapir and Hoijer, 1967, Young and Morgan, 1987, McDonough and Ladefoged, 1993). Therefore, it clearly does reflect a well-established phenomenon that exists across a whole language family, and that needs to be discussed if we are to fully understand rhythm typology. Furthermore, the remarkable duration of intervocalic consonants is clearly obvious auditorily in the Lheidli data used for this dissertation. The consistency with which long consonants are produced intervocalically argues for its reality.

Finally, since its first appearance in the literature, discussion of rhythm and rhythm classes in language has been approached from the perspective of western researchers, who presumably are influenced by rhythm as they hear it in western music.

The idea of isochronous units which create a regular 'beat' in language is a notion directly transposed from western music. What would have happened if initial research on rhythm in language had been conducted by scholars from a culture in which music does not contain such regularly recurring beats? There are certainly styles of music in which the 'forward movement' is not created by anything as simple as isochronous units. Perhaps then, the notion of rhythm classes as we know it is too culture-specific to be of any real value in conducting typological work.

I believe that, while researchers working on rhythm have doubtless been influenced by western music, the idea of classifying languages into some sort of rhythm classes is itself a reasonable idea, and well worth pursuing even if the classes are replaced with fuzzy clusters along a continuum. Indeed, even if there is no isochrony in language, there is clearly something different in the rhythm of English, French, and Japanese, for example, such that these languages can be said to fall into different categories even without mention of isochrony. Also, in considering the importance of secondary cues to rhythm, we are expanding our knowledge in useful ways, and in ways that are certainly compatible with the idea that not all languages have one perceptually salient unit, which is solely responsible for creating the forward movement of speech.

I would like to conclude this section with a brief comment on the relative 'importance' of consonants and vowels in carrying the flow of language. It has often been said that vowels carry the rhythm of a language (Fowler, 1983, Pérez, 1997, Ramus et al., 1999). Fowler in particular has a model of language in which vowels are evenly timed, thus giving the perception of rhythm, and the consonants are simply superimposed on the vocalic tier. The assumption implicit in Fowler's model (and in others') is that vowels are primary and consonants are secondary, in terms of their respective roles in establishing the rhythm of a language.

When considering languages such as Lheidli, it becomes apparent that the importance of consonants in establishing the perception of rhythm in language cannot be ignored. The question of which units are primary in providing language with its 'forward movement' - consonants or vowels - is an interesting one, and particularly relevant to Athapaskan languages which exhibit such interesting consonantal properties. Future work will hopefully shed further light on this issue.

CHAPTER 5 THE PHONOLOGICAL ROLE OF INTERVOCALIC CONSONANTS

We have already seen that intervocalic consonants are substantially longer than consonants in any other position (Chapter 3), and that this duration has a direct influence on the rhythmic structure of the language (Chapter 4). Given that rhythm results from a combination of phonetic and phonological factors, the effect of intervocalic consonants on rhythm does not necessarily entail that they are phonologically active. It could be that their duration is simply one of the phonetic correlates of rhythm. The question addressed in this chapter is whether or not the phonetic length of intervocalic consonants is associated with special phonological status. If the answer to this question is 'no', then the duration of intervocalic consonants should not be contrastive. Furthermore, they should behave as regular onsets, as one would expect given universal syllabification tendencies (Itô, 1986). As onsets, they should not participate in any phenomena in the language which are sensitive to weight, their distribution should correspond to that of onsets, and native speakers should identify them clearly as onsets.

If intervocalic consonants are associated with a special phonological role, there are three ways in which phonetic duration can be encoded in the phonology: (a) as phonological length (contrasting geminates with singletons), (b) as phonological weight (contrasting moraic (coda) consonants with non-moraic ones), or (c) as a combination of both phonological length and weight[1]. If duration is reflected by phonological length,

[1] For a discussion on the distinction between phonological length and weight, see Hume et al. (1997a, 1997b)

then one would expect duration to be contrastive. If duration is reflected by phonological weight, then one would expect intervocalic consonants to participate in phenomena which are sensitive to weight. Furthermore, their distribution should be different from that of regular onsets, and native speakers should not identify them as simple onsets.

Through a series of studies reported below, we shall see that intervocalic consonants are indeed phonologically active: their phonetic duration is mirrored in the phonology of Lheidli, in terms of phonological weight. Not only do consonants play an important role in phonetic timing, in terms of establishing the rhythmic structure of Lheidli, they also play an important role in phonological timing, in terms of establishing the syllable structure of Lheidli. The proposed analysis is that these consonants are non-contrastive, moraic geminates: they are geminates because they are long, because they act both as codas to the preceding syllable and onsets to the following syllable, and because their occurrence does not depend on stress placement. They are not contrastive because there are no minimal pairs in which one word has a long intervocalic consonant and the other has a short one. Their moraicity is evidenced by the fact that their distribution is limited to positions which license a mora. Finally, that the duration of intervocalic consonants (encoded phonologically as weight) interacts with other phonological properties of the language implies that segmental (consonantal) duration is, at least in Lheidli, encoded in the phonology of the language - as phonological knowledge rather than simply as phonetic knowledge.

Chapter 5 is structured as follows: section 5.1 presents the results from a series of studies on vowel durations and distributions. These studies indicate that intervocalic consonants behave as codas, closing the preceding syllable (VC.V). Section 5.2 presents data on the distribution of intervocalic consonants, which argues for syllabifying intervocalic consonants as onsets (V.CV). Section 5.3 provides results from two tasks designed to collect native speaker syllabification intuitions, the results of which indicate that intervocalic consonants are ambisyllabic (V(C)V). Finally, section 5.4 presents findings from a study which shows that the length of intervocalic consonants is not a function of stress placement. Based on the findings in sections 5.1-5.4, section 5.5 provides a formal representation of intervocalic consonants in Lheidli in which they are analyzed as non-contrastive moraic geminates.

5.1 Intervocalic consonants as codas: evidence from vowel alternations

There are several ways in which the phonological role of intervocalic consonants can be explored. In this section, I focus on vowel alternations. Section 5.1.1 presents data from vowel durations, comparing vowels followed by intervocalic consonants to vowels in other positions. Section 5.1.2 discusses the distribution of tense and lax allophones of the high front vowel /i~ɪ/. Section 5.1.3 presents data on the distribution of the reduced vowel /ʌ/ and other phonemic vowels. All of the findings reported on vowel alternations lead to syllabifying intervocalic consonants as codas, which close the preceding syllable (VC.V).

5.1.1 Durational properties of Lheidli vowels

A first insight into the phonological role of intervocalic consonants comes from exploring durational properties of vowels. As mentioned in Chapter 2, Lheidli has no contrastive length distinction among its vowels. However, positional factors do influence the phonetic duration of vowels. The goal of the study presented in this section is twofold: (1) to determine what effect syllable structure and finality have on vowel duration, and (2) through findings on the effect of syllable structure and finality, to gain further insight into the phonological role of intervocalic consonants. The following hypotheses were tested:

Hypothesis I

Vowels are longer in open syllables than in closed syllables.

Hypothesis II

Vowels are longer in the last syllable of the word than in preceding syllables.

Hypothesis I is based on the fact that in general, long vowels are more likely to occur in open syllables than in closed ones (Maddieson, 1985)[2]. Hypothesis II is based on word-final lengthening effects, which make the last segment of the word longer than preceding segments (Klatt, 1979, Kaiki, 1990, Sagisaka, 1992, Tuttle, to appear).

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[2] See also Newman (1944) on Yawelmani Yokuts, Broselow (1976) on Egyptian Arabic, and Clements & Keyser (1983) on Turkish for phonological shortening of long vowels in closed syllables).

The methodology used to collect and analyze the data was discussed in section 1.4. In this chapter, I start by outlining the research design used (5.1.1.1), and then go on to discuss the results of the study on vowel durations (5.1.1.2 through 5.1.1.4).

5.1.1.1 Design of the study

Two factors were considered here: syllable type (open vs. closed), and finality (first syllable vs. second syllable - which is always the final syllable in this data set). Table 5.1 illustrates this design, which includes four conditions: open non-final (CV.CV(C)), open final (CV(C).CV), closed non-final (CVC.CV(C)), and closed final (CV(C).CVC). The vowels measured in each condition are underlined. As mentioned in section 1.4 (General Methodology), the number of items in each condition varied. In Table 5.1, the number of items for each of the four conditions is included in parentheses[3].

Table 5.1 Experimental design of Vowel Duration study

Syllable structure	*Finality*	
	Non-final syllable	*Final syllable*
Onset	CV.CV(C) (212)	CV(C).CV (125)
Coda	CVC.CV(C) (130)	CV(C).CVC (217)
Total	342	342

Although there is not the same number of items in each condition, the numbers are sufficiently large that statistical analyses should be reliable.

[3] For the complete word list used, see Appendix A.

5.1.1.2 Results

The following bar graph illustrate the means for each condition, in terms of raw duration. Values are averaged across all vowel types.

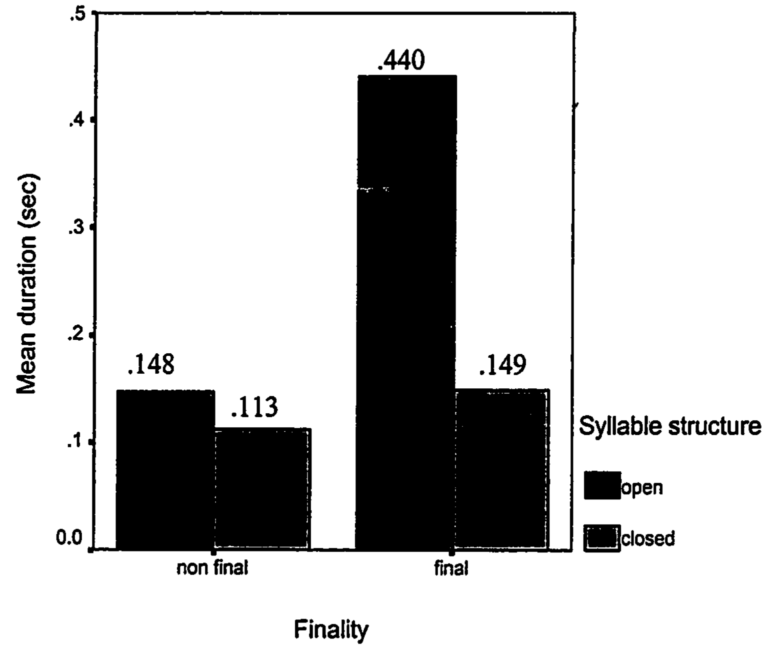

Figure 5.1 Mean duration of vowels in non-final and final position in open and closed syllables

Two conclusions can immediately be drawn from Figure 5.1: (1) word-final vowels in open syllables are much longer - 3 times as long - as vowels in any of the other conditions, and (2) vowels are approximately the same duration in non-final open, non-final closed, and final closed conditions.

Let us now take a closer look at the data, using z-scores to remove the effect of inherent duration of each vowel[4]. Figure 5.2 shows the mean z-scores for vowels in different positions. Recall that the value 0.0 on the vertical axis indicates the mean duration of vowels across all positions. Values above 0.0 represent durations that are above the average duration across positions, i.e lengthened. Similarly, values below 0.0 represent durations that are below the average duration across positions, i.e shortened. For example, vowels in word-final open syllables have approximately z = +1.2. This means that the duration of vowels in word-final open syllables is well above the mean duration of vowels across all positions.

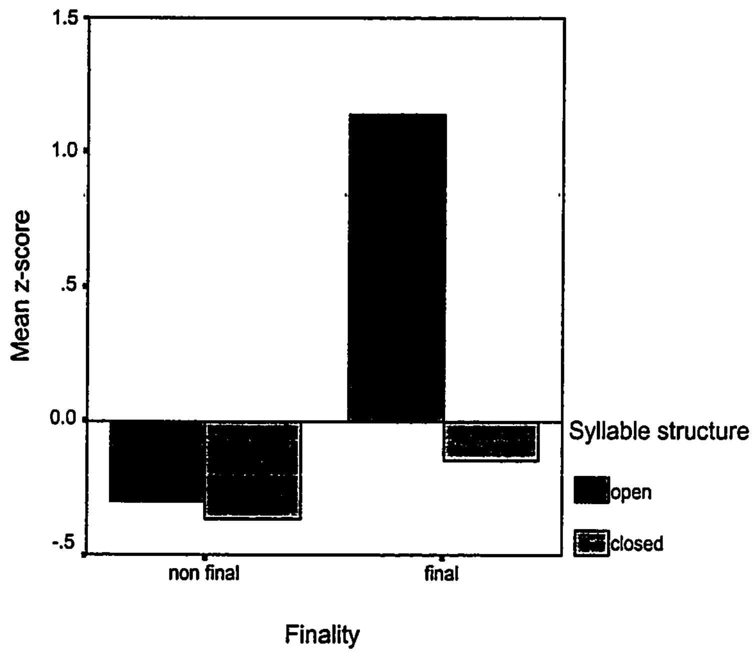

Figure 5.2 Mean z-scores of vowels in non-final and final position in open and closed syllables

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[4] For a discussion of the usefulness of z-scores, please see section Chapter 3, section 3.2.1.2.

The difference between Figures 5.1 and 5.2 results from plotting raw durations (5.1) vs. z-scores (5.2). In Figure 5.2, the only positive z-score is for vowels in word-final open position. Because vowels in final open syllables are so long, they have a strong effect on the average duration of vowels - they raise it substantially. As a result, vowels in all other conditions are below average in duration - hence their negative z-scores.

The data was analyzed with a two-factor between-subjects ANOVA, with syllable structure and finality as the factors. Both main effects and the interaction were significant (finality: $F(1,680) = 157.25$, $p < 0.001$; syllable structure: $F(1,680) = 105.93$, $p < 0.001$; finality by syllable structure interaction: $F(1,680) = 86.12$, $p < 0.001$). An analysis of the simple effect of syllable structure was significant in final position ($F(1,340) = 163.33$, $p < 0.001$), with vowels in final open syllables significantly longer than vowels in final closed syllables. However, the effect of syllable structure was not significant in non-final syllables ($F < 1$).

From these results, what can one say about Hypotheses I and II given above? Hypothesis I (vowels in open syllables are longer than those in closed syllables) was supported in word-final position, but not in word-medial position. Hypothesis II (vowels in final syllables are longer than those in non-final syllables) was supported, both in open and in closed syllables.

5.1.1.3 Discussion

There are two possible explanations for why syllable structure seemed to influence vowel duration word-finally but not word-medially. First, it is possible that syllable structure itself does not influence vowel duration, and that the results obtained reflect a word-final lengthening effect (vowels are lengthened in word-final open syllables). Second, it is possible that syllable structure *does* influence vowel duration, but that word-medially all syllables are closed.

Recall from section 3.2.1.2 that consonants are longer than average word-finally, i.e. they are subject to word-final lengthening. Assuming that word-final lengthening also affects vowels, then their relatively long duration in word-final open syllables can be reduced to an effect of linear positioning, and tells us nothing about syllabification. This explanation is supported by the fact that vowels in word-final closed syllables are also significantly longer than vowels in non-final closed syllables ($F(1, 345) = 6.49$, $p < 0.02$).

If the relative duration of vowels word-finally is solely an effect of word-final lengthening, the ratio by which they are lengthened in this position should be comparable to the ratio by which consonants are lengthened in this position. In other words, the ratio *word-final vowel/word-medial vowel* in open syllables should be the same as *word-final consonant/word-medial consonant* in closed syllables (where the consonant is a coda). Table 5.2 provides these two ratios, which are based on the mean durations of vowels in word-final and word-medial 'open' syllables, and coda consonants in word-final and word-medial closed syllables.

Table 5.2 Ratio of word-final to word-medial coda consonants and word-final to word-medial vowels in open syllables

Position	*Relevant segment*	*Duration (ms)*	*Ratio*
Coda C. Non-final	CVC.CV(C)	256	CV(C).CVC : CVC.CV(C)
Coda C. Final	CV(C).CVC	276	276/256 = 1.08
Vowel Non-final	CVCV(C)	148	CV(C).CV : CVCV(C)
Vowel Final	CV(C).CV	440	440/148 = 2.97

The ratio between word-final and word-medial coda consonants is 1.08. The ratio between word-final and word-medial vowels in open syllables is 2.97. Given how much greater the ratio is for vowels than for consonants, it seems unlikely that - in the case of vowels - we are simply dealing with an effect of word-final lengthening. Rather, there is an additional open-syllable effect in play.

That there is an open-syllable effect on the duration of vowels leads us to the second possible explanation of the results: syllable structure *always* influences vowel duration, but word-medial CV syllables are in fact closed. Although this explanation may seem improbable at first glance - how can CV syllables be considered closed? - it is supported by the distributional facts of Lheidli vowels, discussed in sections 5.1.2 and 5.1.3. This explanation is also supported by the fact that the phenomenon by which intervocalic consonants close the preceding syllable also exists in other languages as well (Kahn, 1976, Borowsky et al., 1984, Hammond, 1999, Jensen, 2000). For these reasons, the second explanation as chosen as most accurately capturing the durational properties of Lheidli vowels: word-medial syllables are always closed, sometimes by an intervocalic consonant.

5.1.1.4 Conclusion on vowel durations

Although there is generally no phonological length distinction in Dakelh, vowel durations do differ substantially depending on position. Two findings are particularly interesting: 1) word-final vowels are 3 times as long as vowels in any other position in the word, and 2) word-medial vowels have the same duration regardless of whether they are in C_CV or C_CCV context. This last finding provides evidence for intervocalic consonants as coda consonants.

5.1.2 Distribution of tense and lax allophones of the high and mid front vowels

Several researchers have commented on vowel quality in Navajo, arguing that the long/short distinction in Navajo front vowels also involves a tense/lax distinction (Sapir and Hoijer, 1967, Young and Morgan, 1987, McDonough et al., 1993, Bird, 1999). For example, phonologically long /i:/ is realized [i:], whereas phonologically short /i/ is realized [ɪ]. The quality distinction in Navajo vowels is said to hold at least of front vowels (Sapir and Hoijer, 1967, Young and Morgan, 1987), and perhaps also of the back vowel [o] (McDonough et al., 1993). In section 5.1.1, we saw that vowel duration in Lheidli was affected by its position in a word. Based on this finding, and on the work done on Navajo mentioned above, I explore in this section the quality of vowels depending on position. The goal is to see whether the differences in vowel duration observed in section 5.1.1 are supported by differences in vowel quality. I limit my investigation to the front vowels: /i~ɪ/ and /e~ɛ/, since these are the vowels for which the tense/lax distinction is the most robust in Navajo. The question asked is whether or not there is an allophonic quality distinction among the front vowels, and if so whether it is conditioned by syllable structure (open vs. closed) and/or finality (final vs. non-final). Answering this question will shed further light on the role of intervocalic consonants in Lheidli, by clarifying whether or not they have the same effect on vowel quality as they do on vowel duration, and whether or not their effect is the same as that of coda consonants. The hypotheses tested are as follows:

Hypothesis I

Vowels in open syllables are tense; vowels in closed syllables are lax

Hypothesis II

Vowels in C_CV as well as C_CCV context are lax

Hypothesis I states that, where Lheidli has a tense/lax alternation (high vowels), the tense allophones will occur in open syllables whereas their lax counterparts will occur in closed syllables. This hypothesis is based on a combination of two facts: (1) in Lheidli, vowels in closed syllables are shorter than vowels in open syllables (see section 5.1.1 above), and (2) short vowels tend to be lax and long vowels tend to be tense (as in Navajo). Assuming Hypothesis I is borne out, word-medially vowels should be lax in all closed syllables, including ones closed by intervocalic consonants (C_CV). Hypothesis II is based on the notion that intervocalic consonants close the preceding syllable - thereby neutralizing the difference between CV and CVC syllables word-medially.

5.1.2.1 Design of the study

The design of this study is the same as that used to investigate vowel duration (see section 5.1.1). Two factors were considered: syllable structure (open vs. closed) and finality (first syllable vs. second syllable - which is always final in the dataset). Comparing word-medial and word-final open syllables allows us to investigate the role of intervocalic consonants in the 'non-final open' condition. The only difference between this study and that presented in section 5.1.1 is that instead of measuring vowel durations, in the present study formants (F1 and F2) were measured.

The data analyzed were a subset of the data used in this dissertation (see Appendix B). Only words with the vowels /e~ɛ/ and /i~ɪ/ were analyzed, and words with each vowel were analyzed separately. In total, 102 words were analyzed with /i~ɪ/ and 101 words were analyzed with /e~ɛ/. Tables 5.3 and 5.4 illustrate the design of each study The number of items used in each condition is included in parentheses.

Table 5.3 Experimental design of /i~ɪ/ study

Syllable structure	*Finality*	
	Non-final syllable	*Final syllable*
Onset	CV.CV(C) (21)	CV(C).CV (39)
Coda	CVC.CV(C) (18)	CV(C).CVC (24)
Total	39	63

Table 5.4 Experimental design of /e~ɛ/ study

Syllable structure	*Finality*	
	Non-final syllable	*Final syllable*
Onset	CV.CV(C) (32)	CV(C).CV (16)
Coda	CVC.CV(C) (13)	CV(C).CVC (40)
Total	45	56

5.1.2.2 Acoustic measurements

In order to measure vowel quality, the first and second formants (F1 and F2) were measured for each vowel. Measurements were taken at the mid point of the vowel, unless there were clear co-articulation effects, in which case measurements were taken at the point in the vowel where the formants stabilized. In cases where co-articulation effects affected the beginning of the vowel, measurements were taken at approximately 2/3 of the way through the vowel. In cases where co-articulation effects affected the end of the vowel, measurements were taken at approximately 1/3 of the way through the vowel. The following example illustrates the former case:

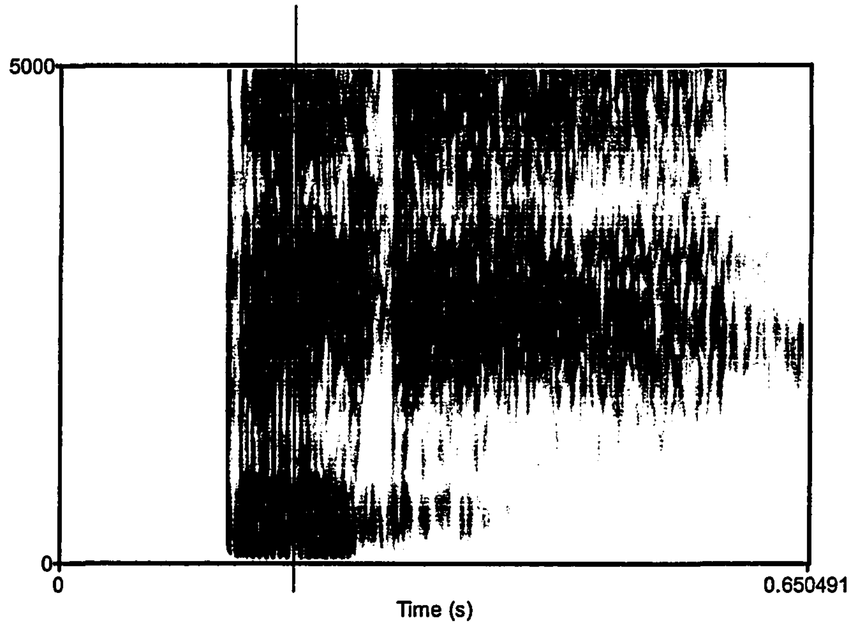

Figure 5.3 Spectrogram of [bɪɬ] in the word *gombilh* ('rabbit snare'). The vertical line indicates the point of measurement for F1 and F2.

If creaky voicing was present at the onset of the vowel, measurements were taken half way through the modal portion of the vowel, as shown in Figure 5.4.

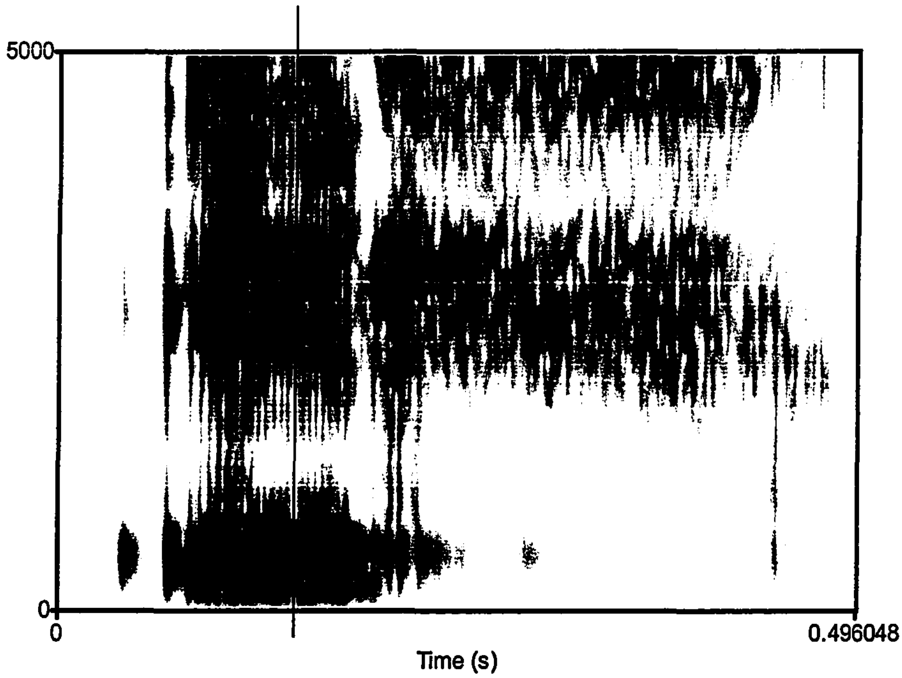

Figure 5.4 Spectrogram of [ʔɪɬ] in the word *'ilhtsul* ('blueberries'). The vertical line indicates the point of measurement for F1 and F2.

5.1.2.3 Results

The tense/lax alternation occurred for both /i~ɪ/ and /e~ɛ/, but only word finally. Word-medially, there was no tense/lax distinction. Whether the medial syllable was open (C_CV) or closed (C_CCV), the vowel was lax. This finding is illustrated by the following graph, in which F1 and F2 are plotted (on the *x-axis* and *y-axis* respectively) for /i/ and /e/ in each of the four conditions.

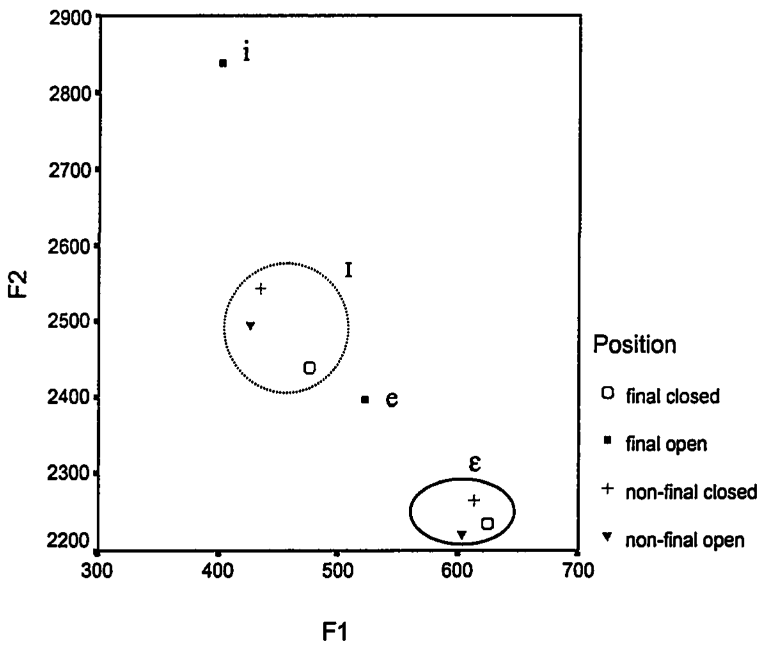

Figure 5.5 Allophones of /i/ and /e/ in open and closed, final and non-final syllables. F1 is on the *x* axis and F2 is on the *y* axis.

With respect to /i/, notice that both the F1 and F2 values of /i/ in non-final syllables (both open and closed) fall between the F1 and F2 values (respectively) of /i/ in final position. This finding is interesting in that it indicates that vowels take on more extreme values word-finally than they do word-medially. This is also true of F1 for /e/, but not of F2. Indeed, the lowest value for F2 is in non-final open syllables, rather than in final open syllables.

The data was analyzed using a series of two-factor between-subjects ANOVAs, with finality (final, non-final) and syllable structure (open, closed) as the factors. For F1 of /i/, the main effect of syllable structure was significant, as was the interaction (syllable structure: $F(1,98) = 15.43$, $p < 0.001$; syllable structure by finality interaction: $F(1,98) = 9.31$; $p < 0.01$). However, the main effect of finality was not significant ($F < 1$). Analysis of the simple effect of syllable structure revealed that there was a significant difference between F1 in open vs. closed syllables, but only in final position ($F(1,61) = 32.63$, $p < 0.001$), with a lower F1 in open syllables than in closed syllables. The effect of syllable structure was not significant in non-final position ($F < 1$).

For F2 of /i/, both main effects and the interaction were significant. (syllable structure: $F(1,98) = 13.59$, $p < 0.001$; finality: $F(1,98) = 6.22$, $p < 0.02$; syllable structure by finality interaction: $F(1,98) = 21.93$; $p < 0.001$). Analysis of simple effects revealed that the effect of syllable structure was significant word-finally ($F(1,61) = 64.10$, $p < 0.001$), with a higher F2 in open syllables than in closed syllables. The effect of syllable structure was not significant in non-final position ($F < 1$). In summary, word-finally, the /i/ is much more front and high in open syllables ([i]) than in closed syllables ([ɪ]). However, this difference disappears word-medially.

Turning now to /e/, an analysis of F1 showed that the main effects of both syllable structure and finality were significant, as was the interaction (syllable structure: $F(1,97) = 15.51$, $p < 0.001$; finality: $F(1,97) = 5.80$, $p < 0.02$; syllable structure by finality interaction: $F(1,97) = 10.55$; $p < 0.01$). Analysis of the simple effect of syllable structure revealed that there was a significant difference between F1 in open vs. closed syllables, but only in final position ($F(1,54) = 27.10$, $p < 0.001$), with a lower F1 in open syllables than in closed syllables. The effect of syllable structure was not significant in non-final position ($F < 1$).

With respect to F2 for /e/, the main effect of finality was significant, as was the interaction (finality: $F(1,97) = 4.06$, $p < 0.05$; syllable structure by finality interaction: $F(1,97) = 8.09$; $p < 0.01$). The main effect of syllable structure was not significant ($F(1,97) = 2.50$, $p > 0.05$). Analysis of simple effects revealed that the effect of syllable structure was significant word-finally ($F(1,54) = 11.41$, $p < 0.01$), with a higher F2 in open syllables than in closed syllables. The effect of syllable structure was not significant in non-final position ($F < 1$).

For /e/ as well as for /i/, the general result is that the vowel is more front and high in open syllables ([i] and [e]) than in closed syllables ([ɪ] and [ɛ]), but only word-finally. The formant values for /i/ and /e/ in non-final syllables (both 'open' and closed) look are similar to those in the final closed condition. This indicates that word-medially, there is no difference between so-called open (C_CV) vs. closed (C_CCV) syllable conditions.

5.1.2.4 Discussion

Both first and second formant measurements agree in terms of distinguishing between tense and lax reflexes of the high and mid front vowels. Taken together, F1 and F2 values indicate that word-finally, these vowels are tense in open syllables but lax in closed syllables. This difference in tenseness in the high and mid front vowels disappears word-medially, where vowels are lax regardless of whether they occur in open or closed syllables. This finding supports the findings discussed in section 5.1.1 on vowel durations in different conditions.

There are two possible explanations for why vowels are tense in only in word-final open syllables. First, it is possible that the crucial difference between final and non-final conditions is linear position: vowels are tense when they occur at the end of a word but lax otherwise. The second possibility is that the crucial difference between final and non-final conditions is that word-finally is the only position in which open syllables are truly open. Word-medially, syllables are never open because intervocalic consonants close the preceding syllable. As mentioned previously, distinguishing between linear and prosodic explanations is difficult. However, this issue is not specific to Lheidli, and not resolvable by this data. Findings in Lheidli correspond to similar facts in languages such as English (Hammond, 1999) and Canadian French, in which lax vowels followed by an intervocalic consonant are closed by this consonant. Since these effects are taken to be prosodic in other languages, I take them to be prosodic in Lheidli as well.

5.1.3 Distribution of /ʌ/ and other phonemic vowels

In the preceding two sections, we saw that the distribution of duration (5.1.1) and quality (5.1.2) in vowels indicates that intervocalic consonants serve to close the preceding syllable. In this section, I provide additional support for this idea through a discussion of the distributional facts of the phonemic vowels of Lheidli, focusing on the /ʌ/ and the diphthongs /ai/ and /ʌi/.

Table 5.5 summarizes the number of instances of each vowel in the data set in each of four conditions: open non-final (CV.CV(C)), closed non-final (CVC.CV(C)), open final (CV(C).CV), closed final (CV(C).CVC)[5]. The relevant position is underlined.

Table 5.5 Distribution of vowels by context

Vowel	*CV.CV(C)*	*CVC.CV(C)*	*CV(C).CV*	*CV(C).CVC*	*Total*
ʌ	91	60	0	67	218
a	46	24	25	52	146
e	32	12	14	41	99
i	22	18	41	25	106
o	4	6	21	26	57
u	10	10	9	5	34
ai	7	0	10	2	19
ʌi	0	0	4	0	4
Total	212	130	124	218	684

For the most part, vowels can occur in all environments. However, there are two notable exceptions. The first involves the centralized, reduced vowel /ʌ/. This vowel is by far the most frequent: 218 of the 684 vowels analyzed are tokens of /ʌ/. However, as Table 5.3 shows, its occurrence is not distributed evenly across positions. Indeed, there is not a single occurrence of /ʌ/ in an open syllable word-finally. In order to test whether this gap is accidental, a Chi Square test for Goodness of Fit was performed (Berkley, 1994, Pierrehumbert, 1994). Results showed that /ʌ/ is not distributed across the four conditions at chance frequency ($X^2(3, n = 218) = 82.27, p < 0.001$): there are significantly fewer tokens of /ʌ/ in word final open syllables than would be expected by chance.

[5] For the complete word list used for this study, see Appendix A.

What is interesting about the distribution of /ʌ/ is that it *does* occur word-medially in so-called open syllables[6]. There are 91 instances of /ʌ/ in word-medial open syllables (C<u>V</u>.CV(C)). There are two ways of interpreting these results. It is possible that /ʌ/ is subject to a simple linear requirement: it must be pre-consonantal. This explanation does not require any prosodic structure at all. The second possibility is that /ʌ/ can only occur in closed syllables. In word-final open syllables, /ʌ/ is not followed by a coda consonant, and therefore cannot occur[7]. In word-medial syllables, on the other hand, /ʌ/ is in a syllable closed by the intervocalic consonant, and consequently can occur. Again, distinguishing between prosodic and linear effects is difficult. In this case, evidence for the second possibility come from other facts of the language discussed in this chapter, all of which converge to support an analysis of Lheidli in which intervocalic consonants close the preceding syllable.

The second exception mentioned above involves diphthongs. These sounds occur primarily in open syllables. Of the 23 diphthongs found in the data set (19 instances of /ai/ and 4 instances of /ʌi/), all but two of these are found in open syllables[8]. The only instance of a diphthong occurring in a closed syllable is /ai/, which is found at the end of

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[6] I say "so-called" because I argue that these syllables are in fact closed by the following intervocalic consonant.

[7] It is possible that in continuous speech, /ʌ/ could be closed by the initial consonant of the following word. However, this would mean that underlying word-final /ʌ/ surfaces as some other vowel only in isolated forms or phrase-finally; this seems highly unlikely.

[8] In the Lheidli lexicon, there are cases of the diphthong /aw/. However, /aw/ was not present in my data set, and is therefore not considered here. The prediction is that it should pattern the same way as /ai/ and /ʌi/.

a word, followed by [h] - in the words *nulgaih* ('he runs') and *dusdaih* ('I am dancing'). In both these cases, what is transcribed as [h] in the orthography may in fact be vowel devoicing, in which case one can say that /ai/ occurs word-finally. By and large, diphthongs cannot occur in syllables closed by a consonant.

In phonological terms, it seems that Lheidli has a weight restriction: syllables must be at the most bimoraic (see Hammond (1999) for a similar discussion of English). In syllables with diphthongs, the two allowable morae are allotted to the vowel, leaving no room for a coda consonant. This phenomenon is relatively common (Hammond, 1999); what is interesting here is that [ai] *does* occur in word-medial open syllables (C$\underline{V}$.CV(C)). This suggests that, at least with diphthongs, the following intervocalic consonant does not close the preceding syllable. This is one case in which intervocalic consonants act as simple onsets. In support of this, syllabification intuitions (discussed in section 5.3) indicate that this is indeed the case. Words like *schaikeh* (my grandchildren) are consistently syllabified [stʃai.keh].

If intervocalic consonants act as simple onsets following /ai/, one would expect their duration to reflect this: they should be similar in duration to onset consonants. The following graph compares the duration of consonants following monophthongs (V_V), diphthongs (V:_V, and consonants (VC_V). Note that this graph is based on only 7 words with diphthongs vs. 205 words with monophthongs. Because there are so few tokens of diphthongs, it was not possible to perform statistics on the differences in consonant durations in the three positions.

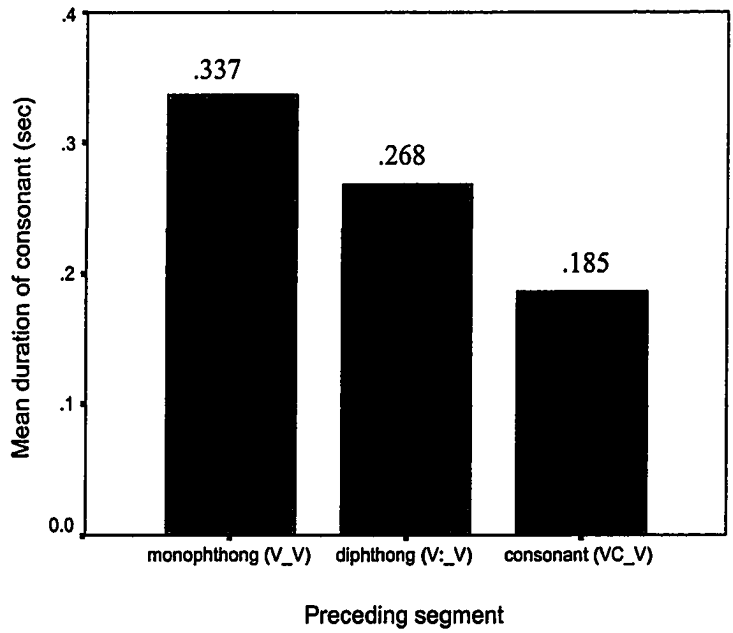

Figure 5.6 Intervocalic consonant duration depending on the preceding segment

As Figure 5.6 shows, intervocalic consonants are shorter when following diphthongs than monophthongs. However, they are still much longer than when they follow another consonant. One possible explanation for this is that /ai/ (and other diphthongs) is actually a *vowel + /j/* sequence. If /ai/ is a VC sequence, a word such as *lait'oh* [lajt'oh] are of the form CVC_1C_2VC. There is a correlation between the duration of word-medial codas and following onsets, illustrated in Figure 5.7.

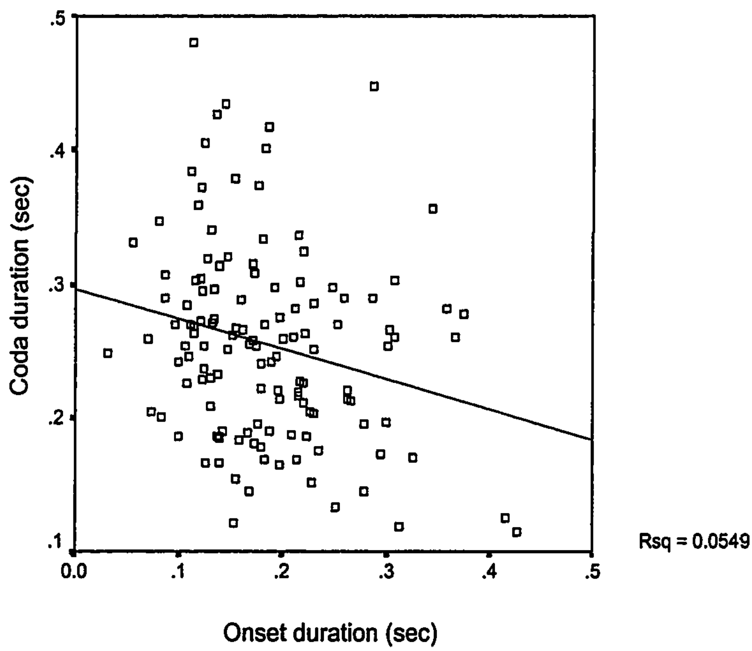

Figure 5.7 Correlation between word medial codas and following onsets

A two-tailed Pearson correlation showed that the negative correlation between the duration of the coda consonant and following onset was significant ($r = -0.234$, $p < 0.01$): the longer the coda consonant is, the shorter the onset is. Based on this correlation, it is possible that the reason /t'/ is so much longer than the average onset following a 'diphthong' (see Figure 5.6) is because the preceding coda /j/ is so short. If this is true, one can say that the sequence [ai] in the word *lait'oh* (for example) should be interpreted as a VC sequence /aj/ rather than a diphthong. This analysis is supported by the fact that in the data set used for analysis throughout this dissertation that there are no words containing the sequence CaiCCV. If [ai] is in fact /aj/, this gap is explained since the sequence jCC forms an illegal consonant cluster (see Chapter 2, section 2.3). A more thorough investigation of this question is necessary to determine whether or not CaiCCV sequences are found at all in Lheidli.

In summary, the distribution of the reduced centralized vowel /ʌ/ provides further evidence that intervocalic consonants close the preceding syllable. The distribution of the diphthongs /ai/ and /ʌi/ shows that in syllables with bimoraic vowels (or *vowel + /j/* sequences), the intervocalic consonant acts as a simple onset to the following syllable. This is the only case observed so far where intervocalic consonants do not close the preceding syllable. This case also implies that weight plays an important role in the language. I return to this issue in section 5.4.

5.1.4 Conclusion on vowel distributions and durations

Findings on the durational properties of vowels (5.1.1), those on the distribution of tense and lax allophones of the front and mid vowels (5.1.2), and those on the distribution of the phonemic vowels of Lheidli (5.1.3) all agree: intervocalic consonants serve as coda consonants, closing the preceding syllable. Vowels are only long and tense (in the case of front mid and high vowels) word-finally in open syllables. Word medially, whether they are in C_CV or C_CCV context, they are short and lax (again, in the case of front mid and high vowels). Furthermore, the vowel /ʌ/, which cannot occur in open syllables, can occur in C_CV context. In the following section, we see that although intervocalic consonants behave as codas with respect to the distribution of vowels, they also behave as onsets, at least in terms of their distribution.

5.2 Intervocalic consonants as onsets: evidence from consonant distributions

A second clue to the phonological role of intervocalic consonants is found in their distribution. The studies of vowel durations and distributions discussed in section 5.1 indicate that intervocalic consonants behave as codas. However, distributional facts of intervocalic consonants indicate that they are not simply codas. In this section I present results from comparing the distribution of intervocalic consonants to that of onset and coda consonants. We shall see that intervocalic consonants have a similar distribution to that of onsets. This finding indicates that intervocalic consonants are not simple codas, rather they are ambisyllabic, i.e. they behave as coda to the preceding syllable and onset to the following syllable[9].

As is often the case in natural languages, the coda in Lheidli is much more restricted than the onset in terms of which consonants can fill this position. This raises the question: does the set of consonants that appears in intervocalic position correspond to that which appears in coda position or to that which appears in onset position? Or do intervocalic consonants form a third set, distinct from both onset and coda consonant sets?

In order to understand the behavior of intervocalic consonants, it is necessary to compare them to consonants in all other positions. In this section I start with a very brief discussion of tautosyllabic consonant clusters (5.2.1). I then go on to compare the distribution of intervocalic consonants to that of onsets, word-medial codas, and word-

[9] Recall from the introduction (section 1.3.3) that I am using 'ambisyllabic' descriptively here, simply to indicate that intervocalic consonants belong to both syllables. Whether or not they are geminates, formally speaking, is considered in section 5.5.

final codas. The data presented in this section is based on the same set of 342 words as that used in all other sections of this dissertation[10]. Although the data set is small, by and large results on distribution agree with previous discussions of consonant distribution in Dakelh (Morice, 1932, Walker, 1979, Poser, 2001).

5.2.1 Tautosyllabic clusters

Before moving to a discussion of individual consonants, I consider briefly tautosyllabic sequences of consonants. The only position in which these occur regularly is word-initially. Although word-initial onsets consist primarily of a single consonant, the sounds /m/, /n/, /ɬ/, and /s/ can occur word-initially followed by another consonant (Poser, 2001). The examples in (1) illustrate. In all cases, except perhaps (1)c, the onset consonants are syllabified as part of the same syllable[11]. Syllabification is indicated in the transcription with periods. Word-medially syllabification has been simplified; as we shall see in section 5.3, intervocalic consonants are in fact ambisyllabic, rather than simple onsets.

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[10] Please see the General Methodology section (1.4) for details, and Appendix A for the complete word list used for this study.

[11] Syllabification is based on native speaker intuition.

(1) Word-initial CC sequences

	Lheidli	*IPA*	*English Gloss*
a.	mbat	[mbat]	your mittens
b.	ndek'a	[nde.k'a]	your tobacco
c.	lhk'utaneh	[ɬk'ʌ.ta.nɛh]	six
d.	schaikeh	[stʃai.kɛh]	my grandchildren

Based on native speaker production, the initial CC sequences are syllabified as complex onsets: [mbat], *[m.bat]. Only in words with an initial [ɬ] is there sometimes an epenthetic vowel preceding [ɬ]. For example, [ɬkʌtanɛh] is sometimes pronounced [ʌɬkʌtanɛh]. This indicates that complex onsets beginning in [ɬ] are somewhat disfavored. Note that the existence of these word-inital CC sequences predicts that they should exist word-medially as well. As we shall see below, this prediction is *not* borne out. Word-initial position seems to allow tautosyllabic clusters which are otherwise disallowed in the language.

Other than word-initially, tautosyllabic clusters are generally disallowed. The only exception is /nt/, occurring before /n/ in a small set of verb forms. All such cases are verbs in the second person singular form, in which the 2nd person singular marker /n/ is followed by the valence marker /d/, which surfaces as [t] in this context, in turn followed by a verb stem beginning in /n/. For example, the word *tadintni* 'you are noisy' is syllabified [t^ha.dint.ni] (Poser, 2001)[12]. However, sequences of two consonants do occur regularly across syllable boundaries. In the following section, I turn the focus to single consonants in various positions in the word.

5.2.2 *Onsets, codas, and intervocalic consonants*

The differences in distribution between consonants in different positions is most easily seen by comparing tables illustrating the different distributions. Tables 5.6, 5.8, 5.9, and 5.12 provide the distribution of consonants in various positions. The shaded areas in these tables indicate consonants that are found in the inventory of the language, but not in the relevant position. For example in Table 5.6 the shaded areas represent sounds which are in the inventory but were not found in onset position in the data set used. In all of the tables, I have excluded the 'lamino-dental' column. This is because the distinction between lamino-dental and apico-alveolar consonants is being lost, such that lamino-dental consonants are rarely pronounced as such anymore, and even more rarely transcribed as such. Because it is not clear from the data which sounds are lamino-dental and which are apico-alveolar, I have taken them all to be alveolar. Obviously, this in an area which requires further investigation.

Let us first take a look at onset consonants. Table 5.6 provides data for word-initial onsets. Word-medial onsets show a similar distribution, and are therefore not

[12] Another possible syllabification for this word is [ta.din.tni]. Poser (2001) finds that this is not the syllabification one gets.

discussed separately. Both word-initially and word-medially, there are very few restrictions on the set of allowable consonants in this position.

Table 5.6 *Word-initial onset consonants. Grayed cells indicate consonants which are in the inventory but not found in onset position in the data used.*

	bilabial (labio-dental)	apical alveolar	lateral	palatal	velar	labio-velar	glottal
stops	b (pʰ) --	d tʰ t'			g kʰ k'	gʷ kʷ kʷ'	ʔ
affricates		dz tsʰ ts'	dl tɬʰ tl'	dʒ tʃʰ tʃ'			
fricatives	-- (f)	z s	-- ɬ	-- ʃ	ɣ x	-- ʍ	-- h
glides/ liquids		(r)	l	j		w	
nasals	m	n			ŋ		

Although several of the cells are shaded in Table 5.6, this is most likely due to the relatively small sample size. A general discussion of the usefulness of statistical methods in testing the significance of gaps in the inventory is provided below. In total, there were 309 onsets in the data set. Table 5.7 provides the number of instances of each consonant in the data set.

Table 5.7 Onsets in #_V position

Consonant	*# of instances*	*Consonant*	*# of instances*
d	34	ɬ	7
n	33	w	6
l	32	dz	5
ts	24	g	5
s	24	m	5
ʔ	22	ʃ	5
t^h	18	tl'	5
j	16	dl	2
h	12	g^w	2
ts'	11	j	2
w̥	10	k'	2
b	8	$k^{w'}$	2
tʃ	7	k^w	2
k^h	7	t'	1
Total	309		

The most common sounds are coronal, which supports cross-linguistic findings on the relative frequency of these consonants (Maddieson, 1984, Paradis and Prunet, 1991, Zamuner, 2001). The only systematic gap is /ŋ/. As in English, the velar nasal occurs only in coda position (Walker, 1979, Poser, 2001).

Tables 5.8 and 5.9 illustrate word-final (V_#) and word-medial (V_.CV) coda consonants. While there are differences between the two tables, this is again probably in large part an effect of sample size. In total, there were 217 word-final codas and 130 word-medial codas. These samples are too small to make any robust claims about the differences in distribution between the two positions.

Table 5.8 Word-final coda consonants. Grayed cells indicate consonants which are in the inventory but not found in word-final coda position in the data used.

	bilabial (labio-dental)	apical alveolar	lateral	palatal	velar	labio-velar	glottal
stops	b (p^h) –	d t^h t'			g k^h k'	g^w k^w k^{w}'	ʔ
affricates		dz ts^h ts'	dl tl^h tl'	dʒ $tʃ^h$ tʃ'			
fricatives	– (f)	z s	-- ɬ	– ʃ	ɣ x	-- w̥	-- h
glides/ liquids		(r)	l	j		w	
nasals	m	n			ŋ		

Table 5.9 Word-medial coda consonants. Grayed cells indicate consonants which are in the inventory but not found in word-medial coda position in the data used.

	bilabial (labio-dental)	apical alveolar	lateral	palatal	velar	labio-velar	glottal
stops	b (p^h) –	d t^h t'			g k^h k'	g^w k^w k^{w}'	ʔ
affricates		dz ts^h ts'	dl tl^h tl'	dʒ $tʃ^h$ tʃ'			
fricatives	– (f)	z s	-- ɬ	– ʃ	ɣ x	– w̥	-- h
glides/ liquids		(r)	l	j		w	
nasals	m	n			ŋ		

As Tables 5.8 and 5.9 illustrate, the coda position is quite restricted. In summary, in coda position there are no ejectives, no affricates (other than a few exceptions)[13], and no palatal or velar fricatives. The only voiceless unaspirated stops found in coda position (in this data set) are in words borrowed from French (word-finally: /b/ in *lutab* [lʌtʰab] 'table', *liyab* [lɪjab] 'devil', *libab* [lɪbab] 'pope'; word-medially: /g/ in *lugli* [lʌgli] 'key', *lugliz* [lʌglɪz] 'church', *lugloo* [lʌglu] 'nail', *luglos* [lʌglos] 'bell'[14]). Finally, consonant clusters in coda position are generally disallowed.

Tables 5.10 and 5.11 provide the number of instances of each consonant in word-medial and word-final coda positions. Other than word-final [h], the most frequent consonants are once again coronals. Although [h] appears to be the most frequent coda word-finally, this is likely an artifact of transcription. Indeed, Lheidli vowels devoice word-finally, and the resulting sounds are often transcribed as *vh* sequences by semi-speakers. Since the data in Table 5.10 was calculated based on written words, what appears as word-final [h] in fact corresponds in many cases simply to vowel devoicing.

[13] Poser cites two exceptions in the Lheidli lexicon: *lor'oots* [lorʔuts] 'rolled oats' and *balhats* [baɬats] 'potlach' (Poser, 2001). Both these words contain word-final affricates. In most cases where we would expect word-final [ts], given cognates in closely related languages, we get [z]. For example, the Babine Witsuwit'en word for 'outside' is *'ats*, whereas in Lheidli, it is *'az* (Poser, 2001).

[14] In these cases, it is not clear whether /g/ is in fact a coda consonant, or part of an onset cluster (/gl/).

Table 5.10 Word-final coda consonants

Consonant	*# of instances*
h	55
n	36
z	31
s	28
t^h	19
ɬ	16
l	15
k^h	9
b	4
k^w	2
w̥	2
Total	217

Table 5.11 Word-medial coda consonants

Consonant	*# of instances*
s	38
n	29
ɬ	20
z	13
g	7
ŋ	6
t^h	6
h	5
m	4
l	2
Total	130

The distribution of intervocalic consonants is of particular interest, because it bears on the proposed syllabification of VCV sequences. Although their unusually long duration suggests that they are not simple onsets (see Chapter 3), and vowel alternations suggest that they are codas (section 5.1), according to their distribution they behave as onsets. Like regular onsets, their distribution is very broad, and includes sounds from every manner and place of articulation. Table 5.12 compares the set of consonants found intervocalically to the set of consonants found in the inventory. Notice how few grey areas there are in this table.

Table 5.12 Distribution of intervocalic consonants. Grayed cells indicate consonants which are in the inventory but not found in intervocalic position in the data used.

	bilabial (labio-dental)	apical alveolar	lateral	palatal	velar	labio-velar	glottal
stops	b (p^h) --	d t^h t'			g k^h k'	g^w k^w k^w'	ʔ
affricates		dz ts^h ts'	dl tl^h tl'	dʒ tʃ^h tʃ'			
fricatives	 (f)	z s	-- ɬ	-- ʃ	ɣ x	-- w̥	-- h
glides/ liquids		(r)	l	j		w	
nasals	m	n			ŋ		

What gaps there are in the distribution of intervocalic consonants are again probably the result of sample size, and not representative of a principled restriction in the language. Table 5.13 provides the number of instances of consonants in intervocalic position. Once again, the two most frequent sounds are coronal.

Table 5.13 Intervocalic consonants

Consonant	*# of instances*	*Consonant*	*# of instances*
n	16	g	7
z	16	tʃ	6
b	13	ts'	6
k^h	13	ɣ	5
j	13	ʒ	5
d	12	ts	4
t^h	12	tʃ'	3
k'	10	tl	2
ɬ	10	w̥	2
t'	10	dl	1
l	9	g^w	1
s	9	h	1
ʔ	8	m	1
dz	8	tl'	1
w	8		
Total	212		

Looking back at the preceding tables, one can see that the distribution of intervocalic consonants resembles that of onsets much more than that of codas. Two factors can be considered here: (a) size of the inventories, and (b) specific consonants involved. In size, the inventory of intervocalic consonants resembles that of onsets much more than that of codas. Indeed, the set of intervocalic consonants is not limited in size in the same way that the set of coda consonants is. Intervocalic consonants are also most similar to onsets in terms of the specific consonants allowed in this position. Recall that the coda position disallowed voiceless unaspirated stops, ejectives, affricates (other than a few exceptions), and fricatives except alveolars. All of these consonants are allowed intervocalically. The following examples illustrate:

(2) Examples of consonants occurring intervocalically but not as simple codas

	Lheidli	*IPA*	*English*
a.	dut'ai	[dʌt'ai]	bird
b.	hujun	[hʌdʒʌn]	they are singing
c.	tl'ughus	[tl'ʌɣʌs]	snake
d.	tagih	[tʰagɪh]	three (generic)

From the distribution of consonants across positions then, it seems that intervocalic consonants are onsets.

Note that no statistical measures were taken to determine which gaps were and were not accidental in the distributions presented above. While in general a Chi Square test of Goodness of Fit can determine whether or not gaps in the distribution of consonants are significant or not, this test requires that the expected number of tokens for each consonant be at least 5. For many consonants, there are too few tokens to run this test. Because Chi Square tests would only be a useful measure of systematic gaps for the most common consonants in the data set, I omit them here. As an indication of the systemasticity of the gaps discussed, I provide in Table 5.14 the proportion of each consonant in onset, coda, and intervocalic position, as well as across positions. Word-initial and word-medial onsets are collapsed, as are word-medial and word-final codas. These proportions provide a good indication of which gaps are systematic. Take for example the sound /d/. Across positions, 5.4% of all consonants are instances of /d/.

Whereas in onset position, 9.8% of all consonants are /d/, in coda postion 0.0% of all consonants are instances of /d/. These proportions indicate that this gap - no /d/s in coda position - is likely to be systematic. The distribution of /d/ contrasts with that of /ɫ/: 5.2% of all consonants across positions are instances of /ɫ/. 1.6% of all onsets are /ɫ/. 10.4% of all codas are /ɫ/. That 10.4% of coda consonants are /ɫ/ indicates that, unlike /d/, /ɫ/ can occur in coda position, and does so frequently.

Table 5.14 Percentage of each consonant in different positions.

Consonant	*Across positions*	*Onset (word-initial and word-medial)*	*Coda (word-medial and word-final)*	*Intervocalic*
h	7.2	2.7	17.3	0.5
l	6.9	10.0	4.9	4.2
t^h	5.9	5.2	7.2	5.7
z	5.9	7.7	12.7	7.5
d	5.4	9.8	--	5.7
ɬ	5.2	1.6	10.4	4.7
j	4.6	--	--	6.1
k^h	3.4	2.7	2.6	6.1
ts^h	3.4	6.8	--	1.9
ʔ	3.3	5.7	--	3.8
b	3.1	3.2	1.2	6.1
$tʃ^h$	2.5	4.3	--	2.8
g	2.2	1.8	2.0	3.3
ts'	2.0	3.2	--	2.8
n	12.9	9.8	18.7	7.5
s	10.6	5.7	19.0	4.2
dz	1.7	2.1	--	3.8
w	1.7	2.1	--	3.8
k'	1.5	1.1	--	4.7
t'	1.4	0.9	--	4.7
w̥	1.4	2.3	0.6	0.9
dʒ	1.1	1.4	--	2.4
dl	1.0	2.1	--	0.5
m	1.0	1.1	1.2	0.5
tl'	0.8	1.6	--	0.5
tʃ'	0.7	0.9	--	1.4
ɣ	0.7	0.5	--	2.4
g^w	0.6	1.1	--	0.5
ŋ	0.6	--	1.7	--
$k^{w̥}$	0.5	0.7	0.6	--
ʃ	0.5	1.1	--	--
$k^{w'}$	0.3	0.7	--	--
tl^h	0.2	--	--	0.9
Total	100	100	100	100

5.2.3 Conclusion on consonant distributions

While intervocalic consonants differ from onset consonants in duration, they differ substantially from coda consonants in terms of distribution. Indeed, the set of allowable intervocalic consonants is not restricted in the same way as the set of coda consonants. Summarizing so far, data on consonant durations indicates that intervocalic consonants are neither onsets nor codas. Data on vowel durations and distributions indicate that intervocalic consonants are codas. Finally, data on consonant distributions indicate that intervocalic consonants are onsets. Taken together, the data provide evidence that intervocalic consonants are neither simple codas nor simple onsets, but a combination of both. In the following section, I provide additional support for this analysis by considering data from native speaker intuitions on syllabification.

5.3 Native speaker syllabification intuitions

The final piece of evidence bearing on the syllabification of intervocalic consonants comes from native speaker intuitions on syllabification. Intuitions were collected in two ways. First, speakers were asked to read words to the beat of a metronome. Second, they were asked for syllabification judgments. Both of these tasks were designed to determine how native speakers syllabify intervocalic consonants. This section discusses the methodologies used, and the results obtained from the two tasks.

5.3.1 The metronome task

The goal of the metronome task was to see how speakers divide bisyllabic words into syllables, given a task in which they are forced to insert a break between the two syllables. Using a metronome in this type of investigation is a novel idea, although it has been used in other tasks, for example by Cummins and Port (1998) and Tajima et al. (1999). The hypotheses were as follows:

Hypothesis I

In words containing a word-medial cluster (VC_1C_2V), the syllable break falls between the two consonants ($VC_1.C_2V$).

Hypothesis II

In words containing a word-medial intervocalic consonants (VC_1V), the syllable break falls in the middle of the intervocalic consonant ($VC_1.C_1V$).

The idea behind these hypotheses is that syllabification should be straightforward in the case of word-medial clusters (Hypothesis I), leading to a syllable break between the consonants. In the case of intervocalic consonants, syllabification should place the intervocalic consonant both in the first and the second syllable (Hypothesis II).

5.3.1.1 Design of the study

Speaking to the beat of a metronome is a difficult task for elderly subjects who have had very little if any exposure to metronomes in that it requires them to do several unfamiliar things at once: read and produce lists of words, speak to the metronome beat, and think about the syllabification of each word. However, the consultant with whom I was working performed this task with minimal difficulty.

The stimuli for this study formed a different data set from that used in previous studies. It consisted of a set of 121 bisyllabic words, taken from the same wordlists as those used for other studies (see Chapter 1, section 1.4.3 for details). However, the recordings used to extract the durational data found in previous studies were different from the recordings used for the syllabification tasks reported in this section and the following one. No durations were measured on the syllabification data. Words for the metronome task had either a word-medial intervocalic consonant (CVCV(C)) or a consonant cluster (CVCCV(C))[15]. The methodology was as follows. The metronome was set at 60 (1 beat per second). The speaker was asked to pronounce each word from the list to the beat of the metronome, such that each syllable onset fell on a beat[16]. Before beginning the recording, I demonstrated the task using English words, and the speaker was given the chance to go through the word list once, for practice. In fact, she practiced only until she felt comfortable performing task, which was approximately a third of the way through the word list.

For the most part, syllabification was straightforward to judge. Because the metronome was set at one beat per second (i.e. each syllable was forced to be one second

[15] See Appendix C for the word list used for this study.
[16] In most words analyzed, the syllable onset did not fall exactly on the beat. However, the important point was that the beat created a pause in the pronunciation of words, which could be used to evaluate where syllable breaks fell.

long), there was a substantial pause between syllables. This pause made it clear how medial consonants were syllabified. There is however one methodological point worth mentioning here. In words with intervocalic stops, it was important to distinguish between cases in which the pause between syllables preceded the stop closure (V.CV) and those in which the pause occurred after the stop closure, but before the release ($VC_1.C_1V$). In the former case, the stop was treated as an onset. In the latter case the, stop was treated as ambisyllabic. As the waveforms and spectrograms below illustrate, these two cases were relatively easy to distinguish because of the nature of stop closures in Lheidli. Lheidli *vowel-stop* sequences generally exhibit closure voicing, i.e. there is a lag between the consonant closure and the disappearance of periodic voicing. This lag is visible in both the waveform and spectrogram, as Figure 5.8 shows (the vertical line indicates the stop closure). This is an example in which the consonant was judged to be ambisyllabic, since the closure occurred before the pause.

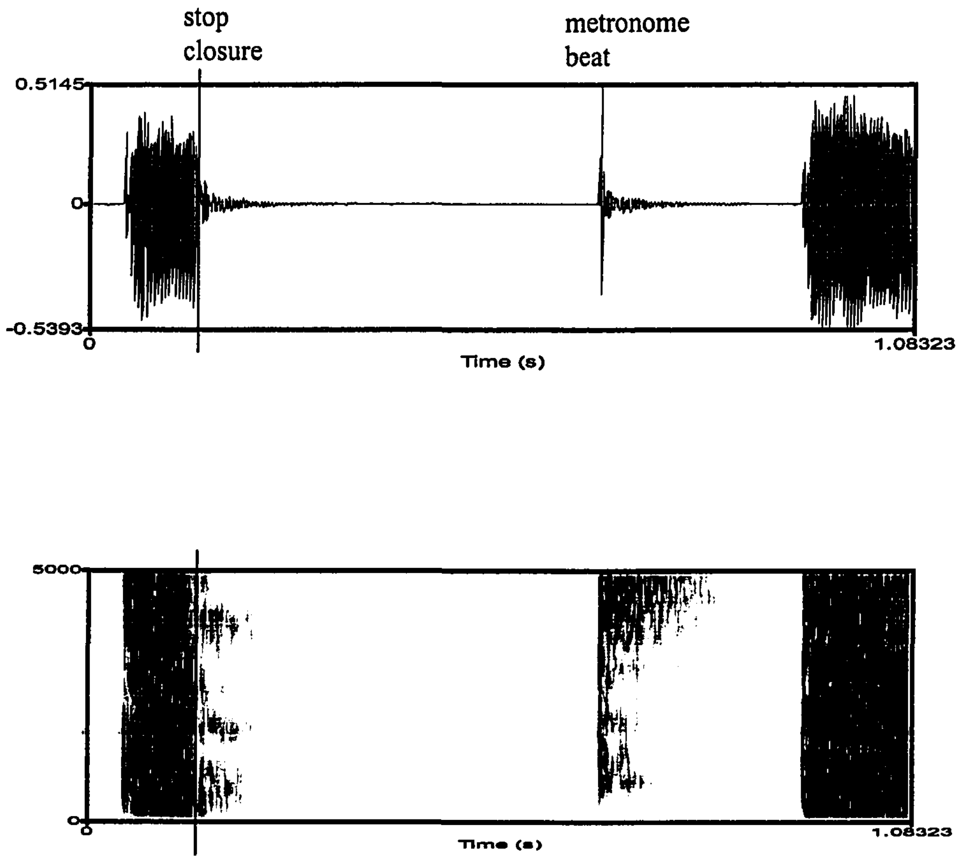

Figure 5.8 Waveform and spectrogram for the [ʔʌdʌ] portion of *'udun* ('another'). The vertical line indicate the stop closure.

In Figure 5.8, the stop closure corresponds to the abrupt decrease in amplitude of the waveform. However, weak formant structure from the vowel persists into the consonant (seen in the spectrogram). Given the presence of closure voicing, the stop in this case was taken to precede the pause between syllables, and the production was classified as VC.CV[17].

If the pause had occurred before the stop closure, then the decrease in amplitude at the end of the first syllable would have corresponded simply to the end of the vowel preceding the pause. There would have been no sharp decrease in amplitude (corresponding to the closure), and one would not have seen the persisting formant structure. Figure 5.9 illustrates a case in which the pause preceded the stop closure:

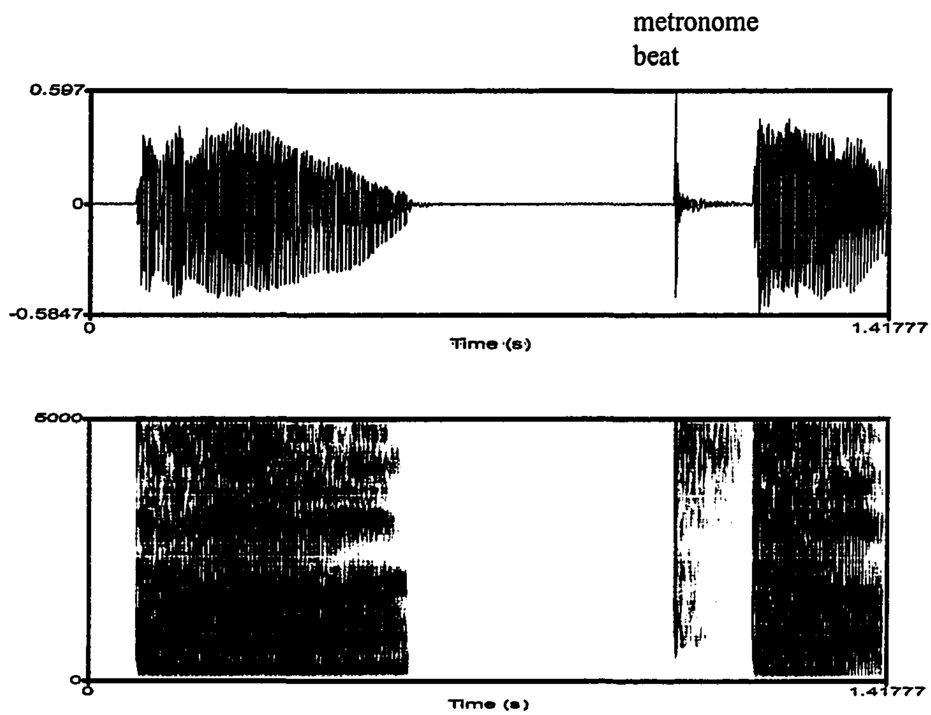

Figure 5.9 Waveform and spectrogram for [dada] in *'dada* ('illness')

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[17] The formant transition was not used in judging syllables to VC.CV vs. V.CV, because the abrupt decrease in amplitude at closure and the closure voicing were sufficient cues to syllabification.

The waveform in Figure 5.9 shows that the vowel offset is gradual rather than abrupt, although this is not clear from the spectrogram. In addition, the spectrogram shows no noticeable closure voicing. Finally, there is no clear formant transition at the offset of the vowel (into a following consonant)[18]. In this case, the pause is taken to occur before the stop closure, and syllabification is assumed to be V.CV.

Words were coded in terms of where the break fell between the two syllables. Coding was based on the data rather than on a pre-set list of possible syllabifications. The following syllabification strategies were encountered for intervocalic consonants (the underscore indicates the pause). Note that VC_CV was only used with fricatives. With stops, it was never the case that stops were pronounced twice (i.e. with two releases). Stops in which the closure preceded the release were coded as VCV.

(3) Pauses in words with intervocalic consonants

a. V_CV (consonant pronounced after the pause)

b. VC_CV (consonant pronounced twice: before and after the pause - this was used only fricatives)

c. VCV (no pause: consonant pronounced continuously)

As for word-medial consonant clusters, only one syllabification strategy was used:

[18] Again, this cue was not necessary to differentiate VC.CV from V.CV, and was therefore not used.

(4) Pauses in words with intervocalic consonants

VC_CV (first consonant pronounced before the pause; second consonant pronounced after the pause)

5.3.1.2 Results

Results of this study showed that, in cases of word-medial consonant clusters, the pause between metronome beats consistently fell between the two consonants of the cluster (VC_CV). There was not a single word in which this was not the case. This result supports Hypothesis I: word-medial clusters are heterosyllabic, and are syllabified VC.CV.

As for the syllabification of word-medial intervocalic consonants, results were less clear. Three cases were observed, given in (3). The first case (V.CV) was taken to reflect that the intervocalic consonant served solely as an onset to the following syllable. The last two cases (VC_CV and VCV) were both assumed to reflect the ambisyllabicity of the intervocalic consonant, since in both these cases, the intervocalic consonant was pronounced before and after the pause. Based on this assumption, the responses VC_CV and VCV were merged.

The following graph illustrates the distribution of words in which the intervocalic consonant was taken as an onset (V.CV) vs. those in which the intervocalic consonant was taken as ambisyllabic (V(C)V):

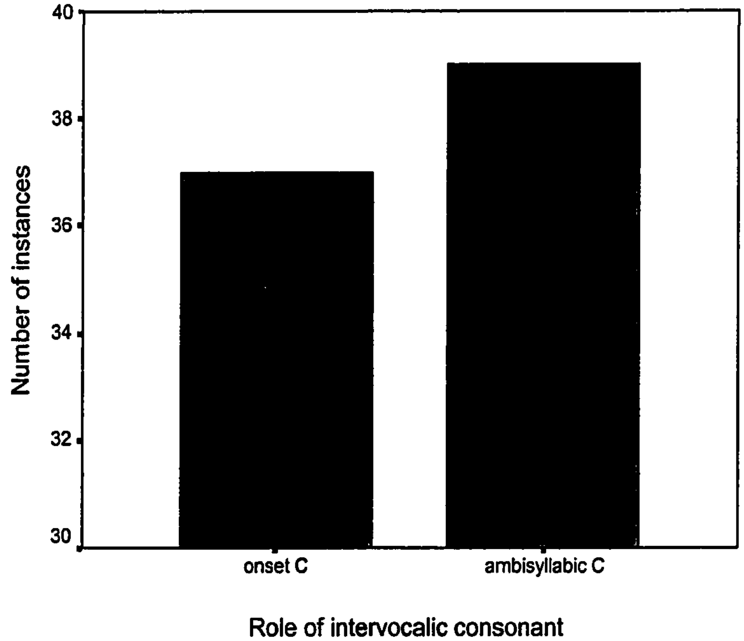

Figure 5.10 Syllabification of intervocalic consonants in the Metronome task

Hypothesis II predicted that intervocalic consonants would be consistently syllabified as part of both the preceding and the following syllable. Although this is the most frequent syllabification (39 instances), Figure 5.10 shows that they are almost as often syllabified as onsets (37 instances). A Chi Square test of Goodness of Fit showed that number of 'ambisyllabic' vs. 'onset' responses did not differ from that predicted by chance (X^2 (1, n

= 76) = 0.052, $p > 0.05$), i.e. there was no significant difference between the number of 'ambisyllabic' and 'onset' responses.

It has been found previously that the syllabification of intervocalic consonants depends on factors such as frequency, stress placement, the nature of the consonant and of the preceding vowel, speech rate, spelling etc. (Pullam, 1970, Kahn, 1976, Seidenberg and Tanenhaus, 1979, Adams, 1981, Fallows, 1981, Selkirk, 1982, Treiman and Danis, 1988). For example, Treiman and Danis (1988) found that intervocalic consonants were more likely to be judged ambisyllabic if they were spelled with a double letter than if it were spelled with a single letter. Furthermore, they found that several phonological factors also affected the syllabification of intervocalic consonants. The nature of the consonant affected syllabification: liquids and nasals were more likely to be syllabified as ambisyllabic (or, less frequently, as codas to the preceding syllable) than obstruents. Syllabification was also affected by the duration of the preceding vowel: intervocalic consonants were more likely to be syllabified as ambisyllabic or as codas (rather than onsets) when the preceding vowel was short than when it was long. Finally, in terms of stress, intervocalic consonants were generally syllabified as onsets to the second syllable in words with second syllable stress and as ambisyllabic or codas to the first syllable in words with first syllable stress.

The following three figures illustrate the syllabifications of intervocalic consonants as a function of the manner of articulation of the intervocalic consonant (5.11), the nature of the preceding vowel (5.12), and stress (5.13). In all cases, results are preliminary and based on small sample sizes. Future work will determine whether these results are maintained with bigger sample sizes.

With respect to manner of articulation, in general the more sonorant the consonant was, the more likely it was to be syllabified as ambisyllabic. In Figure 5.11, stops, affricates, and fricatives form the category *non-sonorant.* They were contrasted with nasals, liquids, and glides, which form the category *sonorant.* This figure shows that sonorants are more likely to be syllabified as ambisyllabic than as onsets. In contrast to this, non-sonorants are more likely to be syllabified as onsets than as ambisyllabic.

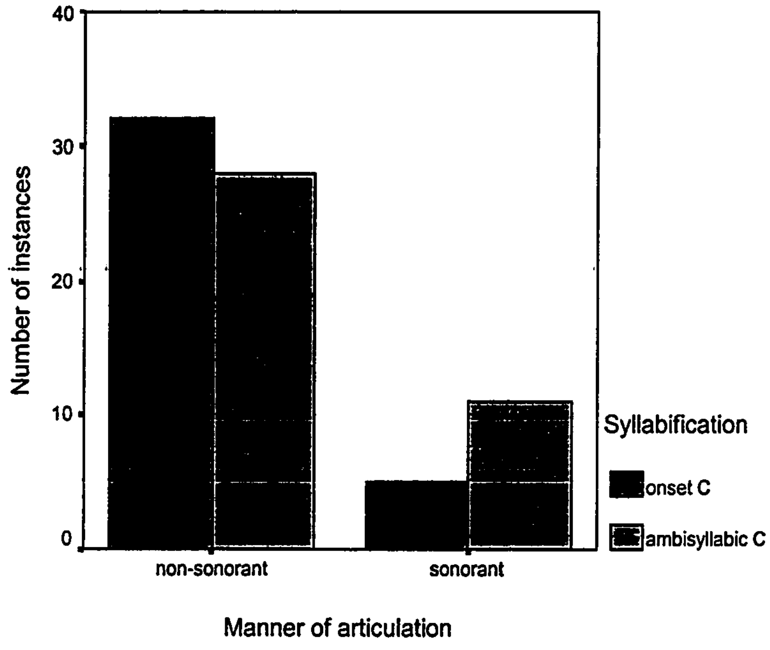

Figure 5.11 Syllabification of intervocalic consonants depending on manner of articulation

Although the tendency illustrated in Figure 5.11 follows Treiman and Danis' (1988) findings, a Chi Square test of Independence showed that the distribution of ambisyllabic consonants across manners of articulation ([+sonorant] vs. [-sonorant]) did not differ significantly from chance ($X^2(1, n = 76) = 2.47, p > 0.05$).

In terms of the preceding vowel, the most striking effect is that of the centralized vowel /ʌ/. Figure 5.12 merges all vowels other than /ʌ/ (labeled 'other vowels') and contrasts them with /ʌ/. This figure shows that following /ʌ/, consonants were syllabified as ambisyllabic more often than as onsets to the following syllable. Following all other vowels, consonants were syllabified as onsets more often than as ambisyllabic.

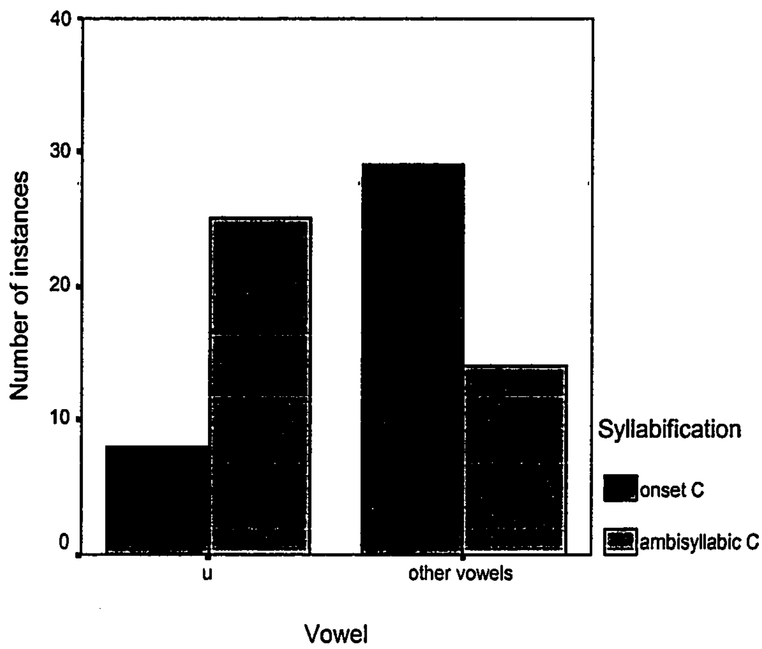

Figure 5.12 Syllabification of intervocalic consonants depending on previous vowel (/ʌ/ vs. other vowels)

A Chi Square test of Independence showed that the distribution of ambisyllabic consonants across different preceding vowels was significantly different from that predicted by chance (X^2 (1, n = 76) = 13.95, $p < 0.001$). This effect was created by the fact that the proportion of intervocalic consonants judged ambisyllabic was significantly higher following /ʌ/ than following other vowels.

Although /ʌ/ is a distinct phoneme - not simply a reduced allophone of full vowels (see Chapter 2, section 2.1) - it is much shorter than any of the other vowels. The average duration of /ʌ/ in the first syllable is 88 ms, whereas the average duration of other vowels in the first syllable is 172 ms. That intervocalic consonants were judged ambisyllabic more often following /ʌ/ than following other, longer vowels supports Treiman and Danis' (1988) finding that consonants are more likely to be part of the preceding syllable (as codas or as ambisyllabic consonants) when following short vowels than when following long vowels.

Note that while the nature of the preceding vowel had an effect on the syllabification of the intervocalic consonants, there was no effect of the following vowel (X^2(1, n = 76) = 1.16, $p > 0.05$). That is, intervocalic consonants were not more likely to be syllabified as onsets when the second vowel was /ʌ/ than when the second vowel was another vowel.

With respect to stress, the results differed from previous findings. Figure 5.13 illustrates the distribution of 'onset' and 'ambisyllabic' judgments as a function of stress placement.

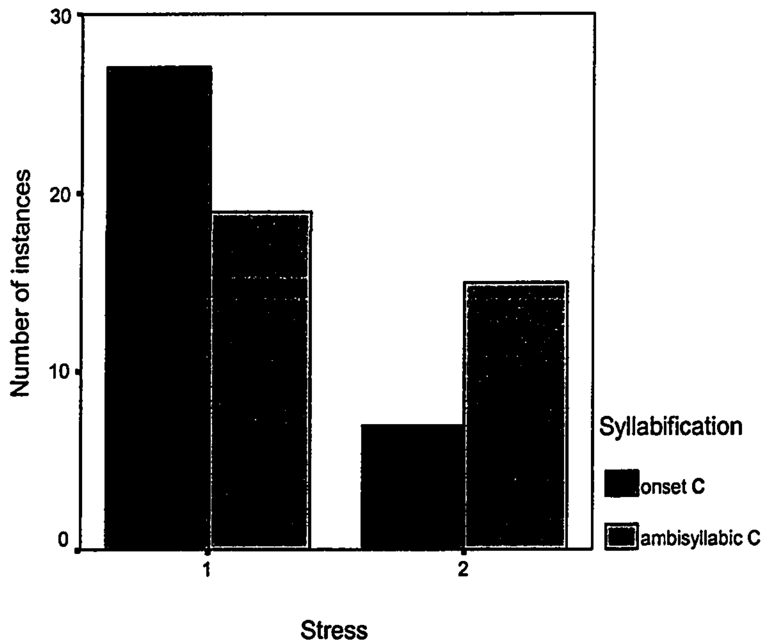

Figure 5.13 Syllabification of intervocalic consonants depending on stress placement

Interestingly, intervocalic consonants were more often syllabified as onsets (V.CV) in words with first syllable stress than in words with second syllable stress. In words with second syllable stress, intervocalic consonants were more often syllabified as ambisyllabic. A Chi Square test of Independence showed that this effect was significant (X^2 (1, n = 68) = 4.30, $p < 0.05$). This finding goes against Treiman and Danis' (1988) finding that intervocalic consonants more often act as onsets (to the second syllable) in words with second syllable stress. In this task, the speaker had one second for each syllable. Given how slowed down the speech was, it seems likely that stress no longer played an important role in the pronunciation of words, and for this reason there were no more ambisyllabicity judgments for words with first syllable stress than for words with second syllable stress (as Treiman and Danis found).

5.3.1.3 Discussion

Although results do not support a scenario in which intervocalic consonants are considered ambisyllabic across the board, they do support the idea that these consonants are not simple onsets. Two findings are relevant here. First, the placement of the pause between metronome beats in cases with word-medial clusters is absolutely consistent: it *always* falls between the two consonants: VC_CV. This means that when the syllabification is clear (VC.CV), it is reflected in the metronome task. That the pause between beats in the case of intervocalic consonants is not consistent indicates that the syllabification is unclear. Second, intervocalic consonants are in fact deemed ambisyllabic in a small majority of cases. At the least, one can say that intervocalic consonants are not simply onsets to the following syllable. If they were, they would consistently be syllabified as such in the metronome task.

Interestingly, not all of the intervocalic consonants which were pronounced VC_CV (consonant pronounced twice: before and after the pause) are also allowable codas in Lheidli. In VC_CV pronunciations, the first pronunciation of C could be taken as a coda consonant, since it precedes a break in speech. Given this interpretation, one might expect that the only consonants which can be pronounced twice, before and after the pause, are consonants which can occur as coda consonants. However, results show that this is not the case. There were nine cases of VC_CV responses for intervocalic consonants. Of these, three were of consonants which occur in coda position: /ɬ/ (twice) and /l/ (once). Six were consonants which do not occur as codas: /w/ (twice), /ɣ/ (once), and /j/ (once). It seems that whether or not the intervocalic consonant was an allowable coda did not affect how it was pronounced in the metronome task.

An additional point worth mentioning, with respect to the frequency with which intervocalic consonants were produced as onsets, is that this result is possibly due to the phonotactic facts of the language. Recall from the discussion in chapter 2 on syllabification that word-medial syllables must have onsets. It is possible that this fact influenced the speaker's judgments: with such a long, forced pause between syllables, the subject may have been more likely to assign intervocalic consonants to the second syllable than she would have been in a more natural task.

Finally, it is important to note that there were no words in which intervocalic consonants were syllabified as the coda consonant of the first syllable. This indicates that although they function as coda consonants, they do not belong solely to the syllables they close.

5.3.2 Syllabification task

The second task used to investigate speakers' intuitions on syllabification was simply to ask them how they thought words should be syllabified. The goal of this study, as well as the hypotheses tested, were the same as for the metronome task (see section 5.3.1).

5.3.2.1 Design of the study

The same list of 121 bisyllabic words was used for this study as for the preceding one (see Appendix C for the word list used). Subjects were asked to judge how many "pieces" words were contained, and where the break was between these pieces. As with the metronome task, I demonstrated the syllabification task using English words.

Words were coded in terms of how the speaker syllabified them. The speaker was not given a set list of possible responses, but rather was left to talk about syllabification in her own words. For this reason, the set of responses she gave was relatively large. Whereas in the metronome task, the speaker actually produced each word, in this task she simply stated where the syllable break should fall. For example a typical response would be "the break goes between the *t* and the *n*" (for the word *ditnik* 'thunder')[19]. The responses from the words with intervocalic consonants are listed in (5) (the period indicates the break between syllables). All of these responses were produced at least once.

(5) Syllabification of words with intervocalic consonants

a.	V.CV	(consonant part of second syllable)
b.	VC.CV	(consonant doubled: each syllable containing one token)
c.	V(C)V	(consonant part of both syllables)

[19] In most cases the speaker uttered the word, producing syllables separately, in addition to saying where the break went. In 29 out of 121 items, production disagreed with intuition in terms of syllabification. In these cases, items were coded for intuitions rather than for production.

d. $V(C)^cV$ (for affricates: stop portion part of both syllables; release part of second syllable)[20]

e. VCV (whole word judged as one syllable)

f. V.C.V (syllabic consonant)

The pronunciation in (5)a was taken to reflect that the intervocalic consonant served solely as an onset to the following syllable. (5)b, (5)c and (5)d were all taken as evidence for the ambisyllabicity of the intervocalic consonant. (5)e and (5)f were taken as uninterpretable.

As for word-medial consonant clusters, only one response was obtained, the same one as was obtained in the metronome task:

(6) Syllabification of words with medial consonant clusters

VC.CV (first consonant pronounced part of first syllable; second consonant part of second syllable)

5.3.2.2 Results

Results of this study were similar to those of the previous one. As mentioned above, VCCV sequences were consistently syllabified VC.CV, with the syllable break falling between the two consonants (supporting Hypothesis I).

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[20] An example of this is *whudzih*, syllabified [w̥ʌ(d)zɪh]. The stop portion [d] of the affricate [dz] is ambisyllabic, and the release [z] part of the second syllable. This corresponded to cases in the metronome task in which the pause fell after the stop closure, but before the release.

As for words with intervocalic consonants, again there was inconsistency as to their syllabification. The syllabifications found are listed in (5) above. Figure 5.14 below illustrates the number of instances for each syllabification. Note that in this graph V(C)V is used for three response types: VC.CV, V(C)V, and V(C)^{c}V. There are all assumed to reflect an ambisyllabic intervocalic consonant.

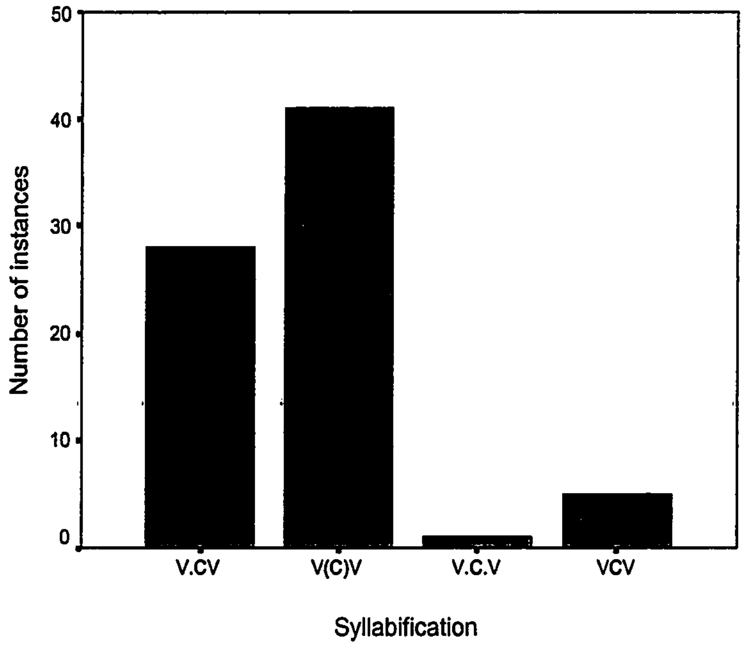

Figure 5.14 Syllabification of words with intervocalic consonants

Figure 5.14 shows that in most cases, intervocalic consonants were judged as ambisyllabic (41 out of 75 cases). However, it also shows that a substantial number of consonants were syllabified as onsets (28 out of 75 cases). Although the results offer partial support for Hypothesis II, it is not the case that intervocalic consonants are consistently judged ambisyllabic, as was predicted. Taking into consideration only the two responses V.CV (41 instances) and V(C)V (28 instances), a Chi Square (goodness of fit) showed that the number of responses of each (V.CV vs. V(C)V) did not differ significantly from that predicted by chance ($X^2(1, n = 69) = 2.44, p > 0.05$).

As in the metronome task, the data was analyzed as a function of the manner of articulation of the intervocalic consonant (Figure 5.15), the nature of the preceding vowel (Figure 5.16), and stress (Figure 5.17). Again, sample sizes were small, and results should therefore be taken as preliminary.

In this task, manner of articulation did not have the same effect as it did in the metronome task. Indeed, non-sonorants were more often syllabified as ambisyllabic than as onsets to the following syllable. Sonorants were marginally more syllabified as onsets than as ambisyllabic (with a difference of only 1). This is illustrated in Figure 5.15.

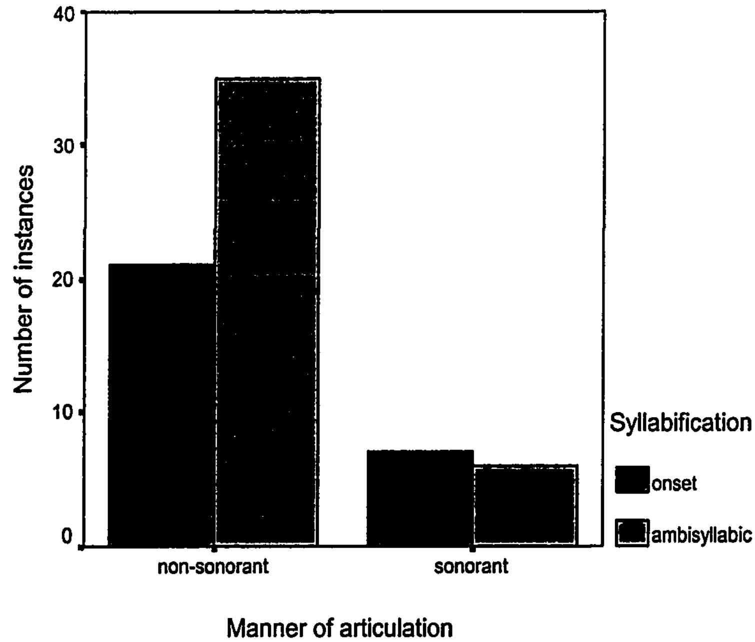

Figure 5.15 Syllabification of intervocalic consonants depending on manner of articulation

As with the metronome task, a Chi Square test of Independence showed that the distribution of ambisyllabic and onset consonants across manners of articulation ([+sonorant] vs. [-sonorant]) was not significantly different from that predicted by chance ($X^2(1, n = 69) = 1.93, p > 0.05$). Although it is not significant, the trend in the current task goes against that of the metronome task, as well as Treiman and Danis' (1988) finding that sonorants were more likely to be part of the first syllable (as ambisyllabic consonants, or codas) than were non-sonorants.

Syllabification of intervocalic consonants as a function of the preceding vowel followed the same pattern as in the metronome task. When the preceding vowel was /ʌ/, consonants were overwhelmingly syllabified as ambisyllabic. For all other vowels, consonants were syllabified more often as onsets.

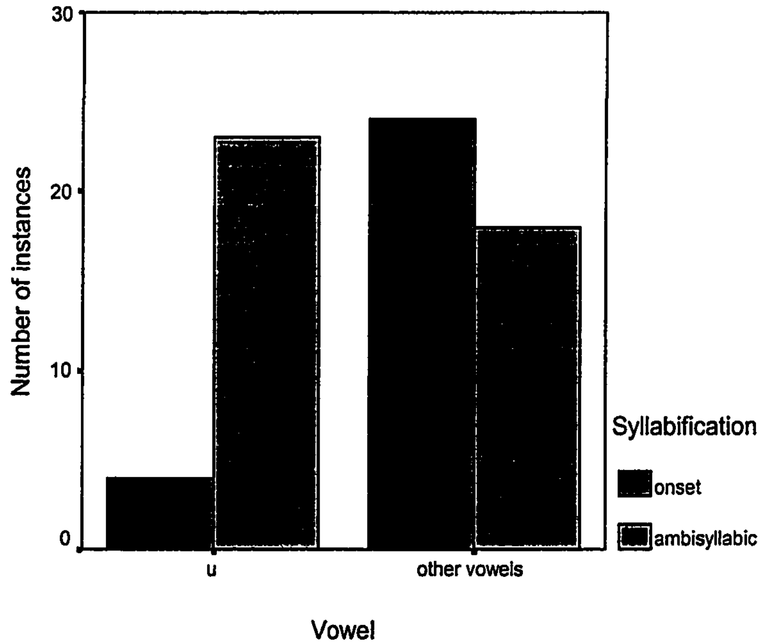

Figure 5.16 Syllabification of intervocalic consonants depending on previous vowel (/ʌ/ vs. other vowels)

A Chi Square of Independence showed that the effect of vowel type (/ʌ/ vs. other vowels) was significant ($X^2(1, n = 69) = 13.52, p < 0.001$). As in the metronome task, the effect of the following vowel on syllabification was not significant ($X^2(1, n = 69) = 13.52, p > 0.05$).

Finally, the effect of stress placement on syllabification was the same in this task as in the Metronome task, as illustrated in Figure 5.17.

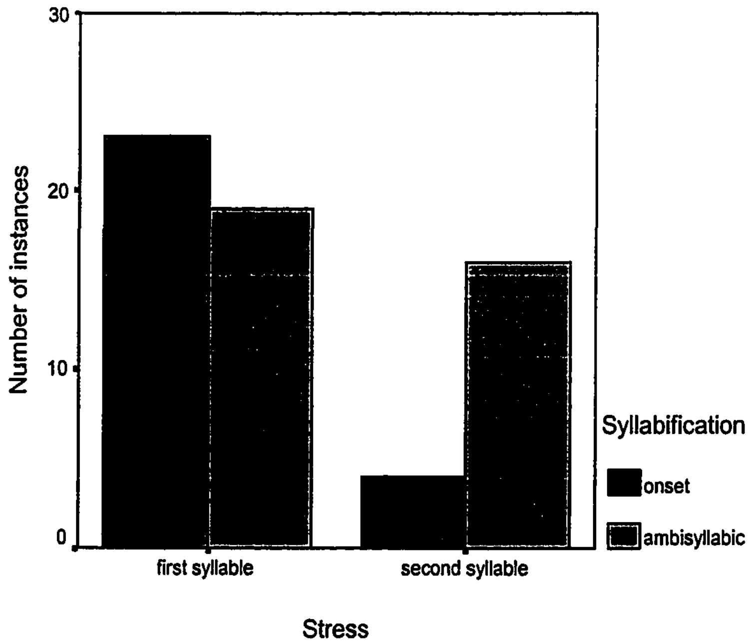

Figure 5.17 Syllabification of intervocalic consonants depending on stress placement

A Chi Square test of Independence showed that the effect of stress on the syllabification of intervocalic consonants was significant ($X^2(1, n = 62) = 6.66, p < 0.01$). Again, that consonants are more often syllabified as onsets (to the second syllable) in words with first syllable stress goes against findings previously reported in the literature (Treiman and Danis, 1988).

5.3.2.3 Discussion

Although intervocalic consonants are syllabified somewhat inconsistently, most often they are considered ambisyllabic, at least partially supporting Hypothesis II. Furthermore, it is important to consider variability in syllabification here. Whereas word-medial clusters are consistently syllabified VC.CV, intervocalic consonants seem to be problematic. The inconsistency in terms of how they are syllabified is important, in that it supports the claim that these consonants are not simply onsets. If they were, they would consistently be syllabified as such. For these two reasons, this study is taken as evidence for the ambisyllabicity of intervocalic consonants.

Note that once again, there were no words in which the intervocalic consonant was interpreted solely as the coda of the preceding syllable (VC.V). This provides further evidence that although intervocalic consonants close the preceding syllable, they also act as onsets to the following syllable.

5.3.3 Conclusion on native speaker syllabification intuitions

The findings reported here on syllabification intuitions by one native speaker do not provide conclusive evidence in and of themselves for ambisyllabicity. However, they do provide additional support for findings reported in previous sections. More specifically, they indicate that intervocalic consonants are indeed ambisyllabic in Lheidli.

One thing worth noting here involves the effect of literacy on judgments of ambisyllabicity. Derwing (1992) investigated native speaker intuitions on the syllabification of geminate consonants in different languages. He found that, across languages, VCV sequences were split into V.CV and VCCV sequences were split into VC.CV. Interestingly, the treatment of geminates depended on literacy level: literate speakers treated geminates as cases of VC.CV; illiterate speakers treated them as V.CV. The question of how to characterize Lheidli intervocalic consonants formally is discussed in the section 5.5, where I argue that they are indeed geminates. This being the case, Derwing's results can be compared to those obtained here. It is possible that results obtained from the metronome and syllabification intuitions tasks would vary depending on the literacy level of the subject. The subject whose data was analyzed is a relatively literate speaker of Lheidli. In the future, it would be interesting to analyze results from semi-speakers to determine whether they differed from those reported above, and if so, whether they produced more (V.CV) responses than the subject consulted for this work.

Based on studies reported in sections 5.1 through 5.3, we have ascertained that intervocalic consonants serve as codas to the preceding syllable as well as onsets to the following syllable - in summary, they are ambisyllabic (in the descriptive sense). We now turn to an investigation of stress placement in Lheidli, in order to determine whether the length of intervocalic consonants depends on whether or not the preceding syllable is stressed. This investigation will provide the final piece of evidence necessary to establish the formal representation of intervocalic consonants, discussed in section 5.5.

5.4 Stress placement and intervocalic consonant duration

From the distribution of intervocalic consonants in Lheidli, one might assume that their occurrence is a function of stress in the language. The fact that they are not contrastive, and that they occur only intervocalically, is reminiscent of ambisyllabic (in the formal sense) consonants in other languages - all of which are stress-timed. In these languages, ambisyllabicity is indeed a function of stress. For example in English, the word *dinner* is syllabified [ˈdɪn.ˌnɚ], with an ambisyllabic [n]. This is because of a requirement in English that stressed syllables must be heavy, hence *[ˈdɪ.ˌnɚ] (Hammond, 1999). Perhaps then, this *Stress-to-Weight Principle* (stressed syllables want to be heavy) is in effect in Lheidli as well, such that intervocalic consonants lengthen to close a preceding stressed syllable. If this is the case, and if weight is reflected phonetically by duration, then intervocalic consonants should be longer when following stressed syllables than when following unstressed syllables.

I test this hypothesis by comparing the length of intervocalic consonants in bisyllabic words with first vs. second syllable stress. The study presented below is based on the study reported in Chapter 2 (2.4) on stress placement in Lheidli. We shall see that the length of intervocalic consonants in Lheidli is not a function of stress: intervocalic consonants are unusually long regardless of whether or not they follow a stressed syllable.

If the length of intervocalic consonants depends on stress placement, then their phonological role can be analyzed as relating to stress requirements of the language. The hypothesis tested is as follows:

Hypothesis

Intervocalic consonants are longer when preceded by a stressed syllable than when preceded by an unstressed syllable.

This hypothesis is based on the *Stress-to-Weight principle* (Prince, 1992), which states that stressed syllables attract weight, i.e. segments that are moraic. If this principle holds in Lheidli, then intervocalic consonants should be longer when following stressed syllables, since they will contribute extra weight to the preceding syllable. Following unstressed syllables, intervocalic consonants should be shorter, since there is no reason for them to contribute extra weight to the preceding syllable. The underlying assumption here is that moraicity is reflected by phonetic duration, an assumption that is not universally accepted (Hume et al., 1997a, Hume et al., 1997b), but which arguably holds in Lheidli. I return to this issue in Chapter 6.

5.4.1 Design of the study

The data used for this study consisted of a subset of the data used for the pilot study on stress, reported on in section 2.4.2 (see Appendix C): only words with intervocalic consonants were used. In total, 76 words were used. Only one factor was involved: stress placement. The conditions were (a) first syllable stress (ˈCVCV(C)), and (b) second syllable stress (CVˈCV(C)).

5.4.2 Results

Figure 5.18 illustrates the difference in duration between intervocalic consonants following stressed and unstressed syllables.

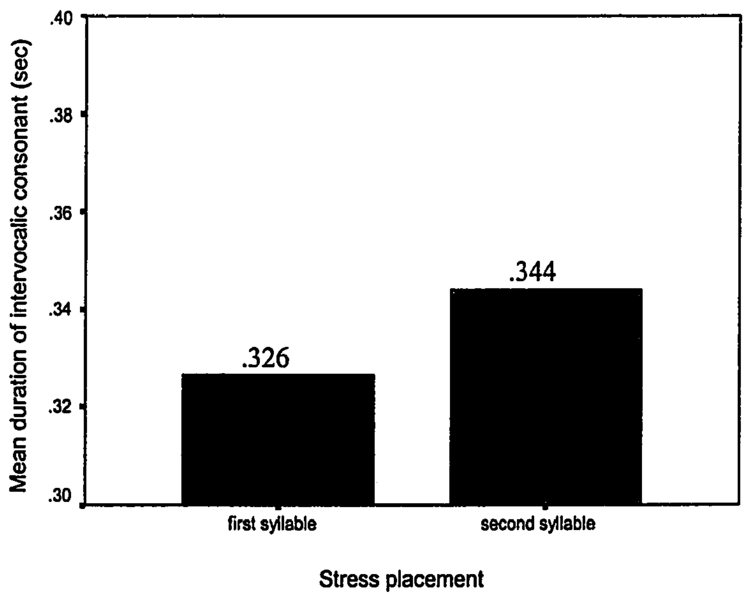

Figure 5.18 Intervocalic consonant duration depending on stress placement

From Figure 5.18, it seems that intervocalic consonants are in fact slightly shorter when following the stressed syllable (326 ms) than when preceding the stressed syllable (344 ms). However, a single-factor ANOVA revealed that the effect of stress on the duration of intervocalic consonants was not significant ($F < 1$). The tendency for intervocalic consonants to be longer when preceding a stressed syllable than when following a stressed syllable goes in the opposite direction from the Stress-to-Weight principle. It seems then that the duration of intervocalic consonants is not a function of stress placement.

5.4.3 Discussion

Results from this study show that the duration of intervocalic consonants is not caused by the Stress-to-Weight principle. If it were, then there would have been a difference in duration between intervocalic consonants following stressed and unstressed syllables.

Given that the duration of intervocalic consonants is not dependent on stress placement, what causes them to be so long? One answer to this question is 'nothing'. These consonants are simply long as a result of phonetic implementation particular to Lheidli (and other Athapaskan languages). If this is the case, the question that arises is 'why only intervocalically?' Here, two answers exist. The first is that language-specific phonetic implementation requires that Lheidli consonants be long intervocalically and nowhere else. This implies that the distribution of long consonants does not involve phonology at all. The second answer is that consonants are long only intervocalically because of positional restrictions in Lheidli, which prevent long consonants from occurring elsewhere in the word. These restrictions have to do with Moraic Theory (Hayes, 1989), and are discussed further in section 5.5 below.

An alternative answer to the first question ('what causes intervocalic consonants to be so long?') is that Lheidli has a syllable minimality restriction that requires all syllables to be closed. Two facts suggest such an analysis: (a) consonants are long only intervocalically, and (b) intervocalically is precisely the environment in which consonants fill two phonological roles: coda and onset. Given that the environment in which consonants are long coincides with the one in which they serve two phonological roles, it seems plausible that their duration is motivated by their double phonological role (coda and onset), which results from syllable minimality. Such a minimality requirement would be unusual. Indeed, several languages exhibit a *word* minimality requirement, whereby words must contain at least two morae (Kenstowicz, 1994). This requirement leads to various phonological processes which ensure that syllables in monosyllabic words are heavy. In these languages, however, syllables can be light as long as words are bimoraic. In contrast to this, Lheidli seems never to allow light syllables, no matter how many morae the word as a whole contains.

Regardless of whether intervocalic consonants are long simply by nature or as a result of syllable minimality, the effect on syllable structure is the same: they close the preceding syllable, and this regardless of stress placement. This finding has important implications for the Jakobsonian typology of syllable types. Indeed, the Jakobsonian typology states that if a language has CVC syllables, it also has CV syllables (Itô, 1986). The prediction, which so far has been borne out, is that no language exists which has CVC syllables but not CV syllables. Lheidli does have open syllables word-finally, but in these syllables the final vowel is lengthened, arguably creating a bimoraic syllable (CVV). Word-internally Lheidli has no true open syllables, since the long intervocalic consonants close the preceding syllable. The implication from the Lheidli data is that the Jakobsonian typology may not capture the facts of natural language appropriately: there are languages - namely Lheidli - which have CVC (and CVV) syllables, but no CV syllables. Note that Lheidli is only problematic if we consider moraic structure, since its syllables are either CVC or CVV (which can be represented $CV_{\mu\mu}$). Without invoking morae, Lheidli can be said to have CV as well as CVC syllables.

5.4.4 Conclusion on stress placement and intervocalic consonant duration

Based the discussion of stress placement and intervocalic consonants above, one can say that in Lheidli, the double role of intervocalic consonants (coda and onset) is not a function of stress. In this sense, Lheidli is unlike English, for example, in which ambisyllabicity is motivated by stress facts. In the following section we turn to the formal representation of intervocalic consonants in Lheidli. Based on their durational properties, and on the fact that these are not a function of stress, I propose that these consonants are geminates, and that Lheidli provides evidence for non-contrastive geminates in language.

5.5 The formal representation of intervocalic consonants

A number of phonetic and phonological facts of Lheidli were presented in this section which argued for an analysis of intervocalic consonants in which they serve both as codas to the preceding syllable and as onsets to the following syllable. In discussing vowels, we saw that vowels preceding intervocalic consonants behave as they do when in a closed syllable, both in terms of duration and distribution (5.1). Furthermore, syllabification intuitions of a native speaker support the interpretation of intervocalic consonants as being ambisyllabic (5.3). Although none of these facts are conclusive when taken alone, together they form a robust argument for intervocalic consonants being part of two syllables. If V_1CV_2 sequences were syllabified $V_1.CV_2$, as one would expect given universal syllabification principles (Itô, 1986), what would explain the unusual length of the "onset" consonant? Why would V_1 behave as if it were followed by a coda consonant? And why would native speakers judge the consonant as belonging to both the preceding and the following syllable?

Recall the question asked at the beginning of this chapter: does the phonology interact with the phonetics with respect to intervocalic consonants? Based on the combination of facts discussed in Chapter 5, I argue that the answer to this question is 'yes.' The phonology mirrors the phonetic duration of intervocalic consonants by assigning these consonants a double role: coda (to the preceding syllable) and onset (to the following syllable. The precise nature of this role is discussed in the remainder of the chapter.

Section 5.5 is structured as follows: 5.5.1 presents an overview of the literature on ambisyllabicity and gemination in language. This section serves as background for section 5.5.2, which focuses on the appropriate formal representation of intervocalic consonants in Lheidli. In this section I propose that these consonants are geminates, and are moraic. I also discuss in more detail the two possible reasons for their distribution (limited to intervocalic position) mentioned in section 5.4.3.3 (the 'no reason' approach vs. the 'syllable minimality' approach).

5.5.1 Ambisyllabicity vs. gemination in the literature

Two terms come to mind immediately in the discussion of Lheidli intervocalic consonants: ambisyllabic and geminate. What is the difference between these two terms, and which is more appropriate in reference to Lheidli? In order to answer this question, it is necessary to determine what is said in the literature about ambisyllabicity and gemination.

The terms *ambisyllabicity* and *gemination* are used either as descriptive terms or as formal terms. As mentioned in the introduction (Chapter 1), as descriptive terms they are used simply to describe different phenomena found across languages. By and large, ambisyllabicity is used in reference to syllabification in stress-timed languages. For example in English it refers to the process by which intervocalic consonants are interpreted as belonging to two syllables. For example, the [m] in *lemon* is perceived as belonging to both syllables of the word: [lɛm.mən]. Gemination, on the other hand, is used in languages such as Japanese, Italian, or Turkish which contrast long and short consonants. In Turkish for example, *ata* (horse-dative) contrasts with *at:a* (horse-locative). The former word contains a short consonant - termed *singleton* - whereas the latter word contains a long consonant - termed *geminate* (Lahiri and Hankamer, 1988). In the Athapaskan literature, neither of these descriptive terms has been used in reference to intervocalic consonants. In discussing Navajo, Sapir and Hoijer (1967) refer simply to *lengthening*, and Young and Morgan (1987) refer to the *doubling of consonants*.

As formal terms, *ambisyllabicity* and *gemination* differ in terms of the phonological properties that are implied of the relevant consonants, and in terms of their formal representation. There are five primary phonological differences between ambisyllabic consonants and geminates. First, ambisyllabic consonants are not usually associated with phonetic duration. Indeed, they are often very short, as English flaps (Kahn, 1976, Borowsky et al., 1984, Jensen, 2000). Geminates, on the other hand, are generally associated with phonetic length (Borowsky et al., 1984, Jensen, 2000), although word-initially this is less often the case (Abramson, 1987, Hume et al., 1997a, Hume et al., 1997b, Davis, 1999).

The second difference - related to the first - is that ambisyllabic consonants are never considered to be associated with a mora. Their short duration is reflected formally by their lack of phonological weight. Geminates, on the other hand, are often considered to be moraic (Hayes, 1989, Davis, 1999), although this is not always the case (Tranel, 1991, Hume et al., 1997a, 1997b). In analyses where geminates are considered moraic, their increased duration is reflected by phonological weight (in terms of morae). The *moraic vs. not-moraic* debate is discussed in more detail in the section on formal representation below.

The third difference between the two terms involves phonological role. Gemination is generally agreed to be contrastive: a language which has geminate consonants contrasts them with singletons[21]. In contrast to this, ambisyllabicity is not contrastive. There are no languages which distinguish ambisyllabic consonants from non-ambisyllabic ones.

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[21] Although see Hammond (1999) for an analysis of English which involves non-contrastive gemination.

Because gemination is contrastive, it is not governed by any other phonological requirement in the language. In contrast to this, ambisyllabicity is governed by prosodic requirements, for example those which ensure that stressed syllables are closed.

The following table summarizes the differences between ambisyllabicity and gemination discussed so far:

Table 5.15 Ambisyllabicity vs. gemination

Ambisyllabicity	*Gemination*
• consonants are usually short (particularly flaps)	• consonants are usually long
• *not* moraic	• moraic
• driven by prosody	• *not* driven by prosody
• *not* contrastive	• contrastive (long vs. short)

The final difference between ambisyllabicity and gemination involves formal representation. Several researchers have proposed ways of representing ambisyllabic consonants and geminates, with and without reference to moraic weight (Kahn, 1976, Clements and Keyser, 1983, Borowsky et al., 1984, Schein and Steriade, 1986, Tranel, 1991, Davis, 1995, Hammond, 1999, Jensen, 2000). Sample representations are provided below.

Kahn (1976), Clements & Keyser (1983) and Borowsky et al. (1984) are among those who propose formal representations of geminates within CV Phonology (MCarthy, 1979, Halle and Vergnaud, 1980, MCarthy, 1981), without reference to morae. Borowsky et al. (1984) claim that ambisyllabicity and gemination are descriptive terms used in reference to different phenomena, but that these two terms refer to the same formal structure, given in Figure 5.19:

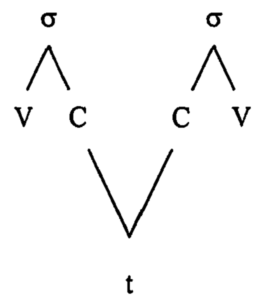

Figure 5.19 Borowsky et al.'s (1984) representation of
geminate and ambisyllabic consonants

Borowsky et al argue that the phonetic differences between ambisyllabic and geminate consonants stem from their phonological role. Consonants which are specified underlying as belonging to both syllables are implemented phonetically as geminates. Consonants which become part of both syllables as a result of prosodic requirements are implemented phonetically as ambisyllabic - as in the flap in the American English pronunciation of *city* /sɪti/ pronounced [sɪɾi]. This view is certainly not universal; Jensen (2000), for example, disagrees with Borowsky et al., and argues that ambisyllabicity and gemination should be treated as different, both descriptively and formally.

More recently, in his work on Moraic Phonology, Hayes argues that geminates are always moraic (Hayes, 1989), i.e. they are specified as such underlyingly. He provides the following representation for geminates:

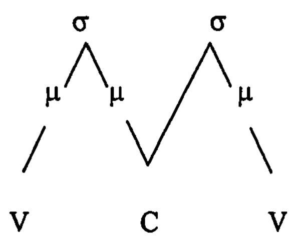

Figure 5.20 Hayes' (1989) representation of geminates

Although Hayes does not discuss ambisyllabic consonants, a plausible representation of these consonants based on his work is presented in 5.21:

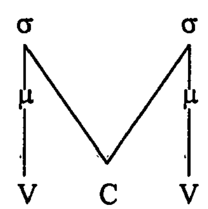

Figure 5.21 Representation of ambisyllabic consonants compatible with Hayes (1989)

The only difference between 5.20 and 5.21 is in the presence vs. absence of a mora associated with the coda portion of the intervocalic consonant.

Hume et al. (1997a, 1997b) and Tranel (1991) disagree with Hayes' approach (Moraic Phonology), which requires geminates to be moraic. Tranel, based on data from Selkup[22], argues that phonological theory must allow for geminates to have inherent

[22] Selkup is West Siberian language (Tranel, 1991).

length which is not necessarily associated to weight. Similarly, Hume et al. argue that (word-initial) geminates in Leti[23] are phonologically long but not heavy. The formal representation Hume et al. provide to capture syllable length and weight uses both morae and X-slots. In languages where geminates are not heavy, geminates are associated with two X-slots, but not with any morae. This reflects the fact that they are phonologically long but not heavy[24].

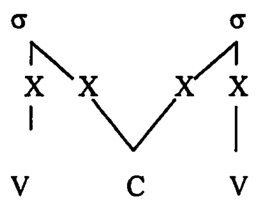

Figure 5.22 Representation of geminate consonants
in Hume et al. (1997)

Hume et al. do not discuss ambisyllabic consonants, but one could imagine that the difference between the light geminates and ambisyllabic consonants lies in the number of X-slots associated with the consonant. Geminates are phonologically long, and are therefore associated with two X-slots. Ambisyllabic consonants are not phonologically long, and are therefore associated with only one X-slot. Figure 5.23 illustrates an ambisyllabic consonant, based on ideas put forth by Hume et al. (1997).

[23] Leti is an Austronesian language of Timor, within the Luangic-Kisaric subgroup (Hume et al., 1997a).
[24] Geminates in Leti are contrasted with long vowels, which are associated with two X-slots, but also with two morae.

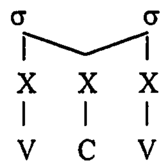

Figure 5.23 Representation of ambisyllabic consonants
based on Hume et al. (1997)

Although researchers disagree as to what differentiates ambisyllabic consonants from geminates, and how to represent these differences formally, one point which is uncontested is that languages cannot have both ambisyllabicity and gemination. In this sense, these phenomena are considered to be in complementary distribution.

In summary, there are three ways of capturing the formal difference between ambisyllabic consonants and geminates. The first is to say that they are the same formally, and their phonetic differences are a result of their phonological role in the language (Borowsky et al., 1984). The second is to say that what distinguishes them is moraic structure: geminates are associated with a mora whereas ambisyllabic consonants are not (Hayes, 1989). The third is to say that what distinguishes them is the number of X-slots associated with them: geminates are associated with two X-slots whereas ambisyllabic consonants are associated with only one (Tranel, 1991, Hume, 1997a, 1997b). In the next section, two questions will be answered: which term best captures the facts of Lheidli, *ambisyllabicity* or *gemination*? And what is the appropriate formal representation of Lheidli intervocalic consonants?

5.5.2 The formal structure of intervocalic consonants in Lheidli

Lheidli intervocalic consonants differ from traditional ambisyllabic consonants in that there is a phonetic correlate to their ambisyllabicity - they are significantly longer than simple onset and coda consonants. Furthermore, their distribution is not a function of stress placement. They differ from traditional geminates in that they are not contrastive, i.e. there are no minimal pairs such as the hypothetical **dunne* vs. *dune* ('man'). Since Lheidli intervocalic consonants differ from ambisyllabic consonants along two dimensions (duration and distribution) and from geminates only along one dimension (contrastiveness), I argue that they are in fact geminates. The idea of non-contrastive geminates is not in fact a new one. Hammond (1999) proposes that English has non-contrastive geminates, for example the /n/ in *dinner*. Colina (in preparation) also discusses the possible occurrence of non-contrastive geminate /ŋ/ in Galician.

Given that intervocalic consonants in Lheidli are geminates, how are they represented formally? The answer to this question depends on how their duration is encoded phonologically: as length (X-slots), as weight (morae) or as a combination of the two. Tranel (1991) and Hume et al. (1997a, 1997b) use the notion of phonological length - represented formally by X slots - to encode contrastive length. Given that Lheidli has no contrastive length, I argue here that in Lheidli, the phonetic duration of intervocalic consonants is not encoded as X-slots, and in this sense Lheidli differs from Leti - as discussed by Hume et al. (1997a, 1997b).

If in Lheidli the duration of intervocalic consonants is not phonologically encoded as X-slots, and if the phonetic duration of its intervocalic consonants is to be encoded at all in the phonology, it must be encoded in terms of weight. Based on the limited distribution of intervocalic consonants, I propose that this is indeed the case. Indeed, why is it the case that Lheidli geminates only occur intervocalically, why not word-initially or word-finally? In Chapter 4, the notion 'perceptual salience' (Hume and Johnson, to appear) was discussed as a possible explanation: long consonants (geminates) occur only intervocalically because this is the position in which they are most salient. However, this explanation was rejected because, given that Lheidli's long consonants are not contrastive, there is no reason to increase the salience of their duration.

Having undertaken a discussion of the phonological representation of these sounds, we can now consider a phonological explanation of the positional restrictions imposed on intervocalic consonants. I propose here that geminates are moraic, and can therefore only occur in positions that license a mora. This means that they cannot occur word-initially, since this position is an onset and does not license a mora. In summary then, Lheidli intervocalic consonants are non-contrastive, moraic geminates. Formally, they are represented as in Hayes (1989). Figure 5.24 provides the formal representation of VCV sequences in Lheidli:

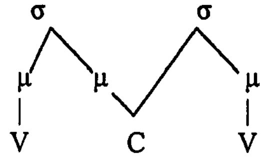

Figure 5.24 VCV sequences in Lheidli, based on Hayes (1989)

Again, the reason that geminates do not occur word-initially is that the onset position does not license a mora (Hayes, 1989). In order to account for why geminates do not occur word-finally in Lheidli, I propose that geminates must be linked to a following syllable. If there is no following syllable, then the geminate gets shortened. In other words, if a consonant is only a coda or only an onset, it is not long. This implies that the length of geminates is in part a function of their moraic weight, and in part a function of their role in syllabification. Even though onsets are weightless, they still require a minimal duration in order to be perceived as onsets[25]. Thus, if consonants lose their role as onsets (as in word-final position), then they also lose the duration associated with the onset position. For this reason, Lheidli word-final and word-medial codas are not as long as word-medial, intervocalic consonants. How the notion of onset duration is encoded, given that these segments are generally assumed not to be moraic, awaits future research. One possible way to approach this question is through the notion of perceptual salience, discussed in Chapter 4 (Liljencrants and Lindblom, 1972, Ohala, 1981, 1993, Flemming, 1995, Wright, 1996, Steriade, 1999, 2001, 2002)..

5.6 Conclusion

In this chapter, I provided evidence from vowel alternations (5.1), consonant distributions (5.2), and syllabification intuitions (5.3) that intervocalic consonants form both the coda of the preceding syllable and the onset of the following syllable. I also

[25] On the role of perception in phonology, see Ohala (1981, 1993), Steriade (1999, 2002), and Hume and Johnson (2001).

showed that these consonants were long regardless of stress placement, i.e. their duration was not a function of the Stress-to-Weight principle (5.4). Based on the studies reported in sections 5.1 through 5.4, I proposed a formal representation for these consonants (5.5), in which I claimed that they are best characterized as non-contrastive moraic geminates.

While I chose to analyze intervocalic consonants as geminates, it is possible to say that these segments are formally ambisyllabic, based on the fact that they are not contrastive. Such an approach would have to allow for the possibility of having ambisyllabic consonants associated to a mora. One way to do this would be to argue that the principle Weight-by-Position can be applied to ambisyllabic consonants (Hayes, 1989). More specifically, languages which have ambisyllabic consonants choose as to whether these consonants are moraic or not. If moraic ambisyllabic consonants were allowed to exist, then the only difference between geminates and ambisyllabic consonants would be in their contrastiveness (whether they were lexical or predictable from stress placement). This approach is certainly worth further exploration, in order to clarify how segments such as intervocalic consonants in Lheidli are best characterized.

Given that I chose to call intervocalic consonants 'geminates' in Lheidli, what implications do the Lheidli data have for language typology and linguistic theory? Lheidli intervocalic consonants show that geminates do not have to be contrastive in language. In Lheidli, they do not contrast with singletons in the same position, i.e. there are no word pairs such as /dʌn:e/ ('moose') vs. */ dʌne/. Given this analysis, one would expect other languages in which geminates were not contrastive. As mentioned above, there is in fact some evidence that this prediction is borne out in English (Hammond, 1999) and Galician

(Colina, in preparation). Again, Hayes' (1989) notion of Weight by Position may be of use here. This principle would allow languages to choose whether their geminates had phonological length or not, and consequently whether or not they were contrastive.

Another important component of the analysis presented above is, in cases where phonetic duration is encoded in the phonology, this does not have to be done through phonological length; rather it can be done through phonological weight[26]. Based on the distributional restrictions of intervocalic consonants in Lheidli, I argue that in this case, phonetic duration is encoded as phonological weight instead of duration. The possible interactions between phonetics and phonology can be captured as follows:

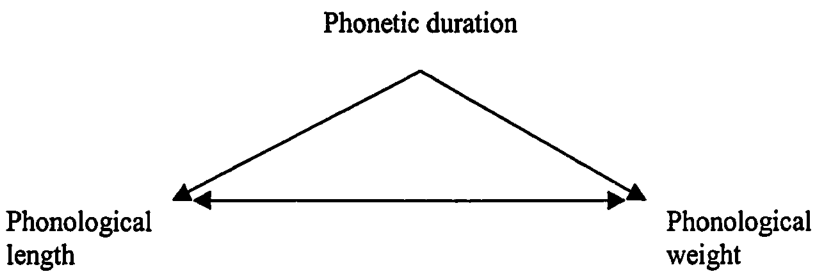

Figure 5.25 The relationship between phonetic duration, phonological length, and phonological weight

The phonology of a language can respond to phonetic duration in two ways: (a) phonological length, and/or (b) phonological weight. An example in which phonetic

[26] The distinction between phonological weight and length is necessary to account for the behavior of geminates in Leti (Hume et al, 1997a, 1997b).

duration is encoded as phonological length is Leti (Hume et al., 1997a, Hume et al., 1997b), in which geminates are phonologically long but not heavy. An example in which phonetic duration is encoded as phonological weight is Lheidli, in which geminates are phonologically heavy, but not contrastive and therefore not phonologically long. An example of a language in which phonetic duration is encoded both as phonological length and phonological weight is Latin, in which phonetically long segments are contrastive (phonologically long) and also have an effect on stress placement, for example (Tranel, 1991).

One final note about the analysis presented here is that it assumes that geminates do not occur word-initially or word-finally. This assumption is based on the duration of consonants across positions: there are no unusually long word-initial consonants; word-final consonants are long due to word-final lengthening, but they are still not as long as intervocalic consonants. There is some evidence that duration is not the only cue to gemination. Indeed, in some languages word-initial geminates are cued not by duration but by perturbations in pitch and amplitude (see for example Abramson (1987) on Pattani Malay). It is possible that Lheidli does have geminates in other positions, but that the measurements used in this dissertation were not sufficient to identify them. Comparing pitch and amplitude measurements across different word-initial consonants is beyond the scope of this project, but future work will certainly include a more thorough investigation of gemination across positions. Note that if geminates are found to exist word-initially, then the analysis presented above, in which they are considered moraic, will have to be revisited.

In conclusion, the goal of chapter 5 was twofold: (1) to determine whether the phonetic duration of Lheidli's intervocalic consonants was correlated with special phonological status, and if so, (b) to provide a formal representation for these consonants. We have seen that, in Lheidli, the phonetics and phonology do indeed interact, and that the formal representation of intervocalic consonants falls out from their syllabification and their distribution. In the following chapter, I conclude by investigating the implications of Lheidli intervocalic consonants for the phonetics-phonology interface, and current linguistic theory as it relates to this interface.

CHAPTER 6 CONCLUSION: PHONETICS AND PHONOLOGY INTEGRATED

In the preceding chapters, I presented a detailed discussion of Lheidli's intervocalic consonants. Chapter 2 provided the necessary background for this discussion by introducing the sounds, syllable structure, and stress system of Lheidli. In Chapter 3, I showed that intervocalic consonants are unusually long (phonetically) compared to (a) consonants in other positions in Lheidli, (b) vowels in Lheidli, and (c) consonants (both singletons and geminates) in other languages.

In Chapters 4 and 5, I went on to investigate the phonetic and phonological implications of Lheidli's intervocalic consonants. Chapter 4 focused on the phonetic role of intervocalic consonants. More specifically, I looked at their effect on the perceived rhythm of the language. I proposed a new model of rhythm - the Enhancement/Inhibition model - in which the perception of rhythm is created by the interplay between the primary correlate of rhythm (alternating stresses or syllables) and the secondary correlates of rhythm. Based on the Lheidli data, I argued that one of the important secondary correlates of rhythm, which has not yet been considered in the literature, is inherent segmental (consonantal) duration.

In Chapter 5, I moved on to the phonological role of Lheidli's intervocalic consonants. Based on studies of (a) vowel durations and distributions, (b) consonant distributions, and (c) native speaker intuitions, I argued that Lheidli intervocalic consonants have a dual phonological role: coda (to the preceding syllable) and onset (to the following syllable). Furthermore, I determined that the phonetic nature and phonological role of intervocalic consonants were not a function of stress placement in the language. The duration and distribution of intervocalic consonants, along with their dual phonological role, led me to a formal representation of these sounds in which they are analyzed as non-contrastive, moraic geminates.

Chapter 6 concludes this dissertation by integrating the findings presented in chapters 3, 4 and 5, i.e. by weaving together the phonetics and phonology of intervocalic consonants in Lheidli. I start by determining what phonetic information is encoded in the grammar and the phonology Lheidli (6.1). I then go on to discuss a model of the interaction between phonetics and phonology (6.2). I end by revisiting the overall goals of this dissertation, commenting briefly on (a) how these goals were achieved, and (b) how this research will be expanded in the future (6.3).

6.1 What is encoded where?

A topic that has received much attention in recent linguistic research involves determining what the interaction is between phonetics and phonology (Keating, 1985, Pierrehumbert and Beckman, 1988, Kingston and Diehl, 1994, Ohala, 1990, 1991, 1995, Cohn, 1998, etc.). In order to fully understand this interaction, it is necessary to know whether various patterns found in natural language are encoded within the grammar and, if so, where they are encoded. In this section, I argue that phonetic elements such as segmental duration and the realization of stress are encoded in the grammar as part of language-specific phonetic implementation. Furthermore, segmental duration (at least in the case of Lheidli intervocalic consonants) is encoded in the phonology as weight

(6.1.1). In contrast to this, rhythm (in Lheidli and cross-linguistically) is not encoded in the grammar at all; rather it falls out from other phonetic and phonological properties of language, including segmental duration (6.1.2). I end this section with a discussion of the implications that the analysis provided here has for the phonetics - phonology interface (6.1.3).

6.1.1 Encoding language-specific phonetics

Based on the Lheidli facts presented in this dissertation, I take the view adopted by Kingston and Diehl (1994), Cohn (1998), and others that language-specific phonetic knowledge exists, and must be specified in the grammar. In what follows, I discuss two properties of language which support this view: segmental duration and the realization of stress. I then distinguish between these two properties, arguing that - at least in Lheidli - segmental duration also is phonologically specified, whereas the realization of stress is not.

If segmental duration were not encoded in the grammar, then one would expect it to be the same across languages. More specifically, one would expect intervocalic consonants in Lheidli to be similar in duration to intervocalic consonants in other languages. Recall from Chapter 3 that intervocalic consonants are much longer in Lheidli than in any other language. The duration of intervocalic consonants must therefore be specified in the language's grammar. As mentioned in the introduction (Chapter 1), part of the reason we know Lheidli is Lheidli and not English is because of the remarkable duration of its intervocalic consonants.

Another aspect of phonetics which must be encoded in the grammar involves the realization of stress. We saw in Chapter 4 that languages do not all realize stress (or prominence) in the same manner. Some use pitch, some amplitude, some duration, and some a combination of the above. The more ways in which stress is manifested phonetically, the more salient (prominent) the stresses are, the more stress-timed a language sounds. Given that the phonetic realization of stress varies from language to language, it too must be encoded in the grammar.

Although inherent segmental duration and the realization of stress must both be specified in the grammar, they differ - at least in Lheidli - as to whether they must be encoded in the phonology or not. Inherent segmental duration, as already discussed, interacts with syllabification in Lheidli. If it did not, intervocalic consonants would be syllabified as simple onsets (V.CV): they would have no effect on the distribution, duration, and quality of preceding vowels, and native speakers would identify them clearly as onsets. Chapter 5 provided extensive evidence that this is not the case: Lheidli intervocalic consonants belong to both the preceding and the following syllables; their effect on the preceding vowel is measurable quantitatively, as is their effect on native speaker syllabification intuitions. Because the duration of intervocalic consonants interacts with other phonological properties of Lheidli (namely syllabification), this duration must be encoded in the phonology of the language. More specifically, it is encoded in the phonology as weight.

The realization of stress in Lheidli differs from inherent segmental duration in that it does not interact with other phonological properties of the language. Lheidli has no vowel reduction (in unstressed syllables), and no prosodic requirements such as the *Stress-to-Weight* Principle, etc. For this reason, the phonetic realization of stress in Lheidli (increase in pitch and amplitude) is encoded in the grammar, but not in the phonology. In summary then, the realization of stress and inherent segmental duration are two language-specific properties which must be encoded in the grammar. Of these, only segmental duration must also be encoded in the phonology - at least in Lheidli.

Table 6.1 Encoding stress and segmental duration

Property	*Encoded in the grammar?*	*Encoded in the phonology?*
Stress	yes	no
Inherent segmental duration	yes	yes

6.1.2 Encoding rhythm

We have just seen that language-specific phonetic properties (stress and inherent segmental duration) must be encoded in the grammar and, in some cases, in the phonology as well. What of rhythm (Chapter 4)? Must rhythm be encoded in the grammar? Must it be encoded in the phonology? In this section I present and evaluate three possible analyses of rhythm, one in which it is specified in the phonology (Analysis I), one in which it is specified in the grammar but not the phonology (Analysis II), and one in which rhythm not specified at all (Analysis III). We shall see that rhythm is simply an effect created by other properties of language, and need not be specified at any level of linguistic knowledge. This provides evidence that not all patterns in language must be encoded in the grammar.

In Analysis I, rhythm is specified in the phonology of the language. Within the framework of Optimality Theory (OT) (MCarthy and Prince, 1993, Prince and Smolensky, 1993), rhythm could be achieved through an explicit constraint such as RHYTHM = STRESS-TIMED, or RHYTHM = SYLLABLE-TIMED, similar to other prosodic constraints such as FTBIN = TROCHEE. Analysis I seems appealing at first glance due to its simplicity. However, problems arise in trying to define RHYTHM = STRESS-TIMED and RHYTHM = SYLLABLE-TIMED, because these constraints are based on concepts which themselves have no clear, simple definition. If 'stress-timed' and 'syllable-timed' were interpretable using the traditional notion of isochrony (see Chapter 4), then constraints referring to these rhythm types could be defined in categorical phonetic terms[1]. For example, RHYTHM = STRESS-TIMED would be defined as 'all feet must be equal in duration'. However, as we saw in Chapter 4, very little evidence has been found for isochrony[2]. Instead, recent research has suggested that the terms 'stress-timed' and 'syllable-timed' are best interpreted as cover terms, each referring to a set of phonetic and phonological properties of language. Furthermore, precisely which phonetic and phonological properties correlate with which rhythm types is still under investigation.

Since there are currently no clear definitions of the concepts 'stress-timed' and 'syllable-timed', there cannot be clear definitions of constraints, which refer to these

[1] See section 6.2 below for a discussion of categorical vs. gradient phonetic constraints in phonology.
[2] Note that even if RHYTHM = STRESS-TIMED could be defined phonetically, one would have to determine what 'equal duration' means, phonetically, i.e. how close in duration two feet must be to be considered equal in duration. This may prove impossible to do.

concepts. For this reason, such constraints (RHYTHM = STRESS-TIMED and RHYTHM = SYLLABLE-TIMED) cannot be formulated in OT[3].

An alternative approach within the realm of phonology is to view RHYTHM = STRESS-TIMED as a 'cover' constraint, short for the (high ranking) set of constraints ensuring stress-timing. In English this set would include constraints dealing with alternating stress (FTBIN = TROCHEE, PARSESYLL, etc.) as well as constraints dealing with other correlates of rhythm such as vowel reduction, syllable complexity, etc. The problem with this approach is that the set of constraints covered by RHYTHM = STRESS-TIMED is necessary in the language independently from the constraint on rhythm. Indeed, FTBIN = TROCHEE, PARSESYLL, etc. ensure that stress is placed appropriately. Other constraints ensure that syllables are well-formed, etc. Because the set of constraints covered by RHYTHM = STRESS-TIMED is required independently from the constraint RHYTHM = STRESS-TIMED, this constraint is redundant and therefore unnecessary.

In addition to the problem of redundancy, viewing RHYTHM = STRESS-TIMED as simply a 'cover' for a set of other constraints implies that rhythm is an *effect* of the relevant set of constraints, rather than a primitive element of phonology. Under OT, if an entity is not associated with a specific constraint, then it does not exist. Viewing RHYTHM = STRESS-TIMED as a cover for other constraints implies that it does not itself refer to a specific constraint. In this sense, it cannot exist within the phonology; instead, it is an effect, an artifact of other phonological elements. In summary, there is no way of

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[3] Note that it is possible to leave the precise definition of RHYTHM = STRESS-TIMED up to 'phonetic implementation'. However, doing this would take away all of the explanatory power of the analysis, in terms of accounting for how rhythm arises.

defining constraints such as RHYTHM = STRESS-TIMED in a satisfactory manner within a formal phonological framework (at least within OT). For this reason, Analysis I, which depends on such constraints, is rejected: rhythm cannot be encoded in the phonology.

If rhythm does not fall within the realm of phonology, perhaps it is specified in the grammar, as part of the language-specific phonetic knowledge (Analysis II). Suppose that this is the case, and that rhythm is encoded in the form of a general rhythm requirement within a language's grammar. If this requirement is to have any effect on the language, it must be met in the phonology through constraints, in the phonetics through (language-specific) phonetic implementation, or through a combination of phonology and phonetics. Under Analysis II then, rhythm can be interpreted as a 'driving force' behind phonetic and phonological properties of language.

The problem with Analysis II involves the interaction between the rhythm requirement and the phonological correlates of rhythm. We know that rhythm is in part a function of phonological properties of the language, including the syllable structure, the presence vs. absence of vowel reduction, the role of lexical stress, etc. (Dauer, 1983, 1987). The idea that the rhythm requirement drives these phonological properties implies that the constraints responsible for these properties are motivated by the rhythm requirement. For example, suppose the grammar of English included the requirement that speech be stress-timed. Saying that this requirement is met (in part) through the phonology implies that the constraints which affect rhythm in English are motivated by this requirement. Such constraints include those creating alternating stresses (FTBIN = TROCHEE, PARSESYLL, etc.), as well as those achieving vowel reduction, complex syllables, etc. This analysis is rejected because under OT (the framework within which this discussion is based), phonology consists solely of constraints and rankings. There is no place for 'driving forces' - such as a general rhythm requirement - external to the phonology.

Even if phonology did allow for external driving forces such as the rhythm requirement, the problem with such a requirement is that it would not allow for languages to fall along a rhythm continuum[4]. If all constraints affecting rhythm were motivated by the rhythm requirement, all languages should fall clearly into a discrete rhythm class. However, recall from Chapter 4 that there are languages which fall between stress-timed and syllable-timed, such as Catalan and Polish. These languages indicate that a rhythm continuum does indeed exist, and must be accounted for.

To allow for a rhythm continuum while keeping the notion of a rhythm requirement, there would have to be a conflict between (a) phonological constraints, which are motivated by the rhythm requirement and (b) other phonological constraints, which inhibit or enhance the salience of the specified rhythm (constraints on syllable well-formedness, for example). Distinguishing between those constraints which achieve rhythm and those which inhibit or enhance it would be impossible to do. Another reason for rejecting Analysis II is that it is not clear what constraint interactions would be necessary to allow languages to be specified as to their rhythm and at the same time to fall on a rhythm continuum rather than into discrete classes.

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[4] Note that this is also a problem for Analysis I.

Summarizing so far, it seems that rhythm is neither encoded in the phonology, nor in the grammar as part of language-specific phonetic knowledge. What are the implications of this finding for research on rhythm? Recall that the traditional view of rhythm classes was based on isochrony. The idea was that speakers strived to produce isochronous (regularly recurring) units: feet in stress-timed languages, syllables in syllable-timed languages, and morae in mora-timed languages. The implication of the traditional view of rhythm classes is that rhythm is specified in the grammar (in terms of isochrony), and that speakers attempt to meet the rhythm requirement of their language in speech production. In the paragraphs above, I have argued that rhythm cannot be specified in the grammar (or in the phonology). This finding provides further evidence against the traditional view of rhythm classes. It also supports Dauer's (1983, 1987) view that rhythm is an effect of phonetic and phonological facts, rather than a primitive element of language. This view forms the basis of Analysis III, and is investigated further below.

Given that rhythm is specified neither in the phonology nor in the grammar, it must be an effect of other properties of the language (Analysis III). I focus here on segmental duration which, as the Lheidli data show, is an important secondary correlate of the perception of rhythm (Chapter 4). There are two ways to view the contribution of segmental duration to rhythm under Analysis III, which differ in whether segmental duration is considered a purely phonetic fact, or a combination of phonological and phonetic facts. First, it is possible to view segmental duration as a purely phonetic fact with no external, phonological motivation (View A): intervocalic consonants in Lheidli are simply long - and are specified as such in Lheidli's language-specific phonetic implementation. Under View A, the phonetic nature of intervocalic consonants is a primitive element of the language. The phonology mirrors the phonetics by providing inherently long consonants with an additional mora. However, the source of rhythm is essentially phonetic: inherent segmental duration is the crucial correlate of rhythm.

The second way of viewing segmental duration is as a function of both phonological and language-specific phonetic facts of Lheidli (View B). Under View B, the duration of intervocalic consonants is motivated by their phonological role. More specifically, Lheidli has a phonological requirement that states that syllables must be at least bimoraic. In order to fill this requirement, intervocalic consonants geminate. This phonological requirement can be captured within OT using a constraint such as MINSYLL (syllables must be at least bimoraic). To ensure that MINSYLL is satisfied by the intervocalic consonant rather than the preceding vowel, one can use FAITH/Vμ (vowels must have the same number of morae in the input as in the output) and FAITH/Cμ (consonants must have the same number of morae in the input as in the output). To ensure that the syllable minimality requirement is satisfied by adding any extra morae to consonants rather than vowels, FAITH/Vμ must outrank FAITH/Cμ. Finally, ONSET (Prince and Smolensky, 1993) ensures that the intervocalic consonant fills both coda and onset positions. These constraints are ranked as follows: MINSYLL, FAITH/Vμ, ONSET >> FAITH/Cμ.

Tableau 6.1 The syllable minimality requirement in OT. Periods indicate syllable boundaries. Parentheses () indicates ambisyllabicity.

/g^wʌ z e h/ μ μ	MINSYLL	ONSET	FAITH/Vμ	FAITH/Cμ
g^wʌ. z e h μμ μμ			*!	*
☞ g^wʌ(z) e h μ μμμ				**
g^wʌ z. eh μμ μμ		*!	*	**
g^wʌ. z eh μ μ μ	*!		*	**

Note that this analysis assumes that vowels are moraic underlyingly. An alternative would be to replace FAITH/Vμ with a constraint disallowing bimoraic vowels (*V/μμ).

Words which end in a vowel underlyingly require an additional constraint: DEPC (a consonant in the output must be present in the input). DEPC ensures that, word-finally, MINSYLL is satisfied by adding a mora to the existing vowel rather than by epenthesizing a consonant. DEPC must outrank FAITHV/μ.

Tableau 6.2 OT analysis of underlyingly word-final open syllables

/g^wʌ z e/ | | μ μ	MINSYLL	ONSET	DEPC	FAITH/Vμ	FAITH/Cμ
g^w ʌ(z) e <h> | | | | μ μ μ μ			*!		*
☞ g^wʌ (z) e | | |\\ μ μ μ μ				*	*
g^w ʌ (z) e | | | μ μ μ	*!				*

The analysis illustrated in Tableau 6.2 predicts that in word-final open syllables, vowel lengthening should occur rather than consonant epenthesis. However, recall from discussion in previous chapters that it is often difficult to tell the difference, acoustically, between word-final [v̥] and [vh] sequences. If it turns out that [v̥] and [vh] actually alternate freely, a more appropriate constraint ranking would involve not ranking DEPC and FAITHV/μ with respect to each other:

Tableau 6.3 Alternative OT analysis of underlyingly word-final open syllables

/g^w ʌ z e/ μ μ	MINSYLL	ONSET	DEPC	FAITH/Vμ	FAITH/Cμ
☞ g^w ʌ(z) e <h> μ μ μ μ			*		*
☞ g^wʌ (z) e μ μ μ μ				*	*
g^w ʌ (z) e μ μ μ	*!				*

This last analysis would imply that [h] need never be a word-final coda underlying. Its appearance in the surface form would be entirely predictable given MINSYLL. Note that additional constraints would be necessary to ensure that [h] would be epenthesized rather than another consonant.

Under View B - in which the duration of intervocalic consonants is a function their phonological role as geminates - the phonetics mirrors the phonology by giving geminate consonants extra (phonetic) duration to match their extra weight (encoded as a mora). In this case, Lheidli-specific phonetic implementation makes geminates much longer than they are in other languages. Here, the crucial correlate of rhythm is in effect twofold, consisting of syllable minimality (phonological) and of phonetic implementation of geminates (phonetic).

Whether the source of rhythm is essentially phonetic in nature (View A), or a combination of phonetics and phonology (View B), an important characteristic of Analysis III is that, at some level, language-specific phonetics must come into play. Under View A, Lheidli-specific phonetic implementation makes intervocalic consonants extremely long. Under View B, Lheidli-specific phonetic implementation makes geminate consonants - resulting from syllable minimality - extremely long.

Although View A and View B are logical distinct views under Analysis III, they are difficult to distinguish in practical terms. Indeed, it is impossible to know, at least given the data at hand, whether Lheidli-specific phonetic implementation applies to intervocalic consonants (phonetic) or to geminates (phonology). One possible indication of which view captures the facts most appropriately involves the limited distribution of long consonants in Lheidli. If the duration of intervocalic consonants were a purely phonetic matter (as under View A), one might expect them to occur across all positions. As discussed in Chapter 3, they only occur in positions that (a) license a mora and (b) allow consonants to fill a double role (coda and onset), i.e. intervocalically[5]. This distribution indicates that their duration maybe be at least partly phonologically motivated, in support of View B.

Regardless of which view one chooses to adopt, the crucial component of Analysis III (under both views) is that rhythm is not a primitive of language. It is not encoded in the grammar (or the phonology); rather it falls out from other phonetic and

[5] It would be interesting to looks at intervocalic consonants occurring across word boundaries, in VC#V and V#CV context. If consonants turn out to be long in these contexts as well, one can say that word boundaries are not relevant for syllabification purposes in Lheidli.

phonological properties of the language. This analysis differs from Analyses I and II - both rejected for various reasons - in which rhythm *is* specified in the grammar.

6.1.3 Summary of the implications of Lheidli for phonetic and phonological theory

The implications of the Lheidli data for phonetic and phonological theory are as follows. First, phonetic implementation must be encoded in the grammar. More specifically, the phonetic duration of a language's segments must be included in its grammar, otherwise one would expect all languages to have segments of similar duration, in cases where duration is not contrastive or used to meet other phonological requirements of the language. In Lheidli, segmental duration must be also be encoded in the phonology, since it interacts with syllable well-formedness constraints (limiting the occurrence of long consonants to intervocalic position).

Second, not all patterns in language must be encoded in the grammar. In the preceding section, three analyses were proposed to account for the perception of rhythm in language. These are summarized in Table 6.2 below, which outlines (a) the domain in which rhythm is encoded, (b) the specific analysis involved, and (c) the problem with the analysis (in the case of Analyses I and II).

Table 6.2 Three possible analyses of phonetic duration and phonological weight

Question	*Analysis I*	*Analysis II*	*Analysis III*
Where is rhythm encoded?	Rhythm is encoded in the phonology	Rhythm is encoded in the grammar	Rhythm is not encoded at all
What is the analysis?	Rhythm is achieved through a constraint such as: RHYTHM = STRESS-TIMED	Rhythm is achieved through a general requirement (a 'driving' principle) such as: Rhythm is stress-timed	Rhythm is an effect of other (language-specific) phonetic and phonological facts of the language
What is the problem?	Constraints such as RHYTHM = STRESS-TIMED cannot be defined within OT. If such constraints are defined, they are redundant with other constraints independently necessary.	There is no way of formalizing the interaction between a grammatical requirement and phonological constraints. There is no way of allowing languages to fall along a rhythm continuum.	None

Analysis III - the chosen analysis - holds that rhythm need not be specified, either in the phonology or, more generally, in the grammar. This raises the question of whether all patterns in language need to be encoded in the grammar. In recent years this question has been the focus of much debate (Hume and Johnson, to appear, Ohala, 1995, Steriade, 2002). Rhythm is a pattern found in natural language, created by the forward movement of language in time. However, I have argued here that it is not a primitive element of language encoded as part of the linguistic knowledge of native speakers; rather, it falls out from other phonetic and phonological properties in the language. The implication from the proposed analysis of rhythm is that not all patterns in language must be encoded in the grammar.

6.2 A model of phonetic and phonological knowledge

Recall that segmental duration is encoded in both the grammar and the phonology whereas the realization of stress is encoded only in the grammar. Whether or not information on phonetic implementation is encoded in the phonology, an account within formal linguistic theory must be given for how it is specified in the grammar. Among phoneticians, the standard view of the interaction between phonology and phonetics in speech production is illustrated in Figure 6.1 (Keating, 1984, Keating, 1985, Cohn, 1998, etc.).

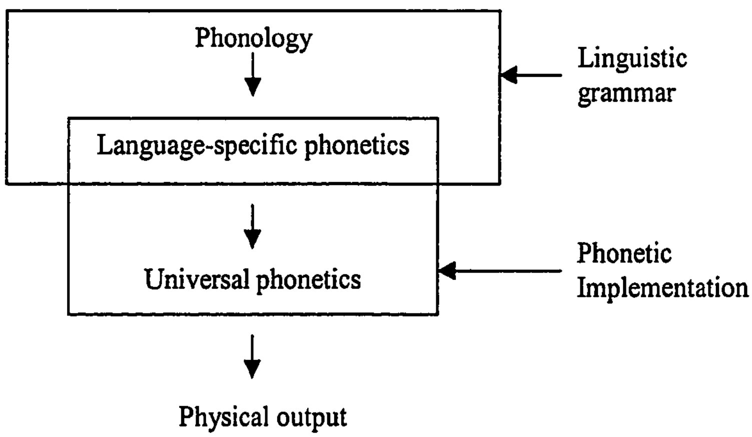

Figure 6.1 The interaction between phonology and phonetics (Cohn, 1990, 1993)

As Figure 6.1 illustrates, phonetic knowledge is considered distinct from phonological knowledge. Under this view, the implementation of stress in Lheidli is straight-forward: it falls within the domain of language-specific phonetics (as part of the linguistic grammar). The implementation of intervocalic consonant duration in Lheidli is less clear. We have seen that this duration is correlated with weight in the phonology. The weight of intervocalic consonants falls within the realm of phonology. However, the realization of intervocalic consonants falls within the realm of language-specific phonetics, since their duration is different from that in other languages. In this sense, segmental duration in Lheidli must be encoded both at the phonological level (moraicity) and the phonetic level (raw duration).

According to Keating (1984, 1985), Cohn (1998) and many others (and illustrated in Figure 6.1), phonology is separate from (language-specific) phonetics. Therefore, if phonological theory (for example Optimality Theory) is taken strictly as a theory of phonology, it need not account for elements of phonetic implementation, whether or not they are language-specific and encoded in the grammar. An alternative view is to say that OT is a theory of speech production as a whole, in which case it must deal with phonetic implementation as well as phonological patterns. In what follows, I attempt to expand the constraints currently accepted in OT to include constraints on systematic sound patterns and alternations, which are part of the grammar but not the phonology. I conclude that these constraints would increase the power of OT to such an extent as to make it an implausible model of speech production. For this reason, I reject it in favor of an analysis of linguistic knowledge in which phonetic knowledge is distinct from phonological knowledge, and does not fall within the realm of what is accounted for by OT.

If OT is to capture all aspects of sound patterns and alternations, it must include a set of constraints, the role of which is to achieve the appropriate phonetic implementation of speech. These would be correspondence constraints (McCarthy and Prince, 1995), similar to those already widely used in the OT literature (for example MAX and DEP). However, the phonetic implementation constraints would differ from existing constraints in that they would refer to specific sounds and patterns. Furthermore, they would not necessarily be input-to-output constraints such as MAX and DEP.

In some cases, stress for example is lexical, and could therefore be captured with input-to-output correspondence constraint: $\text{STRESS}_I/\text{PITCH}_O$ (stress in the input corresponds to raised pitch in the output). In other cases, stress is predictable from the phonological structure of the word(s). In such cases, the appropriate constraint would be an output-to-output constraint: $\text{STRESS}_O = \text{PITCH}_O$ (stress in the output is realized by raised pitch in the output). The problem with such constraints is that they still do not specify the details of phonetic implementation. Indeed, what does 'raised pitch' mean, in terms of frequencies? Is it enough to increase the pitch by 10 Hz, by 50Hz? Or perhaps by 20%? Without specifying the exact nature of phonetic implementation, a constraint such as $\text{STRESS}_O = \text{PITCH}_O$ is not useful. However, specifying the phonetic implementation would require constraints such as $\text{STRESS}_O = \text{PITCH}{+}20\%$ (stress in the output is realized by increasing the pitch in the utterance by 20%). If the constraint set is to be universal, it is highly improbable that such constraints are part of the set. As for segmental duration, the question of how to achieve it through OT constraints is also difficult, since duration is gradient and dependent on speech rate. Again, it seems unlikely that the universal constraint set includes constraints such as CONSDUR = 200-300MS (e.g.), necessary to achieve the appropriate duration of intervocalic consonants in Lheidli.

These two examples point to the primary limitation of OT in terms of dealing with phonetic implementation: it cannot capture gradience adequately without including a vast number of constraints, many of which must be 'fuzzy', i.e. allow for gradient output (e.g. CONSDUR = 200-300MS: consonants must be between 200 and 300 ms long). For this reason, I argue that OT cannot be responsible for capturing gradient properties of language-specific phonetic implementation[6].

Although OT cannot deal easily with gradient phonetic properties, it does deal well with categorical phonetic constraints such as grounded constraints (Archangeli and Pulleyblank, 1994). It seems that the only way in which phonetic properties of language can be encoded in the phonology is through categorical, universal, phonetically grounded phonological constraints. Figure 6.2 illustrates the components of phonetics and phonology within an integrated system of speech production, based on previous views of the phonetics-phonology interaction and on the Lheidli data presented in this dissertation.

[6] Flemming (2001, to appear) deals with gradience within phonological theory, but does not mention a way in which to achieve language-specific properties of phonetic implementation, such as duration or pitch. Boersma and Hayes (2001) also deal with gradience within OT. However, they consider gradience in constraint ranking rather than gradience in language-specific phonetic implementation.

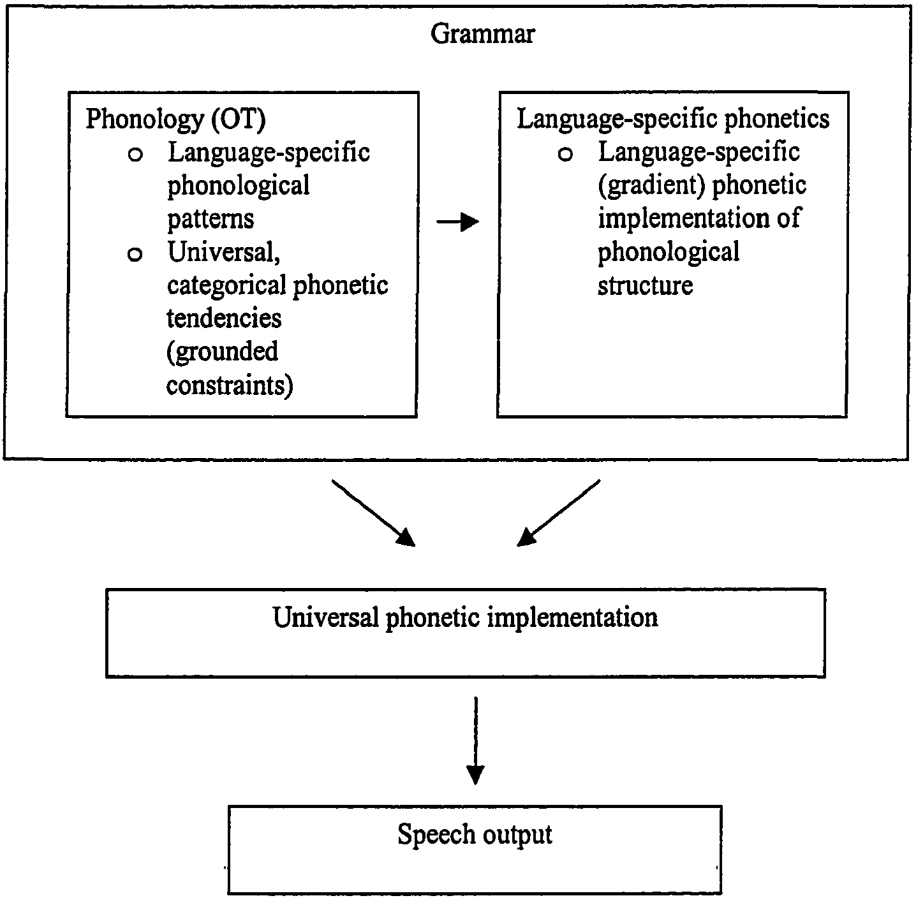

Figure 6.2 Components of speech production

In Figure 6.2, both phonology and language-specific phonetics fall within the realm of grammar. There are two possible paths between phonological structure and speech output. In one path, phonological structure is implemented via language-specific phonetics. Recall from View B of Analysis III that Lheidli-specific phonetic implementation made geminates unusually long. If this view is correct, then this is one case in which phonological structure (geminates) passes through language-specific phonetics, which ensures that geminates are associated with added duration in Lheidli.

In the other path, phonological structure bypasses language-specific phonetics and goes directly to universal phonetics. An example of this involves pitch patterns found with /stop - vowel/ sequences. As mentioned in the introduction (Chapter 1), voiceless and voiced stops have different effects on the pitch at the onset of the following vowel. Voiceless stops raise the pitch, such that there is a decrease in pitch coming out of them. The phonological sequence /pa/ therefore includes a decrease in pitch from /p/ to /a/. In contrast to this, voiced stops lower the pitch, such that there is a rise in pitch coming out of them. The sequence /ba/ therefore includes a rise in pitch from /b/ to /a/. These pitch patterns are part of the universal phonetic implementation of /stop-vowel/ sequences (Hyman, 1976), and apply to all phonological structures which include /stop-vowel/ sequences.

As for language-specific phonetic implementation, its source is sometimes phonological (as in the case of Lheidli geminates according to View B). Other times, it has no phonological source. An example of this is the language-specific use of voice onset time (VOT). The phoneme /g/ is implemented as a prevoiced stop in French, and as a voiceless unaspirated stop in Lheidli. This implementation is not motivated by the phonologies of the respective languages, it is simply a fact of language-specific phonetic implementation. The output of language-specific phonetic implementation also passes through universal phonetic implementation on its way to speech output, similarly to phonological structure.

6.3 General conclusion

The overall goal of this dissertation was twofold: (1) to explore the nature of Lheidli's intervocalic consonants, and (2) through this exploration, to enrich our understanding of the phonetics-phonology interface. These goals were achieved through a series of studies, contributing to the field of linguistics in the following ways.

First, the work presented here constitutes the first detailed phonetic work on Lheidli sounds, and on the fascinating properties of intervocalic consonants in Athapaskan languages. Therefore, simply from a phonetic perspective, this work has provided the field with new data on a language - and language family - which has been very little studied in the past. Findings from this work will increase what we know about phonetic universals.

Second, this work has increased our understanding of what factors contribute to rhythm in language. More specifically, I have shown that inherent segmental duration is an important correlate of rhythm, one that has not yet been considered in the literature. Furthermore, I have proposed that the correlates of rhythm considered so far in the literature do not all carry the same weight in terms of their effect on the rhythm. Under the Enhancement/Inhibition model, alternating stresses (in languages which exhibit this property) or syllables (in other languages) form the most important (primary) correlate of rhythm. Secondary correlates of rhythm serve to enhance or inhibit the salience of the primary correlate. In this dissertation, secondary correlates were presented as equally important in influencing the perception of rhythm. However, future work may show that more complex hierarchical structure exists among secondary correlates of rhythm as well as between secondary and primary correlates.

Third, this work has clarified the descriptive and formal definitions of *ambisyllabic* and *geminate*. As descriptive terms, *ambisyllabic* and *geminate* differ in the phenomena to which they refer. *Ambisyllabic* is used primarily when the focus is syllabification, to indicate that an intervocalic consonant belongs to both the preceding and the following syllable. *Geminate* is used primarily when the focus duration, to refer to long consonants where they contrast with short ones. Descriptively, intervocalic consonants in Lheidli were referred to as geminates when the focus was on their duration and as ambisyllabic when the focus was on their syllabification. In this dissertation, I argued that the best formal analysis of Lheidli intervocalic consonants is one in which they are considered non-contrastive moraic geminates. They are geminates because they are long, because they belong to both syllables, and because their duration is not a function of prosodic requirements. They are non-contrastive because they do not contrast with singletons. Finally, that they are moraic is evidence by their limited distribution (only in positions which license morae). This analysis of intervocalic consonants in Lheidli provides evidence for the existence of non-contrastive geminates in natural language.

Finally, through a thorough investigation of the phonetic and phonological properties of intervocalic consonants in Lheidli, this work has also contributed to our understanding of how phonetics and phonology interact. I have provided additional support for the recent view that language-specific phonetics exists, and must be encoded in the grammar. Furthermore, I have shown that rhythm need not be specified, either in the phonology or in the grammar. These findings contribute to our understanding of how phonetics and phonology are structured in the mind. It is through this understanding that it is possible to evaluate, revise, and improve current linguistic theory.

In addition to the theoretical contributions mentioned above, this work will provide the Lheidli community with the first written documentation of the phonological and phonetic details of their language. Furthermore, based on the material gathered for this dissertation my hope is to provide the community with a teaching phonology of their language, as well as a reference tool. This will contribute to their ongoing language maintenance and revitalization efforts.

In closing, I would like to outline the areas in which this research can be expanded. The first involves characterizing Lheidli sounds phonetically. I presented a brief overview of Lheidli's consonants and vowels in Chapter 2. However, a more detailed exploration of these sounds will no doubt provide the field with new interesting properties which have not yet been observed.

The second area which deserves further attention involves stress in Lheidli. Again, I provided the reader with an outline of the facts. However, more work is needed in order to ascertain conclusively whether Lheidli does indeed have stress, or whether it is better characterized as a pitch-accent language.

Third, the studies discussed in the preceding chapters need to be complemented with studies on longer words and utterances. This will allow us to differentiate between 'non-final' and 'initial' effects, for example.

Finally, in future research, I hope to investigate how morphology might interact with phonetics and phonology in Lheidli. Research on other Athapaskan languages indicates that morphology is directly involved with the distribution of sounds, as well as with stress placement and related phonological properties (McDonough, 1990, Hargus, to appear). The data used for the studies presented here consisted primarily of nouns, i.e. morphologically simple words. However, it would be interesting to replicate these studies using morphologically complex words as well as longer words (mentioned above), in order to gain a clearer picture of how various levels of the Lheidli language interact.

In short, this dissertation has opened up a whole realm of possibilities in terms of future research, which will no doubt keep me and my Lheidli consultants busy for years to come!

APPENDIX A WORD LIST USED FOR ALL STUDIES ON CONSONANT AND VOWEL DURATIONS

All words are written in the Lheidli practical orthography. There is a one-to-one correspondence between the letter(s) used in the practical orthography and the sound represented. Cases where the practical orthography is not transparent are listed in (1).

(1)

Practical Orthography	*IPA*
u	ʌ
oo	u
lh	ɬ
sh	ʃ
zh	ʒ
ch	tʃ
j	dʒ
y	j
gh	x
kh	ɣ
'	ʔ

In the following list of words, (2) indicates two recordings of the word were analyzed.

Lheidli	*English*	*Lheidli*	*English*
'acho (2)	quickly	nincha	they are big
'alhah (2)	that's right	noostel (2)	wolverine
'andit (2)	now	nubalh (2)	swing set
anggwul (2)	pine cone	nulgaih	he runs
'awhuz (2)	always	nulhlhoh	(yutus ~) jump rope
bagwut	his knee	nulhlhus	(potato) masher
booscho	big cat (cougar)	nus'al	I found it
budzi	his heart	nusdaih	I am dancing
bunda (2)	this morning	'oket	I bought

Lheidli	*English*	*Lheidli*	*English*
buzek (2)	his mouth	nusdzak (2)	I am light in weight
chantoo	rain water	nussool	I am small
chintoh (2)	forest, bush	nute	dreaming
chunih (2)	marten	nuwus (2)	soapberry
dada (2)	illness	oodzi (2)	his heart
dadzi (2)	loon	oozi (2)	his corpse
Dakelh (2)	Dakelh, Indian	salhwus	he tickled me
dalhnat (2)	he spit	sanun	Summer month
daskwun	stove poker	sbaiyaz	little lamb
dazsai	he died	schaikeh (2)	my grandchildren
dek'a	tobacco	shas'at	female grizzly bear
ditnik (2)	thunder	shascho	big bear
dlooncho (2)	packrat	shask'oh	grizzly tracks
dohgha	lichen	shasyaz (2)	little grizzly bear
dulk'un	it is red	sich'oh	myself
dune (2)	man	sida (2)	I live (sit)
duni (2)	moose	soocho	just right
dustl'us (2)	paper	stl'esja (2)	I quit
dutai (2)	it is thick	stsiyan	my grandfather
dut'ai (2)	bird	such'i (2)	he shot
dutleh (2)	it is soft	sugui (2)	dried
dzobal	ear lobe	suhch'i	you (2) shot
dzootcho	big coat	sulhwus (2)	he is tickling me
dzootyaz	small coat	suli	it became
dzulhcho	big mountain	sus'an	bear den
dzulhyaz	small mountain	susbilh (2)	bear snare
'et'en (2)	he worked	suscho	big bear
'ewa	that is why	tsati	big (old) beaver

Lheidli	*English*	*Lheidli*	*English*
gesnun	Spring salmon month	susyaz	little bear
gohkw'uz	rabbit kidneys	suzch'i (2)	he shot me
gohyaz	little rabbit	suzdlooh	caught in a net
gombilh (2)	rabbit snare	suzkeh (2)	my children
gwuzeh (2)	whiskey jack	syats'e	my daughter
hawus (2)	foam, beer suds	tada (2)	3 (locative)
ho'en	he saw	tagih (2)	3 (generic)
hoolah	it is not there	talukw (2)	salmon
hooloh	he is not here	tanjun (2)	you (2) will sing
hoonliz (2)	skunk	tejun (2)	he will sing
hoonyan	old woman	telhlhoh	he is jumping
huba (2)	for them	tescho	big knife
hujun	they sang	tesyaz	little knife
huwus	foam, beer	tl'asus	dress, pants
'ilhoh	1 (multiplicative)	tl'ughus (2)	snake
ilhtsul	blueberries	tsa'at (2)	female beaver
inchooh	rosebud	tsaken	beaver's house
'ink'ez (2)	and	tsalhtse (2)	cranberry
'inle (2)	it was	tsambilh	beaver snare
'int'en	you (1) are working	tsati	big (old) beaver
inyi	you (1) are eating	tsazo (2)	beaver castor
	(specified object)	tse'an	cave
'inyi	you (1) are eating	ts'eke (2)	woman
	(unspecified object)	tsek'et	muskrat
jenyo (2)	bull moose	ts'ekoo (2)	women
k'azus	shell bag	tset'ah (2)	Two Mile Mill
kegon (2)	shoes	tsets'ai (2)	plate
kesgwut	moccasins	tsetselh	axe

Lheidli	*English*	*Lheidli*	*English*
ketul	stockings	tsi'alh (2)	pillow
kezus	slippers	ts'icho	big boat
k'ochaz	crackling (fat)	tsigha	hair
koocho	big house	ts'ihna	beehive
kooyaz	little house	tsits'is	dandruff
k'usdla	sheets	ts'iyawh (2)	everything, everyone
kwuncho (2)	hell	ts'iyaz	little boat
kw'usul (2)	beads	ts'oozus	bra
lait'oh (2)	he is stupid	tsunts'alh	spoon
lak'et	palm	ts'uyi (2)	food
lhaneh	many (humans)	tsuzyaz	kindling
Lheidli	Lheidli	tubeh (2)	very
lhelhch'a	all different directions	tuzniz	midnight
lhiyaz	little dog	tuzoh (2)	he spits
lhombilh	fish net	'udun (2)	another (place)
lhuk'ui (2)	9 (generic)	'udzi	heart
liba	bread	'ughaz	shavings
libab	pope	'ughelh	he is scraping (off - hair)
ligok	rooster		
lilet	milk	ulhtsun (2)	it stinks
lili (2)	bed	usda	he is sitting
liyab	devil	'usloo	my mother
lizas	angel	usts'un	my bone
lubaz	boat	usyi (2)	I am eating
lubel	shovel	'ut'en (2)	he is working
lubot (2)	pot	utnai (2)	he is drinking
ludi (2)	tea	'utsoo	grandmother
lugli	key	'utsun	meat

Lheidli	*English*	*Lheidli*	*English*
lugliz (2)	church	'uts'un (2)	bone
lugloo (2)	nail	'utun (2)	freezer
luglos (2)	bell	'uyi	he is eating
luhoos	pitchfork	uyi (2)	he is eating
lujos	hoe	'uzus	bag
lumes	mass	wasi (2)	lynx
lusel	salt	whelhnoh	you swallowed
lusyet (2)	plate	whenghoh	near
lutab (2)	table	whenun (2)	hillside, slope
maitoo	berry juice	whenyah	she left
mandah	canvas	whudzih (2)	caribou
musdus (2)	cow	whunih	he is awake
musih	thank you	whusdli (2)	it happened
nai'ai	I found it	wuzdli (2)	I cared for him/her
naje	it healed	wutun (2)	it freezes
nak'et	eye socket	yak'uz	Heaven
nak'us	one eye	yalhlhoh (2)	he smeared it
naneh (2)	2 (human)	yalhtsul	raspberries
nanguz (2)	fox	yezih	elk
nawus (2)	soapberry	yu'alh	he is chewing it
ndek'a (2)	your tobacco	yulez	he is cooking it (by immersion)
ndulht'i (2)	that kind		
nduna (2)	this (human)	yulhlhoh (2)	he smeared it
ndunne	these (human)	yussul	snowflake
nedo (2)	Frenchman	yutl'oo	he is weaving it
neke (2)	our feet	yuzdlooh	he snared
nilhdza (2)	far away	yuzkuk (2)	he slapped him
nilhts'i	it is windy		

APPENDIX B WORD LIST USED FOR VOWEL QUALITY (TENSE/LAX) STUDY

Lheidli	*English*	*Lheidli*	*English*
andit (2)	now	nute	dreaming
budzi	his heart	'oket	I bought
buzek (2)	his mouth	oodzi (2)	his heart
chintoh (2)	forest, bush	oozi	his corpse
chunih (2)	marten	oozi'	his corpse
dadzi (2)	loon	schaikeh (2)	my grandchildren
Dakelh (2)	Dakelh, Indian	sich'oh	myself
dek'a	tobacco	sida (2)	I live (sit)
ditnik (2)	thunder	stl'esja (2)	I quit
dune (2)	man	stsiyan	my grandfather
duni (2)	moose	such'i (2)	he shot
dutleh (2)	it is soft	suhch'i	you (2) shot
'et'en (2)	he worked	suli	it became
'ewa	that is why	susbilh (2)	bear snare
gesnun	Spring salmon month	suzch'i	he shot me
gombilh (2)	rabbit snare	suzkeh (2)	my children
gwuzeh (2)	whiskey jack	syats'e	my daughter
hoonliz (2)	skunk	tagih (2)	3 (generic)
'ilhoh	1 (multiplicative)	tejun (2)	he will sing
ilhtsul	blueberries	telhlhoh	he is jumping
inchooh	rosebud	tescho	big knife
'ink'ez (2)	and	tess'a	I will cache
'inle (2)	it was	tesyaz	small knife
'int'en	you (1) are working	tsaken	beaver's house
inyi (2)	you (1) are eating	tsalhtse (2)	cranberry
jenyo (2)	bull moose	tsambilh	beaver snare
kegon (2)	shoes	tsati	big (old) beaver

Lheidli	*English*	*Lheidli*	*English*
kesgwut	moccasins	tse'an	cave
ketul	stockings	ts'eke (2)	woman
kezus	slippers	tsek'et	muskrat
lak'et	palm	ts'ekoo (2)	women
lhaneh	many (humans)	tset'ah (2)	Two Mile Mill
Lheidli	Lheidli	tsets'ai (2)	plate
lhelhch'a	all different directions	tsetselh (2)	axe
lhiyaz	little dog	tsi'alh (2)	pillow
lhombilh	fish net	ts'icho	big boat
libab	pope	tsigha	hair
ligok	rooster	ts'ihna	beehive
lilet	milk	tsits'is	dandruff
lili (2)	bed	ts'iyawh (2)	everything, everyone
liyab	devil	ts'iyaz	little boat
lizas	angel	ts'uyi (2)	food
lubel	shovel	tubeh (2)	very
ludi (2)	tea	tuzniz	midnight
lugli	key	'udzi	heart
lugliz (2)	church	'ughelh	he is scraping (off hair)
lumes	mass		
lusel	salt	usyi	I am eating
lusyet (2)	plate	'ut'en (2)	he is working
musih	thank you	uyi (2)	he is eating
naje	it healed	wasi (2)	lynx
nak'et	eye socket	whelhnoh	you swallowed
naneh (2)	3 (human)	whenghoh	near
ndek'a (2)	your tobacco	whenun (2)	hillside, slope
ndulht'i (2)	that kind	whenyah	she left

Lheidli	*English*	*Lheidli*	*English*
ndunne	these (human)	whudzih (2)	caribou
nedo (2)	Frenchman	whunih	he is awake
neke (2)	our feet	whusdli (2)	it happened
nilhdza (2)	far away	wuzdli (2)	I cared for him/her
nilhts'i	it is windy	yezih	elk
nincha	they are big	yulez	he is cooking it (by immersion)
noostel (2)	wolverine		

Appendix C Word list used for studies involving stress placement, and for the Metronome and Syllabification Intuitions studies

Lheidli	*English*	*Lheidli*	*English*
‘acho	quickly	nduna	this (human)
‘alhah	that’s right	nedo	Frenchman
‘andit	now	neke	our feet
‘anggwul	pine cone	nilhdza	far away
‘awhuz	always	nincha	they are big
‘et’en	he worked	noostel	wolverine
‘ewa	that is why	nubalh	swing set
‘ink’ez	and	nusdzak	I am light in weight
‘inle	it was	nuwus	soapberry
‘oket	I bought	oodzi	his heart
‘udun	another (place)	oozi	his corpse
‘ughaz	shavings	salhwus	he tickled me
‘ughelh	he is scraping (off - hair)	schaikeh	my grandchildren
		sich’oh	myself
‘usloo	my mother	sida (2)	I live (sit)
‘usts’un	my bone	stl’esja	I quit
‘utsun	meat	stsiyan	my grandfather
‘utun	freezer	such’i	he shot
bagwut	his knee	sugui	dried
bazek	his mouth	suhch’i	you (2) shot
bunda	this morning	sulhwus	he is tickling me
chintoh	forest, bush	suli	it became
chunih	marten	suzch’i	he shot me
dada	illness	suzkeh	my children
dadzi	loon	syats’e	my daughter
Dakelh	Dakelh, Indian	tada	3 (locative)

Lheidli	*English*	*Lheidli*	*English*
dalhnat	he spit	tagih	3 (generic)
dazsai	he died	talukw	salmon
dek'a	tobacco	tanjun	you (2) will sing
ditnik	thunder	tejun	he will sing
dlooncho	packrat	tl'ughus	snake
dune	man	ts'eke	woman
dustl'us	paper	ts'ekoo	women
dut'ai	bird	ts'iyawh	everything, everyone
dutai	it is thick	ts'uyi	food
dutleh	it is soft	tsa'at	female beaver
gombilh	rabbit snare	tsalhtse	cranberry
gwuzeh	whiskey jack	tsetselh	axe
hawus	foam, beer	tsits'is	dandruff
ho'en	he saw	tubeh	very
hoonliz	skunk	tuzoh	he spits
hoonyan	old woman	ulhtsun	it stinks
huba	for them	usyi	I am eating
hujun	they sang	ut'en	he is working
ilhtsul	blueberries	utnai	he is drinking
inyi	you are eating	uyi	he is eating
jenyo	bull moose	wasi	lynx
kegon	shoes	whenun	hillside, slope
kesgwut	moccasins	whudzih	caribou
kw'usul	beads	whusdli	it happened
lait'oh	he is stupid	wutun	it freezes
Lheidli	Lheidli	wuzdli	I cared for him/her
lhelhch'a	all different directions	yalhlhoh	he smeared it
lhuk'ui	9 (generic)	yalhtsul	raspberries

Lheidli	*English*	*Lheidli*	*English*
musdus	cow	yezih	elk
naneh	2 (human)	yu'alh	he is chewing it
nanguz	fox	yulez	he is cooking it (by immersion)
nus'al	I found it		
nuwus	soapberry	yulhlhoh	he smeared it
ndek'a	your tobacco	yutl'oo	he is weaving it
ndulht'i	that kind	yuzkuk	he slapped him

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