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Publication Date

1994

DURATION IN MORAIC THEORY

by

Kathleen Anne Hubbard

B.A. (University of Virginia) 1987
M.A. (University of California at Berkeley) 1990

A dissertation submitted in partial satisfaction of the

requirements for the degree of

Doctor of Philosophy

in

Linguistics

in the

GRADUATE DIVISION

of the

UNIVERSITY of CALIFORNIA at BERKELEY

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Larry M. Hyman 28 Nov 94
Chair Date

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Date

28 Nov 94
Date

University of California at Berkeley

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DURATION IN MORAIC THEORY

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ABSTRACT

Duration in Moraic Theory

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Kathleen Anne Hubbard

Doctor of Philosophy in Linguistics

University of California at Berkeley

Professor Larry M. Hyman, Chair

This dissertation explores the relationship of abstract phonological representations to surface speech output, specifically the mapping of prosodic structure to phonetic timing. Comparison of theoretical models of linguistic structure with acoustic measurements of duration in nine Bantu languages shows that, at least in languages of a certain type, there is a systematic reflection of moraic structure in surface timing.

First, it is demonstrated that word duration in these languages is largely determined by mora count. On the basis of this correspondence, details of moraic structure are examined phonetically, with special attention to compensatory lengthening (CL) from prenasalization, a common phenomenon in Bantu languages.

Differences in the output of CL in canonical CL languages (CiYao, Kikerewe, and Luganda) are ascribed entirely to phonetic implementation. CL in Runyambo, however, is shown to differ from the normal case both phonetically and phonologically, in giving to a vowel only half of the mora originally attached to a nasal: this difference is visible both phonetically (in duration) and phonologically (with respect to tone assignment). It is argued that languages with no CL have no bimoraic syllables at all; while this is the expected representation for KiNdendeule and KiLega, which have no surface long vowels, it is an interesting result for CiTonga and Chichewa, whose apparent long vowels turn out to be bisyllabic, not just bimoraic. Finally, the three types of long vowel in Bukusu are represented as bimoraic-monosyllabic, bimoraic-bisyllabic, and bisyllabic separated by a ghost consonant, respectively.

The implications of these results for a theory of phonological and phonetic timing are considered. Since moraic structure survives through phonetic implementation in these languages, with varying degrees of transparency, it must be the case that segments are adjusted to compensate for inherent differences in duration. Closer examination of data from Luganda and Runyambo shows that the mechanisms for segmental adjustment may differ between languages, the same factors may be ranked differently in different languages, compensation takes place both in vowels and in consonants, and the effects of compensation extend across a domain larger than the syllable. It is argued that a successful algorithm for mapping underlying phonological structure to surface phonetic implementation must gives highest priority to assigning a minimum target duration to moraic elements (or other prosodic units, in languages with other typological characteristics), and only then takes into account other factors such as featural content of segments and phrasal boundaries.

Larry M Hyman 28 Nov 94

Chair Date

ACKNOWLEDGEMENTS

Far too many people have contributed to the efforts that resulted in this dissertation for me to thank them all individually. But certain of my advisors and friends deserve my special gratitude, and I hereby attempt to give them their due.

It is to Larry Hyman that I owe the greatest debt; he somehow managed to draw me away from historical Indo-European studies and a potential leaning toward syntax with his very first Introductory Morphology course, in which he set the class to work on Luganda data. Over the next few years he convinced me that the puzzles of phonological theory and the delights of Bantu languages were worth my wholehearted attention. His boundless energy, infinite mental storehouse of data, and sharp attention to the holes in a hypothesis have inspired and challenged me; his open-minded perspective and the obvious joy he finds in linguistics have made me a better and happier scholar.

Sharon Inkelas also deserves special thanks, for helping me see where my energies belonged, reassuring me that the job could be done, and suggesting new avenues for my thinking. Ian Maddieson was largely responsible for my choice of dissertation topic, and his patient tutoring in the lab is what allowed me to pursue it. Steven Greenberg made the Phonology Lab at Berkeley what it is today and helped me use it well; John Ohala trained me in phonetics before I was let loose in the lab, and continued to offer support and advice as I made my way through my projects. Sam Mchombo was my first Swahili teacher, the other reason I switched allegiance to Bantu, and a wonderful consultant. Vince Sarich has been a patient and enthusiastic outside reader. When I ventured away from Berkeley to pursue my work, I was given warm welcome and helpful advice by Robert Botne, Robert Port, and Paul Newman at the University of Indiana, David Odden and Mary Beckman at Ohio State University, and Pat Keating and Peter Ladefoged at UCLA. Of course, any shortcomings of this work are to be held against me and not any of my advisors.

This study was made possible in a very real sense by the language consultants I worked with during the last three years: first among them is Josephat Rugemalira, who spent many hours showing me the details of his language and making countless tape recordings for phonetic analysis; Josephat was a valued teacher and friend during his years here. I thank also Fred Semwogerere, Francis Katamba, Leah Rugemalira, Adolf Kafanabo, Deo Ngonyani, Kisanga Gray, Janine Gray, Armindo Ngunga, Al Mtenje, Sam Mchombo, Nasiombe Mutonyi, Deo Tungaraza and Sibanyana Mudenda for their patience and energy.

I am also grateful to the foundations and programs that provided funding for this work: the Woodrow Wilson National Fellowship Foundation for a Mellon Fellowship in the Humanities, the Foreign Language and Area Studies program, and the U.C. Berkeley Dissertation Year Fellowship program. Travel and data collection in 1993 were funded by a Provost's Research Grant, and research on Luganda in 1992 and 1993 was supported in part by Larry Hyman's National Science Foundation grant BNS91-09234. I am especially grateful to the Mellon Fellowships office, not only for three years of support but also for sponsoring two conferences that brought me into contact with scholars in other fields and helped me define what I meant by getting a Ph.D.

I would not have survived graduate school without the love and support of my friends here; those deserving special thanks include Laurel Sutton (my guardian angel), Sondra Reinman, Michael Meacham, and Cheryl Zoll, with whom at one time or another I've shared syntax assignments, orals anxieties, Christmas dinners, fine wine, early-morning basketball, late-night lab marathons, and many hours of laughter and conversation. To my more distant linguist friends -- especially Nasiombe Mutonyi, Frederick Parkinson, Sharon Rose, and Alex Schott -- I say thanks for the long hot summer in Columbus, and all the sustaining e-mail over the last two years. Credit for electronically buoying me up through the end of graduate school also belongs to Erich Schwarz and my other widely-scattered Internet friends. My aunt, Carolyn Jenkins, kindly provided a place for me to write when I needed it. Finally, thanks go to Howard Lim, without whom I would never have made it to Berkeley or beyond.

I dedicate this work to my parents, who believed from the time I could read that learning was my calling. They were right.

TABLE OF CONTENTS

CHAPTER ONE: THE PHONOLOGICAL ROLE OF THE MORA

This study explores the relationship between the prosodic feature of quantity and the phonetic parameter of duration: I show first that it is possible to establish a meaningful correlation between abstract timing structures and surface durational output, then I identify the mechanisms by which overall timing templates are maintained, and finally I propose a theory of mapping from underlying structure to phonetic realization. To do this, I focus on the mora as a unit of timing in non-stress languages; my data come primarily from Bantu languages of subsaharan Africa, many of which are well-known for their phonological use of the mora.

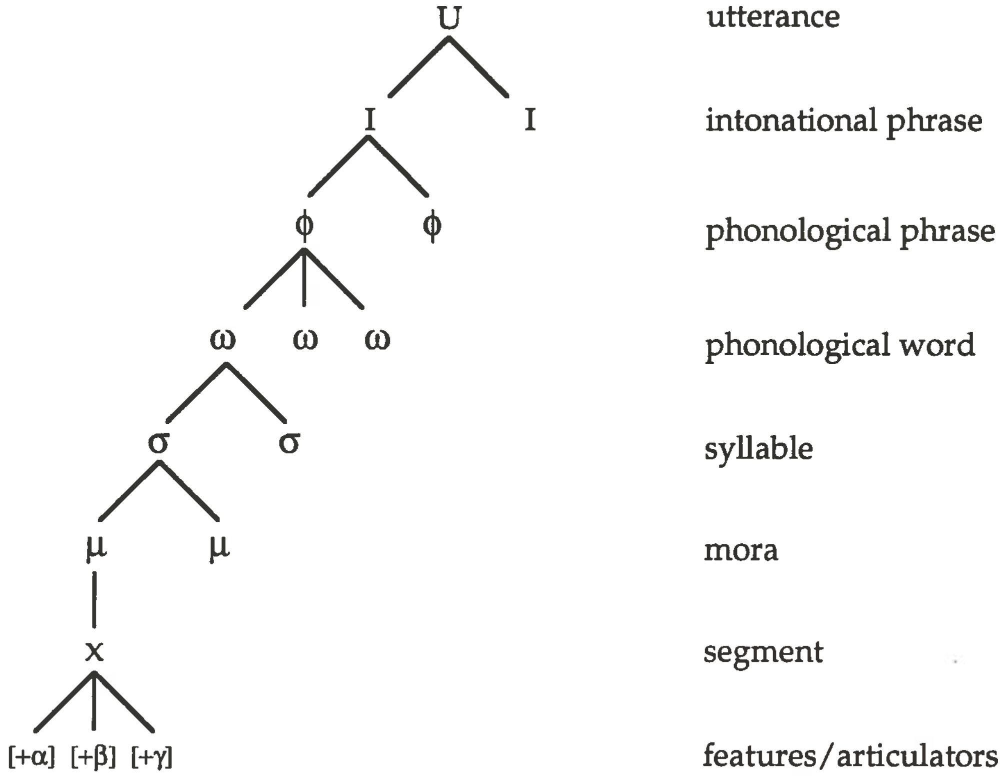
In Chapter 1, I lay out the theoretical underpinnings of the present study and review the phonological status of the unit "mora". §1.1 locates this work in the realm of contemporary phonological theory, and §1.2 specifies the scope and organization of the dissertation. In §1.3 I discuss the notions *prosody* and *quantity*. In §1.4 I examine the phonological unit *syllable*, and move on to the *mora* in §1.5. This section includes phonological evidence for the mora, motivations for timing-tier theory, questions about details of moraic representation (e.g. onset placement, moras multiply linked to segments, trimoraic syllables), and diachronic evidence for the mora. Finally, in §1.6 I discuss the relationship between moras and timing and propose a means of investigating this relationship.

1.1 Background and theoretical assumptions

The theoretical framework assumed in this work is a non-linear model in the generative tradition: I look to structural representations to do much of the work of accounting for phonological patterns and alternations, and I assume that these structures are characterized by multiple tiers of representation linked in principled ways (Goldsmith 1976, etc.) While the details of feature geometry are not important for the present study, I assume a representation along the lines of Clements (1985) in which the root node is the uppermost level of organization for segments, possibly also incorporating the aperture model of Steriade (1993) to represent closure and release of segments.

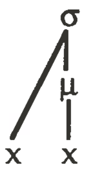
In this study I address levels of phonological organization higher than the segment, namely the mora and the syllable; I assume the principles of prosodic phonology (Selkirk 1984, etc.) for the means by which phonological domains are formed and related to one another. The ultimate insight of prosodic phonology is that it captures the hierarchical nature of speech (as in (1)): features (or gestures) make up segments, which make up moras, which are gathered into syllables; syllables are grouped into stress feet, feet into phonological words, words into phonological phrases, then intonational phrases, then the utterance.

(1)



According to prosodic domain theory (Selkirk 1984, Hayes 1984, Nespor and Vogel 1986), which is concerned with the levels from the phonological word up, prosodic constituents are exhaustively parsed — that is, every element at level A is dominated by or contained in a domain of level B — and the levels are strictly layered, such that a higher level domain may not be contained in a lower domain. Below the level of the phonological word, there is disagreement as to whether parsing is exhaustive. I follow Hayes (1989) in assuming that the syllable is a prosodic unit which both dominates moras and attaches to segments, as in (2).

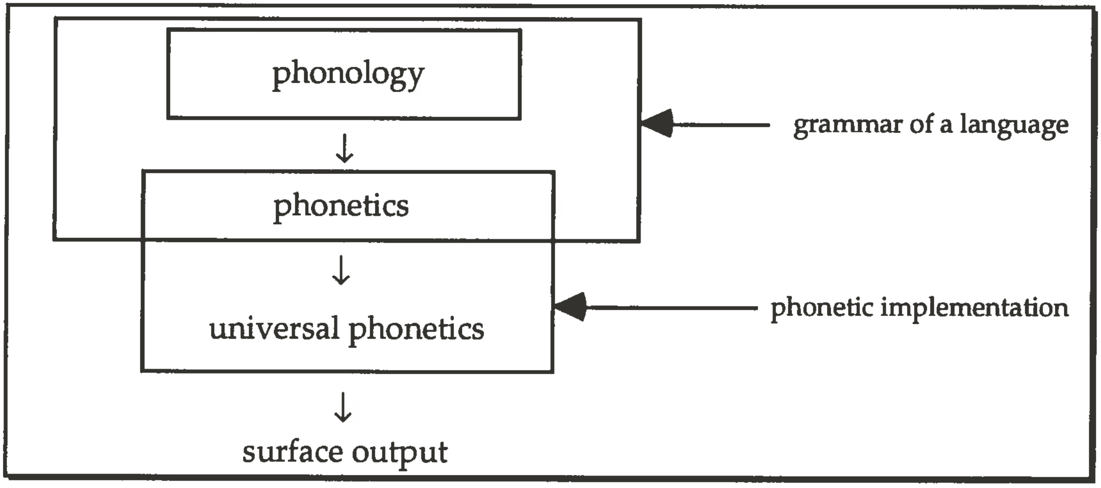
(2)



I do not address the issue of what happens below the level of the segment; it may be more accurate to think of features not as discrete elements but as overlapping gestures, as in the model of Articulatory Phonology (Browman and Goldstein 1986), when we look at how a continuous speech stream is analyzed into units.

This work concentrates on another aspect of the place of phonology in a grammar, namely the phonetic implementation of phonological structures. I assume, following Cohn (1990), that there is a phonetic rule component in the grammar of each language, which receives the output of the phonological derivation and subjects it to language-particular phonetic rules, then passes that output along to the set of universal phonetic constraints (this is represented in (3)). This language-specific phonetic component, then, is responsible for phenomena that are non-mechanical but also not phonologically contrastive — e.g. the dramatic lengthening of vowels before voiced stops in English.

(3)



It is in the language-specific phonetic component that I locate the implementation of phonological timing: I show that in languages where subsyllabic timing is phonologically relevant — i.e. languages with distinctive quantity — the phonological assignment of timing status is preserved through the phonetic implementation. At the same time, when multi-tiered phonological structures are linearized and non-weighted segments are integrated into a phonetic string along with weight-bearing segments, and when this product is subjected to the universal physical constraints on speech production, durational adjustments are made that render the mapping between abstract timing structure and surface timing output rather complex. The central claim of this work is that that mapping is systematic and that it can be illuminated in a useful way by comparing phonological patterns with phonetic data.

1.2 Goals and organization of the dissertation

This study develops a theory of phonological and phonetic timing based on acoustic evidence for moraic structures in a number of Bantu languages. The essential questions are phonological ones: (1) What counts as a mora? (2) Do observed phonological differences in the treatment of quantity correspond to measurable phonetic behaviors, or are they strictly abstract? (3) How do weight-bearing elements become integrated with weightless ones on the way from underlying structure to the surface? In this chapter, I review the phonological background to moraic theory, and show why the mora is an important element in contemporary models of phonology. In Chapter 2, I turn to the phonetic literature to review the phonetics of duration as a linguistic element, both as the distinctive feature of quantity and as a lower-level phonetic attribute. Here I detail my phonetic methodology, showing how it avoids some of the pitfalls inherent in the study of duration.

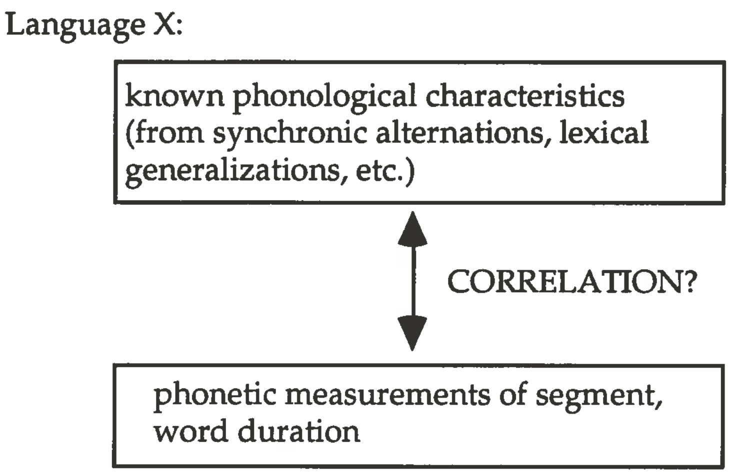
In Chapter 3, I report my experimental data. Comparing phonetic measurements of segment duration with known phonological structures, I show that (1) the mora is indeed a phonetic timing unit in the Bantu languages in which it is phonologically operative, (2) differences between languages in phonological patterns such as compensatory lengthening, tone assignment, and the lexical status of length are visible in surface timing as well, and (3) phonetic duration is best predicted by a model that first assigns minimum duration to moraic elements, and then adjusts segment durations to account for feature specifications and other factors (which are ranked differently on a language-specific basis).

The data come from the following nine languages:

language	*where spoken*	*Guthrie classif.*	*# of subjects*	*vowel length*	*consonant quantity*	*vowel hiatus*
Kindendeule	Tanzania	P.1X	1	no	no	limited
KiLega	Zaire	D.25	2	no	no	no
CiTonga	Zambia	M.64	1	derived	no	yes
Chichewa	Malawi	N.31	2	derived	no	yes
CiYao	Mozambique	P.21	1	yes	no	no
Luganda	Uganda	J.15	2	yes	yes	no
Kikerewe	Tanzania	J.24	1	yes	no	no
Runyambo	Tanzania	J.21	3	yes	no	no
Bukusu	Kenya	J.31c	1	yes	no	no

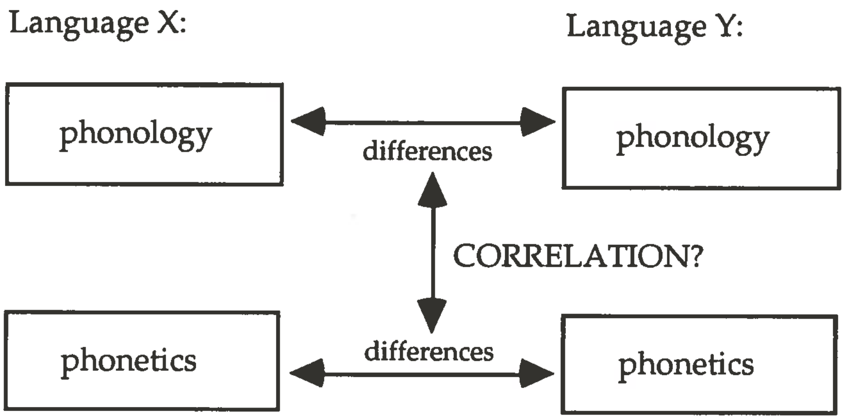
This selection of languages provides contrasts on particular issues of phonological importance — such as presence vs. absence of lexical length contrasts, differing tonal patterns, and various compensatory lengthening behaviors — which demonstrate a range of phonology-phonetics links across languages. To explore these links, I make two types of comparison. Within a language, I look to see whether known phonological structures correspond to phonetic output, and if so how:

(4)



In addition, I look across languages to see if phonological differences between them correspond to differences in their phonetic timing as well.

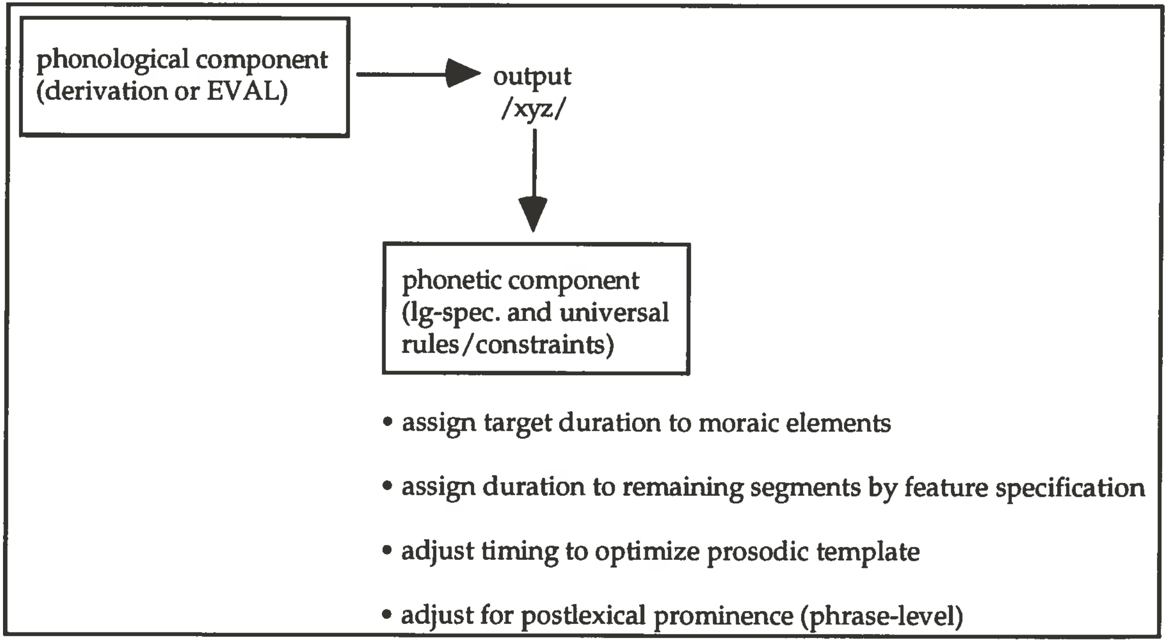
(5)



The experimental data reveal that there are indeed important correlations between phonological structure and phonetic timing. I show that (i) languages with vowel quantity distinctions make use of the mora as a phonetic as well as a phonological timing unit; (ii) compensatory lengthening, the phenomenon in which one segment lengthens in response to the shortening or deletion of a neighboring segment, can vary between languages in both its structural and surface behaviors, *or* it can have the same phonological representation in two languages but different phonetic outcomes; (iii) languages without length contrasts do not have compensatory lengthening; and (iv) in languages that maintain a moraic timing constant, segmental compensation to achieve this constant occurs both in vowels and in consonants, and occurs across syllable boundaries.

These results suggest a general theory of phonological and phonetic timing, which I sketch in Chapter 4. The central claim here is that speech timing depends more heavily on prosodic than on segmental features, as schematized in (6).

(6)



That is, a successful algorithm for projecting phonological timing structure to surface output gives precedence to prosodic targets (in the case of many Bantu languages and Japanese, the mora; in other languages such as Italian, the syllable; in others such as English, the stress foot, and so on) — while segmental specifications, phrasal characteristics, and other factors are weighted less heavily in the mapping process. This departs from earlier duration algorithms (e.g. Klatt 1979) in giving highest priority to a prosodic unit, and less to inherent segmental or coarticulatory effects.

1.3 Prosody

Prosodic aspects of language present some of the most complex and most intriguing puzzles for the enterprise of linguistic analysis. Like other phonologically distinctive elements, prosodic features such as tone, stress, and quantity inhabit the boundary between rule-governed and mechanical behavior: their character is determined by physical constraints, but their use and their structural roles are systematized in a way that demands their inclusion in any theory of grammar of the sort pursued in modern linguistics. The especially interesting aspect of prosodic elements is their role in gathering up features and segments and integrating them into higher order units. For the key question of linguistic science — what constitutes knowledge of a language, or knowledge of Language — this aspect of phonological processing is crucial: how does a continuous speech stream get chunked into meaningful elements that the human cognitive system can interpret? Prosodic features clearly play a central role in this process.

1.3.1 Quantity

In this work I define prosodic features as quantity, tone, and stress (those identified by Lehiste (1970) as the suprasegmental features); the phonetic correlates of these are duration, pitch, and a complex of duration/pitch/ intensity. Not considered under this rubric are phenomena such as vowel harmony, pharyngealization, nasalization, etc.: these have to do with what I refer to as "segmental" features. While segmental features can indeed float and spread and interact with prosodic domains (and thus the term "suprasegmental" often applies to them too), they differ from prosodic features in that they may be present or absent in a given speech stream, while prosodic features are elements that are always present in the speech signal.[1] Every stream of speech is uttered at some pitch, some degree of intensity or loudness, and has some durational span. This is what makes prosodic features more difficult to investigate than segmental features; while these features are present in all speech, they also get used as linguistically distinctive elements. Moreover, these same parameters can be varied to express non-phonological information such as syntactic and pragmatic boundaries, semantic disambiguation or contrast, emphasis, surprise, and emotional affect.[2] So although duration, pitch, and intensity are relatively easy to measure phonetically, separating out which portion of each of these elements is linguistically employed is a distinct challenge. For this reason it is crucial to bring a sophisticated understanding of the phonological patterns of a given language to the phonetic investigation of prosodic features.

So what exactly is quantity? The term is used to refer both to light/heavy distinctions between syllables, and long/short distinctions between vowels and

---

[1] While stress is not present in every utterance, the phonetic features that constitute stress are indeed present in all speech signals (with the exception of certain utterances in the highly anomalous language Bella Coola, which has words consisting only of voiceless consonants (Bagemihl 1991) -- these of course lack pitch).

[2] The segmental feature of glottalization may also be used to mark non-phonological information, e.g. morphological categories such as the imperative in Lahu (Matisoff 1973) and the negative in Dagbani (Hyman 1988). But again, glottalization is not always present in the speech stream, so I would still characterize it differently from purely prosodic features. That glottalization is able to function in this way at all suggests that a crucial distinction lies between laryngeal and supra-laryngeal gestures (Hyman 1988). I will not treat this further here.

consonants. These two aspects of quantity are not always linked (see e.g. Hayes 1989): weight is a characteristic of many stress languages, in that heavy syllables typically attract stress, but not all stress languages also have segmental length distinctions. At the same time, many languages that lack stress — and thus need not be represented with the phonological structure used to capture stress assignment, i.e. metrical grids or trees or feet — do have long/short segment contrasts. Since both length and weight are successfully represented with moraic and syllabic representations of the sort used here, it is sometimes forgotten that a language may possess only one or the other of the two features. But it is an advantage of the moraic model that it handles these phenomena, which *are* often linked, in the same way. The point to remember is that while all languages may be said to have syllables and moras, not all languages need metrical structure as well.

Since stress languages have a further degree of phonological complexity, and because stress is far more difficult to measure phonetically[3], I direct my attention in this study to non-stress languages of the type found in the Bantu family.[4] The results I show here for quantity languages are a step toward elucidating the phonology-phonetics relationship in languages with other

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[3] The event perceived as "stress" does not correspond to any single acoustic property (Ladefoged 1958); generally it involves one or more of the prosodic features discussed above — pitch, duration, intensity — but a stressed syllable may lack one or more of these. The more reliable correlates of stress are found in production, by tracking muscular activity, air pressure, etc. (Stetson 1951, Ladefoged 1958). Since the measurement tools available for this study were acoustic, this was not possible.

[4] Many Bantu languages are said to have phrase-penultimate stress; however this is not the primary prosodic feature of most Bantu languages -- all of which are tonal except for Swahili (a truly word-penultimate stress language) and some of its relatives. The lengthening of penultimate syllables found in many Southern Bantu languages is also present in less dramatic form in languages such as Runyambo, so I would say "penultimate prominence" is a postlexical, intonational prosodic feature typical of the Bantu family. In any case, the point here is that the prosodic systems of the languages examined in this study are fundamentally different from those of English or Russian -- stress is not the primary prosodic feature in any of them.

typological characteristics, which will eventually improve our understanding of the length~weight connection.

In languages where quantity primarily refers to length, then, we can identify quantity as a phonological feature of segments, a feature that is subject to synchronic alternation at many levels of construction — syllable, morpheme, word, phonological phrase, etc. Because these languages distinguish lexically between long vs. short vowels and/or single vs. geminate consonants, and because they often possess synchronic processes of quantity alternation, compensatory lengthening, and morphological exploitation of quantity distinctions, we know that timing of speech sounds in these languages must be governed by phonological rules. But it is also clear that, even if quantity is primarily a feature of segments, its realization in phonetic timing cannot be accounted for strictly segmentally — timing is defined over units larger than the segment, and generally smaller than the word: as a starting point, we can look at the most obvious of these elements, the syllable.

1.4 Organization of sounds: the syllable

The syllable in early linguistic theory was considered either as a phonetic phenomenon (involving "chest pulses" or peaks of energy, e.g. Stetson 1951) or as a structural element of immediate constituent analysis (Harris 1951, Haugen 1956). The intuition reflected in these descriptions is that the speech stream is chunked into units roughly defined by peaks and valleys of alternating high and low sonority. This unit is indeed an easily accessible notion; most speakers of any language have strong intuitions about how many syllables are in an utterance, even if they cannot clearly identify the syllable boundaries (Trager and Bloch 1941, Brosnahan and Malmberg 1970). And in word recall tasks, speakers can often remember the syllable structure of the item they are trying to access when they cannot remember anything else about it (Fudge 1969).

Phonological evidence for the importance of the syllable is of two types: "static" or distributional facts, and "processual" phenomena (rules and alternations that make reference to the syllable). Among the static features of speech is the cross-linguistically preferred status of alternating consonants and vowels (statistics from Bell and Hooper 1978): some 50% of the world's languages prohibit VV hiatus, up to 15% disallow CC sequences, and *no* languages *require* VV or CC. And it is not simply the alternation of C's and V's that is preferred; it is the ordered combination CV (rather than VC) that is universally privileged. Syllables must begin with a C in 20-40% of the world's languages, must end with a V in 10-25%, and there are no languages possessing *only* V-initial syllables. If a language has syllables that end in consonants, it also has syllables that end in vowels; no language requires syllable-final consonants, and in languages that have them, it is often the case that fewer of the consonants in the language can close a syllable than can begin a syllable. In languages that have consonant clusters, they are far more likely to be permitted syllable-initially (50% of the world's languages) than syllable-finally (25%) — that is, CCV syllabification is universally preferred to VCC, a phenomenon often referred to as "onset maximization". So two distributional features of syllables recur overwhelmingly often across languages: (1) CV is the universally preferred shape for a syllable, and further structural complexity is constrained in regular ways; (2) there are strong asymmetries between syllable-initial and syllable-final position. These observations are summarized in (7).

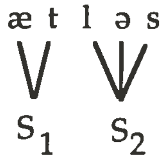
(7)	CV	present in all lgs, obligatory in many, no restrictions on C
	VC	present in some lgs, not obligatory in any, C restricted in some
	VV	not obligatory in any lg, prohibited in many
	CC	not obligatory in any lg, prohibited in many, more likely in onset

The syllable is also important in phonological rules and alternations (Hooper 1972, Vennemann 1972, 1974): some rules care about where in the syllable a segment is located (e.g. Spanish nasal assimilation, German devoicing); in general, "weakening" rules commonly target syllable-final consonants, and "strengthening" rules target syllable-initial consonants. The syllable is often the domain for featural phenomena, such as vowel nasalization (Hooper 1977), pharyngealization (Lehn 1963, Hoberman 1988), etc. Finally, rhythmic structures in stress and accent systems are typically defined on syllables.

1.4.1 The non-linear syllable

So it has long been recognized that there is something special about the syllable, something beyond what is represented in SPE phonology by the use of segments plus boundary markers inserted into the linear string. In an interesting observation about Mazateco syllables, Pike and Pike (1947) say that "the structure of these syllables does not consist of a series of sounds equally related, but is rather like an overlapping series of layers of bricks" (p. 78) — meaning that the syllable is more than a linear sequence of elements; there is some superstructure overlaying the segments. This is an early hint at the structure proposed by Kahn (1976), in which the syllable is an element represented on a different tier from segments. Kahn shows that many phonological phenomena in English can be framed much more simply in terms of syllables than segments: the distribution of /t/ allophones (aspirated, glottalized, flapped), epenthesis and deletion of /r/, stress placement, and phonotactic constraints (among others) yield much more easily to a generative analysis if the syllable is admitted into phonological representation as a domain that parcels segments into higher units, as proposed by Kahn in (8).

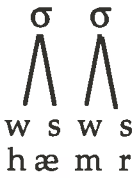
(8) Kahn 1976



Of major concern in Kahn's work is the question of how syllabification is assigned: by what process, at what point(s) in the phonological component of the grammar, is syllable affiliation determined? Can it be altered by rule? Can a segment belong to more than one syllable at a time (ambisyllabicity)?

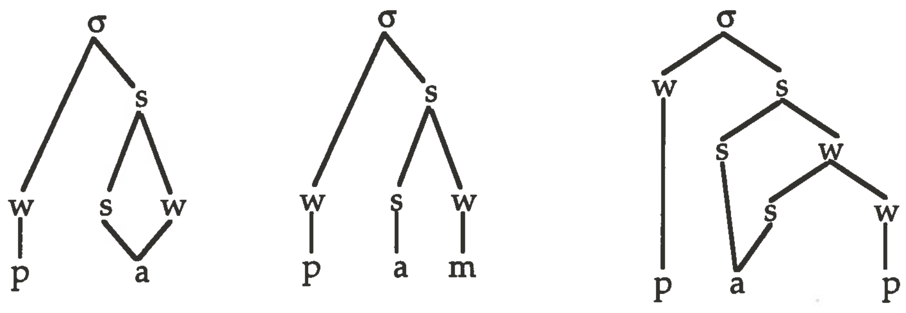
Another important insight about prosodic structure is that the internal structure of the syllable itself is important. Kiparsky (1979) extends the idea of strong/weak alternation (used of syllables in metrical structure by Liberman and Prince 1977) to the subsyllabic level, as in (9).

(9) 'hammer'



This proposal, however, ends up representing a long vowel in two different ways, depending on whether anything follows it within the syllable (Clements and Keyser 1983):

(10) a. b. c.



[pa:] [pam] [pa:p]

The long vowel in (10a) is dominated by SW, while the long vowel in (10c), because of the way postnuclear consonants are represented in (10b), is dominated by SS. Clements and Keyser (1983) point out that since there is no known contrast between long vowels in these environments, it is desirable instead to have a uniform representation of light and heavy syllables.

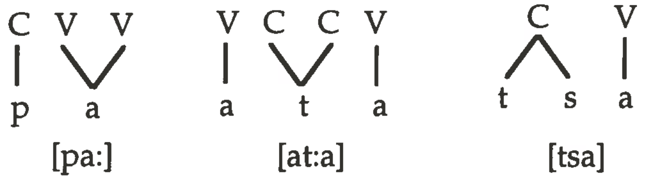
1.4.2 The timing tier

The timing-tier model of Clements and Keyser (1983) develops the notion that syllable structure must be represented non-linearly, but avoids the problems of a hierarchical tree structure, and captures the fact that prosodic and segmental structure are often independent of each other. In this representation, syllables are built on the timing units C and V (which define syllable peaks and margins, roughly doing the work of the feature [syllabic]).

(11)

These C's and V's are an extension of McCarthy's (1981, 1982) prosodic templates to syllabic phonology; since they directly encode syllabicity on the timing tier, there is no need to specify [consonantal] or [syllabic] in the segmental feature matrix. One C or V timing unit is assigned to each segment, representing the fact that either the segmental melody or the timing tier may be separately affected by phonological rules. Thus long vowels and geminate consonants are represented as single melodic elements linked to multiple timing slots, while contour segments such as affricates and prenasalized stops are represented as multiple melodic elements associated to a single timing unit (a natural extension of autosegmental tonology).

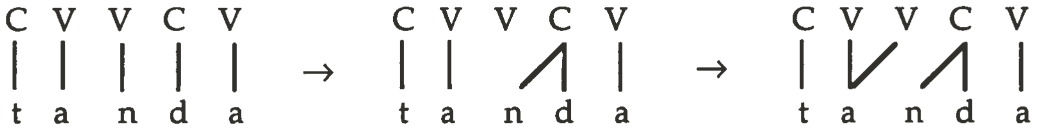
(12)



The C and V timing units are never defined specifically in terms of phonetic duration; the phonological role they represent is that long segments involve a single segmental feature matrix linked to multiple timing units, and phonological processes can affect either just the segmental or just the CV tier. Thus the formulation of Luganda compensatory lengthening in Clements (1986) involves reassociation of a segment from its own V unit to a multiple link with the next C, and spreading of the preceding vowel to take up the vacated timing slot.

Example (13) shows this compensatory lengthening process in Runyambo in terms of timing-tier representation.[5]

(13) CV theory: /tanda/ → [taanda]



underlying representation prenasalization linking convention

Clements emphasizes that this conception of compensatory lengthening as maintenance of syllable timing is phonological, not phonetic. It is of course related to phonetic duration, and makes predictions about relative duration: unless there are other overriding factors, a multiply-linked segment should be longer than a singly-linked segment. But Clements cautions that since the mapping between the discrete phonological timing units used here and the nondiscrete relations of phonetic duration is as yet poorly understood, the CV model should not be seen as one that directly encodes durations in milliseconds. This disclaimer about the phonetic predictions made by duration-based

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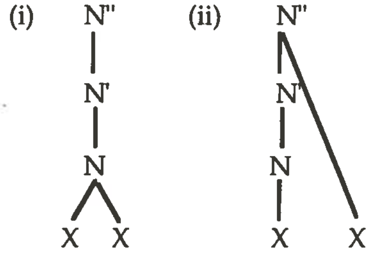
[5] In related X-tier theory (Levin 1985), the syllabic status of timing elements is represented not by the designations C and V, but rather by their position within an elaborated model of the syllable that incorporates the notion "head". Heavy syllables with long vowels are represented as in (i), heavy syllables with coda consonants as in (ii).



The differences between X theory and CV theory are not crucial to this study and will not be discussed further.

phonological representations persists into later versions of timing-tier theory as well.

1.5 The mora: phonological evidence

While timing-tier theory represents an improvement over earlier models, it fails to indicate that phonological timing actually revolves around weight-bearing elements. Weight-tier theory, developed by Hyman (1984, 1985), accounts for the fact that weight is contributed by syllable nuclei, and sometimes consonants in the rhyme, but never onset consonants. This model focuses on moras as the units relevant to syllable weight, vowel length, tone assignment, etc.; it is further developed by McCarthy and Prince (1986), Zec (1988), and Hayes (1989). The failing of CV representation is that it must stipulate some very general prosodic facts that can be captured more straightforwardly in moraic theory: e.g. onsets do not contribute to syllable weight, and segment deletion only triggers compensatory lengthening if it occurs in the rhyme (Steriade 1982, Hayes 1989). Instead of mediating syllabic structure and segmental content through a tier that accords one timing unit to each segment, moraic theory assumes that timing revolves more around the bearers of weight, stress, and tone.

It was recognized long ago (Trubetzkoy 1969, Jakobson 1971) that the abstract property of syllable weight suggested that a subconstituent "mora" was relevant to phonological description: a heavy syllable was said to be associated with two moras, a light syllable with one. The term "mora" was also used to designate the roughly constant timing unit reported in Japanese (Bloch 1950, etc.); note that the relationship between weight and timing is at issue because of typological differences between languages (see §1.3.1). The weight-length connection had been explicit since at least Jakobson (1971), who observed that languages with a syllable weight distinction often have a vowel length contrast as well. But Bloch's use of "mora" points out that the two do not necessarily co-occur; Japanese has distinctive length but no light-heavy syllable contrast. Hayes (1989) mentions that there are also languages which have weight but not length. Most of the Bantu languages investigated here represent the Japanese situation, i.e. length is distinctive but weight is not.

For example, Bantu tone assignment rules do not care which syllable their target mora belongs to; they are not looking for a heavy syllable. Indeed, tone is never attracted specifically to bimoraic syllables in any of the languages discussed here. Likewise, prosodically sensitive morphological alternations in these languages care how many total moras are in their domain, not how many syllables those moras are distributed into. In short, making reference to moras is not the same thing as diagnosing syllable weight. In stress languages, a prosodic marker is assigned to a heavy syllable, which is indeed characterized as having two moras, but it is the *membership* of those moras in a single syllable that is crucial — while this is exactly what does not matter in Bantu languages. The point is that the mora has two jobs (representing weight and representing length), which it often performs simultaneously, but not always.

Phonological evidence for the importance of the mora is found, like that for the syllable unit, in both static and rule-governed phenomena: in the lexicon, of course, the mora serves to distinguish long from short segments.[6] In the phonological rule component, moras are relevant to compensatory lengthening, tone assignment, stress assignment, and morphological processes such as

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[6] The mora is not, of course, the only representational means of distinguishing long and short segments (e.g. Selkirk 1990) -- but this is one of the fundamental jobs the mora does in a model that uses moras.

reduplication and truncation. Japanese, for example, makes reference to a bimoraic foot in the formation of hypocoristics, as shown in (9): the portion of the name that precedes the suffix *-tyaN* must be either one or two bimoraic units, regardless of syllable structure (Poser 1984).

(14) Japanese hypocoristics:
midori → mii-tyaN
mit-tyaN
mido-tyaN

siNzaburoo → siN-tyaN
siNzabu-tyaN

wasaburo → waa-tyaN
wasa-tyaN
sabu-tyaN

A number of Bantu languages make reference to the mora in morphological processes of affixation or reduplication. When a verb stem reduplicates in Luganda, the final vowel is lengthened if the stem is bimoraic, but if the stem contains more than two moras, it does not lengthen (Hyman 1992).

(15) Luganda verb stem reduplication (gives meaning 'to X here and there')

(a)	ku-**lim-a**	'to cultivate'	ku-lim-aa-lim-a
(b)	ku-**lagir-a**	'to command'	ku-lagir-a-lagir-a
(c)	ku-**liim-a**	'to spy'	ku-liim-a-liim-a
(d)	ku-**bing-a**	'to chase'	ku-bing-a-bing-a

In Runyambo, the first vowel of the completive verb suffix is short if the preceding syllable is bimoraic, long if it is monomoraic.

(16) Runyambo suffixal allomorphy

(a)	ku-**kóm-a**	'to tie'	ku-kóm-eerer-a	'to pack up'
(b)	ku-**reeb-a**	'to look'	ku-reeb-erer-a	'to supervise'
(c)	ku-**béih-a**	'to deceive'	ku-béíh-erer-a	'to accuse unjustly'
(d)	ku-**jend-a**	'to go	ku-jend-erer-a	'to progress'

Tonal rules also target the mora in many Bantu languages: in Cibemba, there is a rule that spreads underlying High tone one mora to the right (Hyman 1992):

(17) (a) /tu-ka-súm-a/ → tu-ka-súm-á
(b) /tu-ka-pútul-a/ → tu-ka-pútúl-a
(c) /tu-ka-léet-a/ → tu-ka-léét-a

From (a) and (b), there is no way to distinguish between syllable and mora as tone bearing unit. But if the spreading rule were targeting the syllable, we would expect (c) to surface as **tu-ka-léét-á;*[7] instead the H tone spreads to the second mora of the syllable.

Another example of tone docking on the mora is found in Runyambo, where certain verb tenses assign a H tone to the second mora of the stem (the stem portion of the verb is boldfaced):

(18) Runyambo 2nd-mora tone assignment

(a) a-**jun-á**... 'he helps'
3sg-help-FV

(b) tu-raa-**gurúk-a** 'we will jump'
1pl-fut-jump-FV

(c) a-**siíj-ir-e** 'he smeared' (→ a-sííj-ir-e)
3sg-smear-pst-FV

In roots whose first vowel is long, the grammatical H goes to the first syllable, not the second. As shown in parentheses, there are no rising tones in the language, so the whole syllable surfaces with H tone by simplification.

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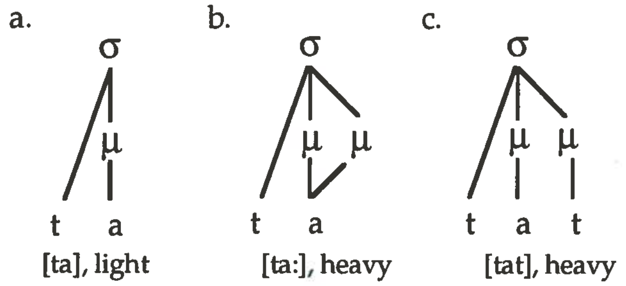
[7] Given that *-lee-* is a single syllable, which I assume it is in Cibemba. Chapter 3 addresses the issue of tautosyllabic vs. heterosyllabic vowels.

Finally, evidence from phonological writing systems around the world show that the mora is a robust phonological constituent. Poser (1992) shows that while conventional wisdom holds that the syllabary is the most common type of phonological writing system, in fact true syllabaries are exceedingly rare. Most systems that have been called syllabic are in fact based on the mora, or on onset and rhyme. Moraic writing systems include Japanese *kana*, Moose Cree, Ojibwa, and Hieroglyphic Luwian. Poser claims that writing systems do not make use of arbitrary sequences, only of motivated phonological constituents, and thus the preponderance of moraic systems support the independent status of the mora as a phonological unit.

1.5.1 The moraic model

The basic points of the moraic model as described in Hayes (1989) are as follows: moras dominate segments, and are dominated by syllables.[8]

(19)



In some languages, CVC syllables count as heavy, as in Latin stress, poetic metrics, and vowel shortening (Allen 1973); in other languages, only CVV is bimoraic and CVC counts as light, such as in Lardil reduplication (Hale 1973). This difference can be captured by universally having all vowels linked to moras

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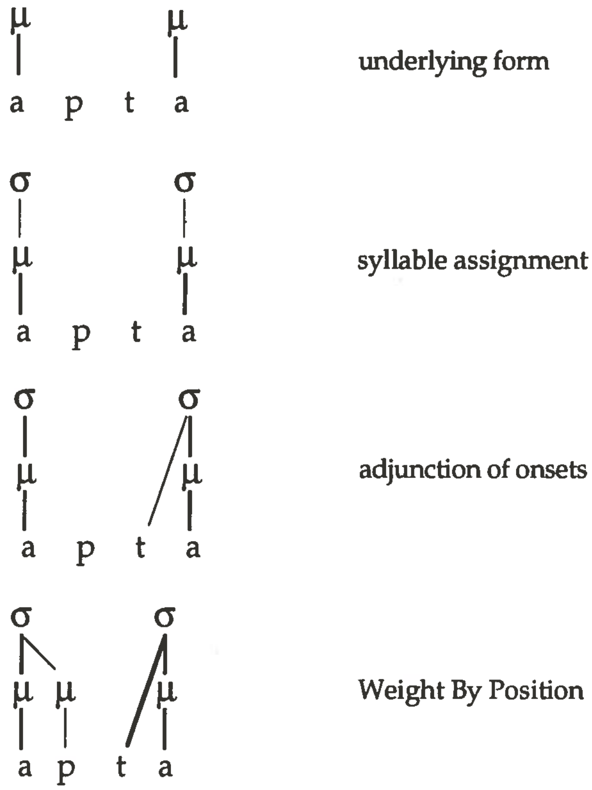
[8] Hyman 1985 and Bagemihl 1991 allow for moras that are undominated by syllables; here I am simply giving one of the commonly-assumed versions of the model.

in underlying representation,[9] then in some languages assigning moras to postvocalic consonants by rule at the time of syllabification by a process which Hayes (1989) calls "Weight By Position".

(20)



Some languages assign weight only to certain coda consonants (e.g. resonants but not obstruents), so the WBP rule can be sensitive to featural restrictions. Onset consonants, in contrast, never receive weight: this is an axiom of moraic theory, yet it leaves open to dispute how onsets should be represented within the syllable.

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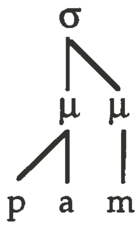
[9] Or by assigning moras to what Steriade (1990) would call "unconditionally moraic segments" as the first step in syllabification. Hayes (1989) points out that moras need not be underlyingly linked in a given langauge if that language has predictable distribution of glides vs. high vowels (i.e. if mora-domination is completely non-contrastive lexically). In such languages, moras can be left out of the lexicon altogether, and can be assigned as part of syllabification.

1.5.2 Representation of weightless consonants

Hyman (1985) links onsets to moras, following the traditional division of a heavy syllable *pam* into the constituents [[pa][m]].

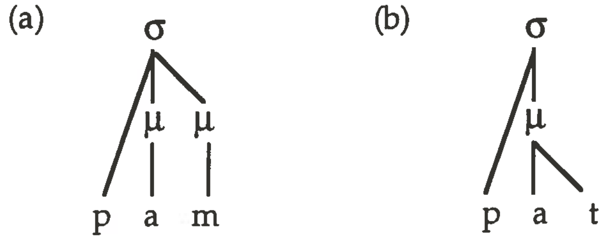
(21) (Hyman 1985)



This represents onsets in the same way as non-weight-bearing coda consonants, and it exhaustively parses segmental elements into moras (which is considered obligatory at levels of prosodic organization above the syllable, i.e. phonological word, phonological phrase, intonational phrase, etc.)

Hayes, in contrast, links onsets directly to the syllable node (as in (22)), excluding them entirely from the weight domain. In this model syllable-final non-moraic consonants are linked to the mora, but syllable-initial ones to the syllable — though this is never explicitly justified.

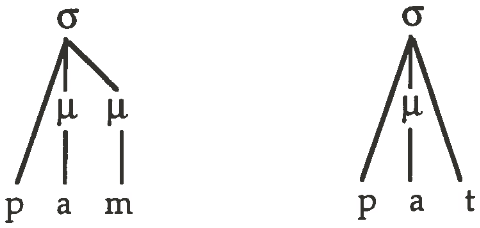
(22) (Hayes 1989)



(where /t/ = weightless)

McCarthy and Prince (1986) point out that it is reasonable to have moras dominate only weight-bearing melodic elements, while the syllable provides the locus for gathering up other melodic elements into prosodic constituents with the weight-bearers. But if this is the case, then it would be inconsistent when coda consonants do not contribute weight to have them adjoined to a mora: thus, although this point of subsyllabic organization is not crucial for their program, McCarthy and Prince allow for the possibility that such coda consonants are also linked directly to the syllable node.

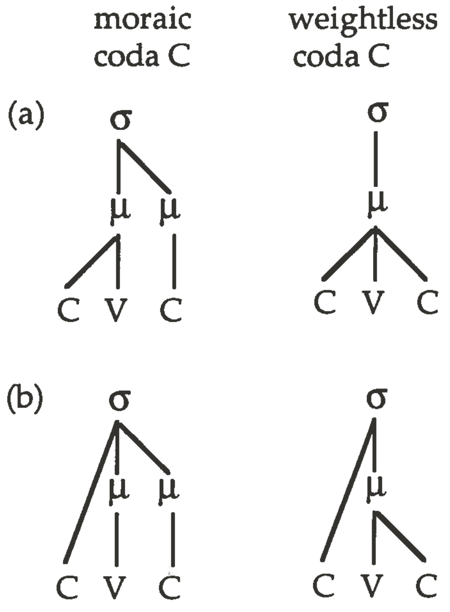
(23) (McCarthy and Prince 1986)



(where /t/ = weightless)

So the possible representations in moraic phonology are these:

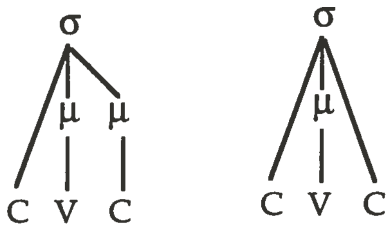
(24)



all weightless consonants report to moras (Hyman)

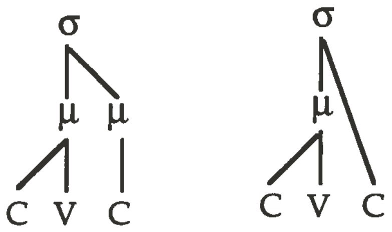
only onset consonants fail to report to moras (Hayes)

(c)



neither onset nor weightless
coda consonants report to
moras (McCarthy & Prince)

(d)



only weightless coda consonants
fail to report to moras (not
considered)

The fourth logical possibility (24d), namely that onsets reports to the mora but weightless codas report to the syllable, has not been considered in the literature, presumably because of the greater observed affinity between nucleus and coda than onset and nucleus.

If the mora is indeed a timing constant, then these representations make different predictions about the durational relationships between onsets, non-moraic codas, and moraic segments. But because of the phonetic disclaimers traditionally assumed in phonological timing models, even determining precisely what phonetic predictions are made by a given moraic representation is difficult. Obviously, non-weighted segments have duration; how they get integrated into a phonetic string with moraic segments is the issue.

The problem of how to represent onsets is one that offers an opportunity to bring phonetic evidence to bear on a representational question. Let us assume for a moment that the mora is indeed a unit of approximately constant duration. Under that hypothesis, if onsets are linked to the mora, then (*ceteris paribus*) a CV syllable and a V syllable should have the same duration — i.e., the vowel in the CV syllable should be shorter than the V on its own. If the onset is complex, we would expect the following vowel to be shorter than following a simple onset: that is, a vowel should be shorter after a CC onset than after a C onset, and after a CCC onset it should be shorter still. This is the implication if onsets are linked to the mora, and the mora is a timing constant. If, on the other hand, onsets are linked directly to the syllable node, the phonetic prediction should be that rather than eating into the duration of a vowel, onset consonants add to the total length of a syllable. This issue is taken up in §2.3.

1.5.3 Below the mora

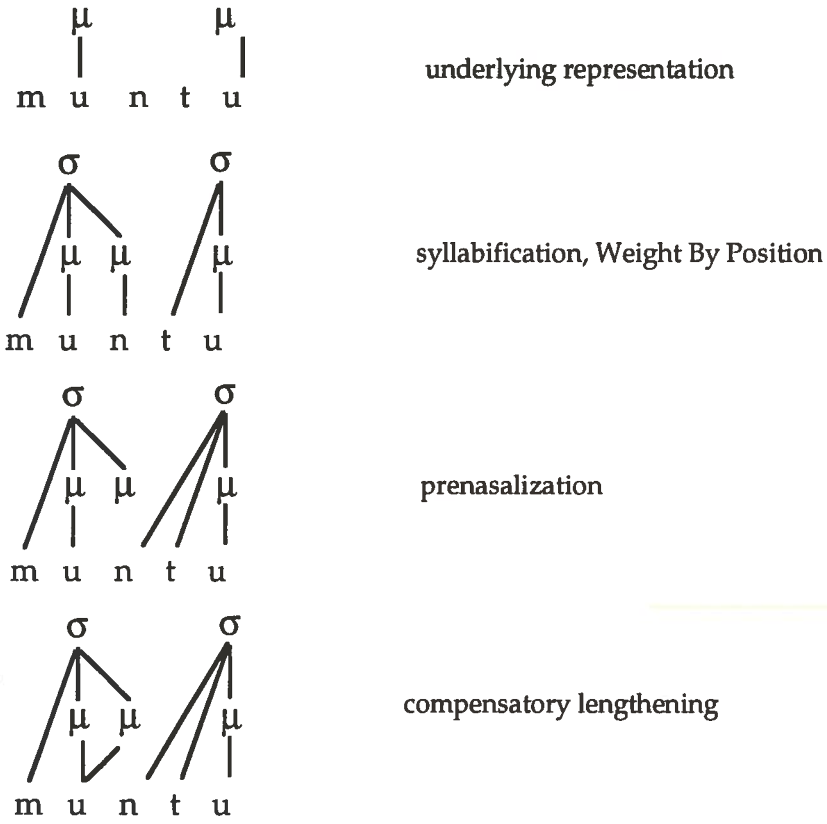
Central to the issue of how weightless segments should be attached in syllable structure is the question of sub-moraic organization. In Hayes' version of moraic theory, each mora is linked to only one weight-bearing segment, though a given segment may be linked to more than one mora — which on the face of it is a unexplained gap in the relationships of autosegmental tiers; it is usually assumed that one-to-one, one-to-many, and many-to-one associations are all possible (indeed this is one of the most salient characteristics of autosegmental phonology). In Maddieson (1993), however, it is proposed that a rule which reorganizes phonological timing may cause weight-bearing segments to *share* a mora. The rule in question is the by now familiar Bantu compensatory lengthening (as in Clements 1986): in many Bantu languages, vowels lengthen before a nasal-consonant sequence and after a consonant-glide sequence, both root-internally and across morphological boundaries.

(25) CVNC → CVVNC

As discussed above, this is said to be a matter of one segment giving up its mora: the nasal joins with the following consonant to form a prenasalized segment.

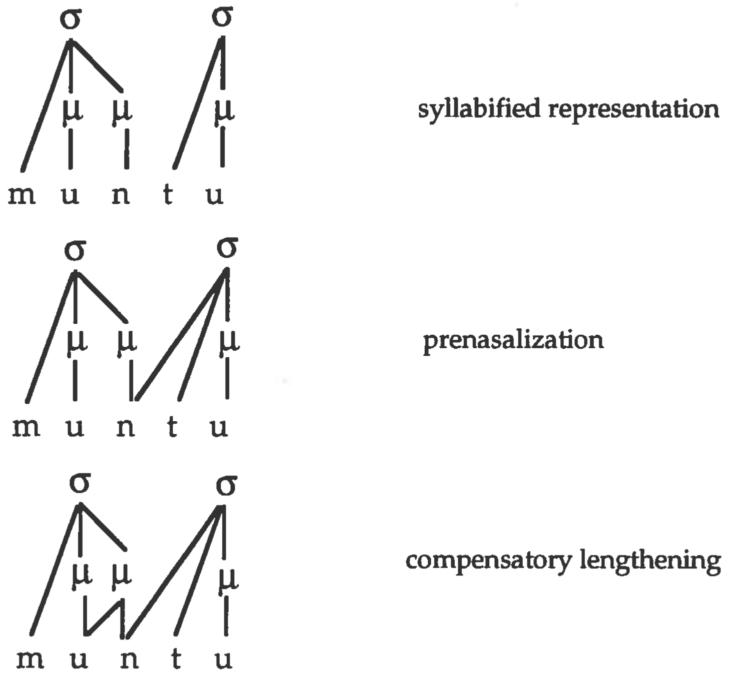
Then the nucleus vowel links to the vacated mora (becoming bimoraic, thus phonetically long). The Luganda process can be formalized in the moraic model as follows:

(26) Luganda



Maddieson (1993) finds that, if the mora is taken to be a durational constant, the actual timing of these strings in Luganda more or less accords with the representations in (21) — but the timing of related Sukuma does not. In these languages there are three surface categories of vowel: lexically short, lexically long, and phonologically lengthened (by Glide Formation or Prenasalization). In Sukuma, the ratio of short vowel duration to long vowel duration is approximately 1:2, while the short:lengthened ratio is 1:1.5. In Luganda, vowels that are lengthened by rule have surface duration closer to that of underlying long vowels. Maddieson proposes that the CL rule of Sukuma differs from that of Luganda as represented in (27):

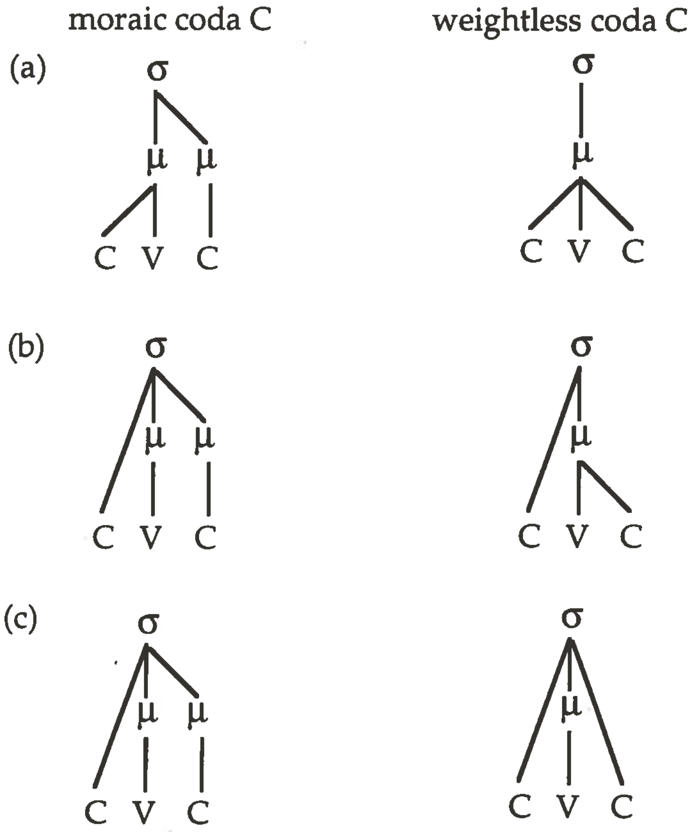
(27) Sukuma



That is, instead of the nasal giving up all of its weight and shifting its association entirely to the next syllable (as part of a complex onset), the rule leaves the nasal linked to its original mora and also links it to the following onset — while the vowel spreads into the nasal's mora, gaining additional weight but not becoming fully bimoraic.

Maddieson notes that what results from this shared-mora representation is two "semi-geminates": both the vowel and the nasal in this context in Sukuma are phonetically longer than their singly-linked counterparts. Runyambo data presented in §3.3.4 show that this structure may be phonologically contrastive: tone rules in Runyambo treat the shared-mora situation differently from one in which only a single segment is dominated by each mora.[10] Thus, because mora-sharing is phonologically contrastive, we cannot follow McCarthy and Prince (1986) in ascribing no difference to mora-linked vs. syllable-linked weightless consonants. It does matter whether segmental elements are linked to moras, because such a link is phonologically contrastive; it makes each of the multiple elements reporting to a given mora partially weighted. In other words, given Maddieson's analysis of Sukuma and my analysis of Runyambo, the (a) and (b) proposals above (repeated here) cannot be appropriate representations for weightless segments. Consonants that play no role in phonological timing must be linked directly to the syllable node as in (c).

(28)



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[10] Recent work on various dialects of Arabic also supports the notion that shared-mora status is phonologically and phonetically distinct (Broselow to appear).

1.5.4 Above the mora

In the preceding discussion of Bantu compensatory lengthening, as in most work on moraic theory, it is assumed that the maximal weight of a syllable is two moras: when a vowel lengthens, it takes over some or all of the weight of the underlying coda nasal it precedes, but the result is still a total of two moras. Indeed it has been a central assumption in the study of phonological weight that there are two possible types of syllable, light and heavy, represented by one and two timing units (weight units or moras) respectively. This is typically treated as universal, while the language-specific issue is what kind of segment string counts as mono- vs. bi-moraic. One argument for maximally bimoraic syllables is that in many languages, when morphological concatenation or a phonological rule (such as glide formation) would result in a trimoraic syllable, one mora is deleted (or its linking is prevented) such that the syllable surfaces as bimoraic.

(29) Runyambo
/ku-tiongoz-a/ 'to laugh oneself silly' [kutyongoza] ([o] = short)

This form contains two triggers for compensatory lengthening of a vowel: glide formation and prenasalization. These compensatory lengthening processes (see Chapter 3) are pervasive in Runyambo, applying both within lexical items (where there is never a short/long vowel contrast in post-CG or pre-NC environments) and across morpheme and word boundaries:

(30) /ku-tueka.../ 'send' → [kutwééka...][11]
/bi-abo.../ 'cl. 8-their' → [byaabo...]
/omuntu#afa.../ 'the person dies' → [omuuntwááfa...]

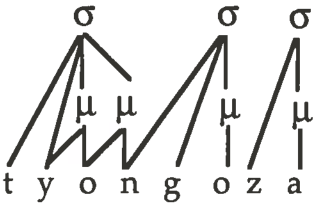
---

[11] These are the surface forms in non-phrase-final position (indicated by ...).

(31)	/ku-jend-a/	'to go'	→	[kujeenda]
	/o-mu-ntu/	'person'	→	[omuuntu]
	/tibákoma#nte/	'they don't see the cow'	→	[tibákomaante]

But the vowel /o/ in /ku-tiongoza/ surfaces as short (not long or lengthened). Thus, from three moraic elements — /i/, /o/, and /n/ — a surface syllable with only two moras is formed. Following Maddieson's notion of "semi-geminates", we can assume that the /i/ ends up with 1/2 of a mora's status, the /o/ with one full mora's worth, and the /n/ with 1/2. The details of the derivation are straightforward so I omit them here, but the representation of this form at the end of the phonological component is as follows:

(32) Runyambo *-tyongoza* 'laugh oneself silly'



Another piece of evidence that syllables are normally maximally bimoraic is that in many languages with both geminate consonants and long vowels, there is complementary distribution of these within syllables, such that sequences of $CV_iV_i.CV$ and $CVC_j.C_jV$ are permissible, but $^*CV_iV_iC_j.C_jV$ is not. Yet there are languages that do have what look like "superheavy" or "trimoraic" syllables: Arabic, Finnish, Japanese, and Estonian are among those that are claimed to have such syllables, at least in some environments.

So what should be the status of the conventional binary distinction between syllable weights (light vs. heavy)? Given the overwhelming cross-linguistic predominance of the maximally-bimoraic syllable, it is desirable to encode the binary opposition within a theory of grammar. In an optimality-theoretic framework (Prince and Smolensky 1993), the constraint against syllables of more than two moras does not have to be surface-true: since all constraints in such a theory are violable, this constraint can be ranked such that surface forms that violate it would be highly marked (and in most of the world's languages, the constraint would be unviolated).[12] Looking to the phonetics of superheavy syllables, it indeed appears that the languages that have them tend to neutralize them, which is consistent with a constraint-based account (if the language *can* conform to a constraint, it will): Vance (1987) reports that overlong syllables in Japanese, which arise only from morphological concatenation or borrowing, show a strong tendency at normal speech tempos to reduce to the length of long syllables.

Another language that is well known for "overlength" is Estonian. Unlike the situtation in Japanese, where straightforward sequences of long V + geminate C arise in certain contexts, Estonian overlength is a property of a two-syllable domain, not of segments (Lehiste 1966, 1993), and it is tied up with the stress system of the language. Prince (1980) proposes a metrical analysis of Estonian in which Q3 (overlong) syllables are seen as a variant of normal long syllables in that they receive a whole metrical foot of their own (by rule). In this example, the form *kau:kele* 'far away' has overlength on the first syllable; one argument for that syllable being a foot unto itself is that adjacent stresses are forbidden within the foot, but the stress pattern *káu:kéle* is seen in forms such as this one.

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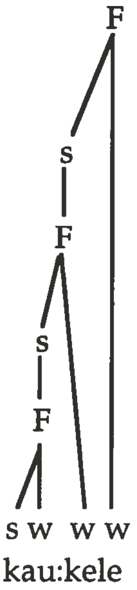
[12] Given that bimoraic syllables are more marked than monomoraic ones, and trimoraic syllables are extremely rare, Hyman (p.c.) suggests that this may be a gradient constraint: $\mu > \mu\mu > \mu\mu\mu$ (where ">" means "is more harmonic than").

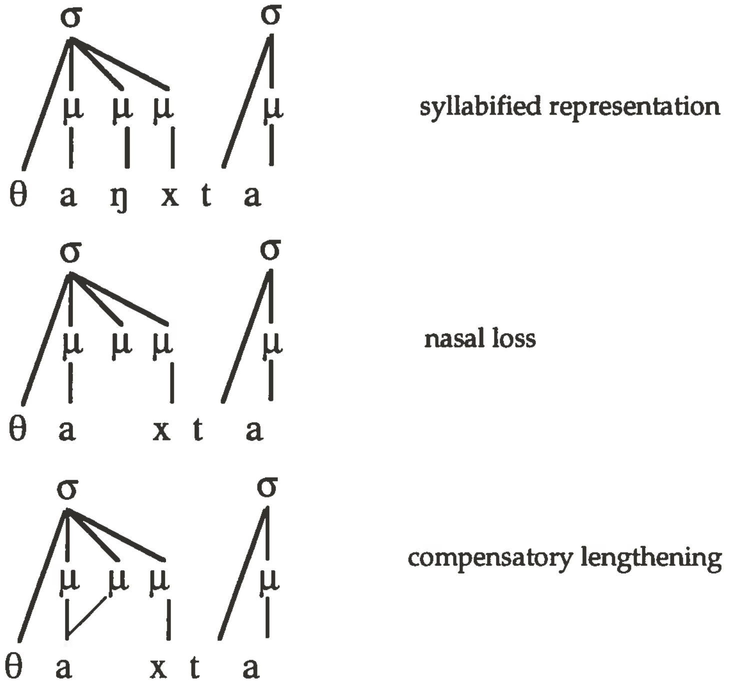
(33)



Hayes (1989) points out that this metrical account is not generalizable to other cases of overlength, which often arise from compensatory lengthening in a doubly closed syllable (e.g. Proto-Germanic **θaŋxta* > *θaːxta*) or from vowel loss in a following syllable (dialectal German **spreːkə* > *spreːːk*).

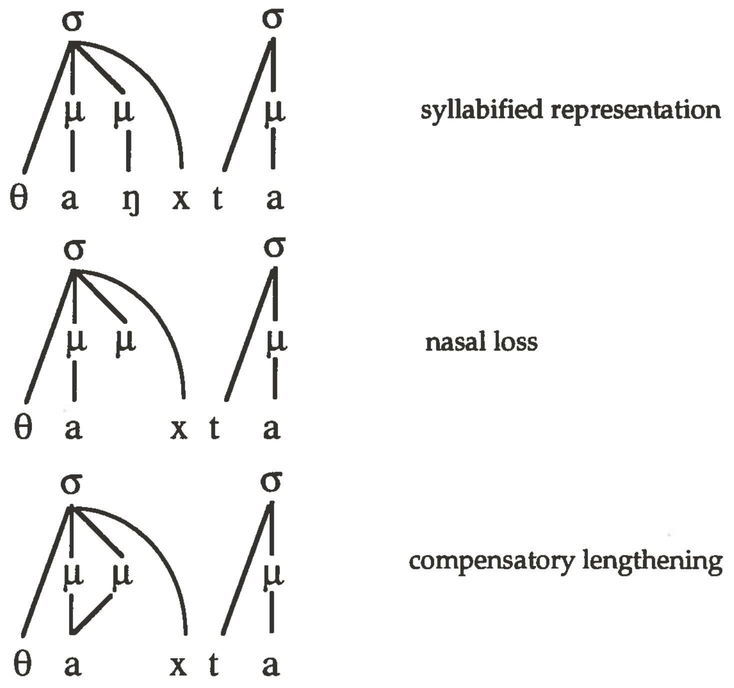
But both of Hayes' historical examples involving superheavy syllables can be reanalyzed in a way that does not require violation of maximal bimoraicity. In the case of Proto-Germanic, Hayes says there is no way to derive the CL that occurs on the vowel /a/ unless the syllable *θaŋx* is trimoraic.

(34) Proto-Germanic *θaŋxta > θaːxta (“thought”): Hayes 1989



But this is not the case if, as I argue, weightless coda consonants are linked to the syllable node and not the mora, and if a coda cluster only contributes one mora to the weight of a syllable:

(35) Proto-Germanic *θaŋxta > θaːxta reanalyzed:

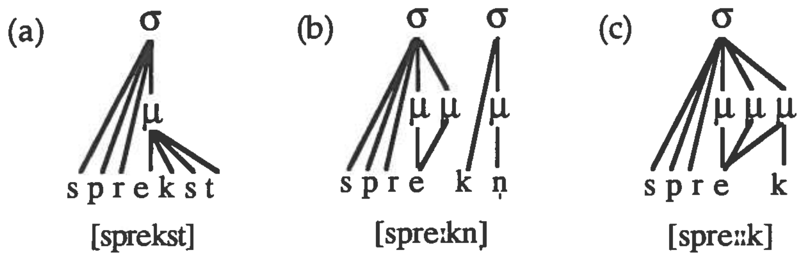


Hayes' other example, from the Dithmarschen/Stavenhagen dialect of German (Hock 1986), concerns a long vowel created by a rule lengthening stressed vowels in open syllables, which is then further lengthened following vowel loss in the next syllable:

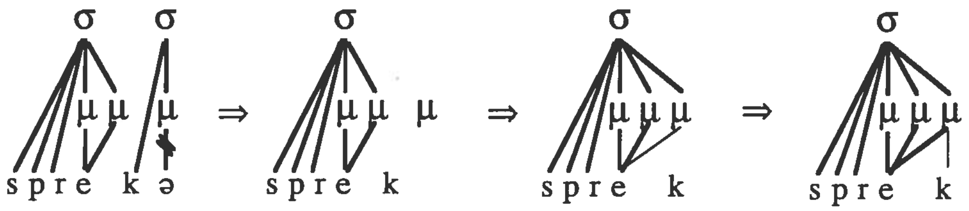
(36) (a) 'speak-2sg'	(b) 'speak-1pl'	(c) 'speak-1sg'	
*sprikst	*sprekn̩	*sprekə	proto-form
——	spreːkn̩	spreːkə	V lengthening
——	——	spreːːk	schwa loss, CL
sprekst	spreːkn̩	spreːːk	present form

Hayes' representations for these forms are as follows:

(37) dialectal German (Hayes 1989): modern forms

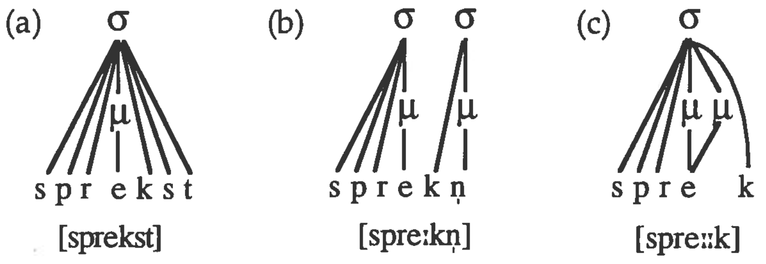


(38) historical derivation of superheavy *spreːːk* (Hayes 1989)



But if the open-syllable situation in (37b) is taken to be the unmarked one synchronically, then we can instead imagine that vowels are simply phonetically shorter in closed syllables (something that is cross-linguistically common, see Maddieson 1985).

(39) dialectal German, modern forms: reanalysis



This means that the closed-syllable (a) and open-syllable (b) vowels are both represented monomoraically, but in the phonetic implementation, closed-syllable vowels receive shorter duration than open-syllable vowels. Of course this does not deny that the vowel in modern *spreːkn̩* was historically short and underwent lengthening; my claim is simply that three synchronic surface categories of vowel duration do not necessarily entail mono-, bi-, and tri-moraic representations (cf. §3.3.4 on the three-way surface contrast in Luganda vs. Runyambo). That is, the language-specific phonetic rules for this dialect can produce the surface length contrast between closed- and open-syllable monomoraic vowels.

The evidence indicates that the cross-linguistic preference is so strongly in favor of binary weight distinctions that when trimoraic syllables arise they are always treated as marked, and tend to eventually reduce. And it is still the case that weight can only be added in the coda; onsets do not contribute to the quantity of superheavy syllables. Thus I will assume that the two main tenets of moraic theory are correct (onsets do not contribute weight,[13] and syllables are either mono- or bi-moraic), and that convincing evidence, both phonological and phonetic, is required to justify trimoraic representations in a language. Ideally, a constraint-based account of overlength will capture the marked status of overlong syllables; further work is necessary to determine the frequency and distribution of such syllables and their place in the timing systems of the languages in which they occur.

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[13] The instances in which onsets do appear to contribute to syllable weight (Everett and Everett 1984, Davis 1988) are marginal: (a) they all involve stress, i.e. not minimality or morphological requirements; (b) there is only case where presence vs. absence of an onset is claimed to be crucial (Western Aranda), and this has been reanalyzed by Halle and Vergnaud (1980) using extrametricality; (c) all other cases except Pirahã revolve exclusively around the *identity* of the onset consonant, not its presence or absence -- and they involve not core stress assignment but resyllabification, where it appears that a phonetic-level rule is attracting stress to syllables of greater overall duration. The only case I find genuinely troubling is that of Pirahã, which partly involves onset C identity but also presence/absence. It may be that in Universal Grammar we will want to state constraints against onset weight of the sort that capture the rarity of trimoraic syllables. I will not pursue this question further here.

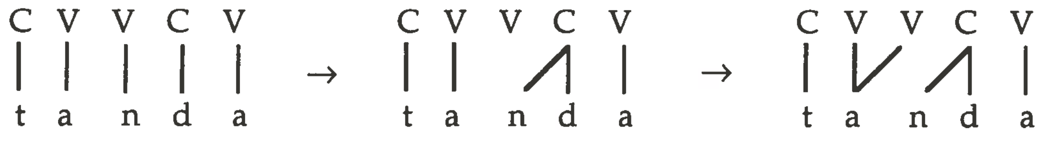
1.5.5 The diachronic role of the mora

There are two types of compensatory lengthening that have arisen in the discussion of phonological timing: CL as a synchronic alternation (as in the Bantu examples above), and CL as a historical change (as in the Germanic examples above). Much of the literature on CL concerns the historical aspect, in which it has sometimes been thought of not as a matter of timing redistribution, but as an extended process of segmental assimilation: de Chene and Anderson (1979) claim that "compensatory lengthening" results from weakening of consonants, followed by monophthongization of the resulting semi-vocalic segment and the adjacent vowel.

(40) Greek:
ek^{h}-o-nti 'they have' → ek^{h}oisi (Aeolic) → ek^{h}ōsi (Ionic-Attic)

Clements (1986, see §1.4.2 above) instead favors a timing-realignment model; in his view CL is a syllable-based phenomenon, which has as its result the maintenance of syllable quantity.

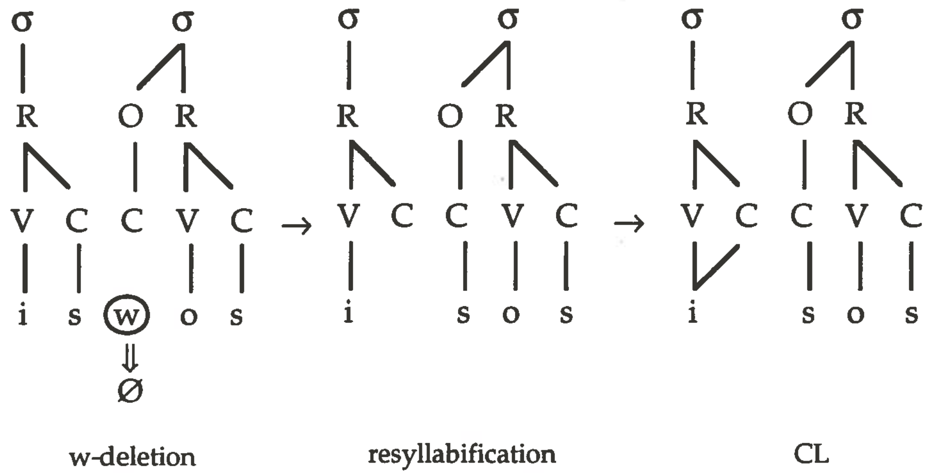
(41) CV theory: /tanda/ → [taanda]



underlying representation prenasalization linking convention

Steriade (1982) takes still another approach, giving a metrical account of the type of CL that results from loss of a segment in another syllable (VCwV → VVCV).

(42) Steriade (1982): Ionic Greek *iswos* > *īsos*



Hock (1986) shows that the moraic model is supported by a wide range of historical compensatory lengthening processes. Hock maintains that the correct explanation of CL relies on the mora, which was actually employed by Sievers, Brugmann, and others in the 19th century. It is shown that while some cases of historical CL can be captured equally well by the weakening-plus-assimilation account or the loss-with-mora-retention account, there are other cases for which weakening cannot be the explanation, thus a theory of CL cannot accept only this model.

The cases in question do not involve segment loss, but rather a feature change such that a segment is removed from the domain of mora count — as with glide formation in Old Icelandic and Bantu, shift of syllabicity in Sanskrit, etc.

(43) diachronic shift of moraicity

(a)	Old Icelandic	*liugan 'lie'	>	lyūga
(b)	Proto-Bantu	*muana 'child'	>	mwaana (Luganda)[14]
(c)	Sanskrit	dīv-ana 'gambling'~ dīv-ya-ti 'he gambles' ~ dyūta 'having gambled'		

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[14] Although Bantuists reconstruct **jana* for 'child' (Guthrie 1967), this root was probably already realized *-ana* when preceded by *mu-* in Proto-Bantu.

It is not only segment loss or demorification that can trigger CL: there are also instances of vowel *reduction* that lead to CL, as in Irish and Soest, where CL starts before the triggering segment is completely lost. In these examples, the reduction to /ə/ of the vowel in the second syllable causes the preceding vowel to lengthen:

(44) CL from reduction

(a) Tyrone Irish *srathar* > [stra:hər], *tachas* > [tɔ:^{h}əs]

(b) Westphalian Soest *hege > hiəge > hīəɣə
*seven > siəv(e)n > sīəvn

This accords nicely with Maddieson's (1992) claim that the split mora of Sukuma represents an intermediate historical stage on the way to Luganda. In sum, the evidence Hock presents argues that the analysis of diachronic CL is improved by use of the mora as a timing unit.

1.6 The mora and timing

In all of the phonological timing models discussed in this chapter, it is explicitly stated that the representations do not necessarily translate to phonetic timing: all other things being equal, a melodic element linked to two timing units should be longer than an element linked to just one — but since many factors other than phonological structure may influence phonetic timing, no specific claims about output are made.

Is the mora, then, strictly a unit of abstract representation? Is it relevant only to morphological and phonological processes (such as reduplication, allomorphy, compensatory lengthening, and location of stress), and not to surface timing? This is certainly a possibility; indeed, the impression given in the phonological literature is that this is all the mora is required to be. However, the traditional notion of the 'mora' is that it is indeed a unit of surface timing: in Japanese, a sequence CV is supposed to take about the same time to utter as a moraic nasal or the first part of a geminate consonant (Q). The mora, in this conception, is supposed to be a durational constant.

But it is a phonetic fact that not all segments are timed in the same way: for one thing, inherent durations of different segments are very different (high vowels are shorter than low vowels, voiceless consonants are longer than their voiced counterparts, etc.) Another factor affecting what might otherwise be a phonetically constant mora is the alteration of segment duration to signal boundaries (as in syntactic "boundary lengthening") or to express affect (such as emphasis, surprise, etc.). These non-phonological influences on duration present a problem for the traditional notion of the mora. So can the two be reconciled? Is the mora indeed phonetically real?

Previous studies in this area (Beckman 1982, Port et al. 1987, Nagano-Madsen 1992) have come down on both sides of the question. What seems clear is that the answer depends on the typological characteristics of the language in question. Teasing out the relationship between weight and length is most difficult in languages in which lexical stress is a primary determinant of rhythm or timing, since stress has multiple correlates, only one of which is duration, and certain other aspects of stress (such as pitch) may interact with segmental or syllabic timing. In cases such as the Bantu languages studied here, on the other hand, the prosodic system is tonal rather than stress-based, removing one of the complexities from timing structure. Moreover, Bantu languages are rich in prosodic phenomena such as distinctive vowel length (and more rarely, consonant length), compensatory lengthening, tone assignment, and morphological alternations, all of which involve clearly phonological effects of timing that can be compared with surface duration. For a large number of these languages, it has been shown that the mora is a useful element of phonological representation (i.e. length and tone distinctions and morphological alternations refer to a sub-syllabic unit of weight), thus they are a logical choice for the study of moras and duration.

1.7 Summary

In this chapter I have reviewed the theoretical basis for prosodic units, the phonological status of the mora, and the representational issues raised by moraic theory. I have proposed phonetic investigation of these issues, which revolve around phonological timing; and I have motivated such a study of Bantu languages on the grounds that they display a rich variety of moraic phenomena, and provide a relatively straightforward separation of timing from other prosodic elements. In Chapter 2, I turn to the phonetic study of prosodic features, to determine in what ways it is possible to test the predictions made by different phonological models of timing.

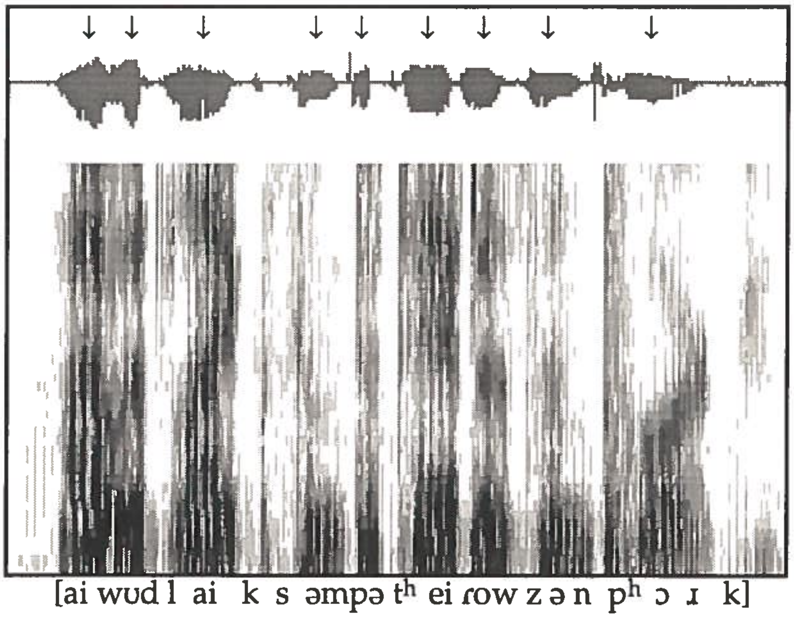
CHAPTER TWO: THE PHONETICS OF TIMING

In the preceding chapter, it was shown that the units syllable and mora are important elements of phonological analysis, and that certain questions about phonological timing remain unanswered. This chapter provides a review of the experimental evidence for the syllable and mora, and an examination of the means for investigating phonetic timing in order to illuminate phonological questions. First, in §2.1, I show that a wide range of non-phonolog ical evidence — developmental, perceptual (psycholinguistic), auditory (neurolinguistic), and articulatory — points to the importance of prosodic units in speech processing and production. Then in §2.2 I discuss the ways in which acoustic measurements of duration can be used to explore phonological aspects of timing, demonstrated in §2.3 with a pilot study of English onset timing to argue for a representation in which onset consonants are linked to the syllable node rather than the mora. Finally, in §2.4, I give the details of my experimental methodology for examining moraic timing in Bantu languages.

2.1 The phonetic character of the syllable

It has long been recognized that speech is organized in chunks larger than the segment, though the physical correlates of these chunks have been disputed. The most grossly obvious acoustic feature of continuous speech, namely peaks and valleys of amplitude, generally corresponds with syllables. In (1), arrows indicate the syllables in the utterance "I would like some potatoes and pork".

(1) “I would like some potatoes and pork”



This alternating high- vs. low-energy contour is a basic acoustic pattern that often matches up with the phonological notion “syllable”. However, it is not a reliable or quantifiable indicator of syllable status — indeed, no physical criterion has been found to correlate consistently with the syllable (Brosnahan and Malmberg 1970, Laver 1994). At one time it was thought that the objective measure of syllables was to be found in articulation, since they are not measurable by acoustic or auditory means: Stetson (1951), who took the syllable to be the primary unit of “motor phonetics”, determined that the syllable is characterized by “chest pulses” produced by the expiratory action of certain muscles in the chest and abdomen (this is measured by electromyography, or indirectly by measuring air pressure in the chest). However, Ladefoged (1958) showed that while this notion is partially correct, not all the muscles identified by Stetson are in fact involved in these pulses, and more importantly, these muscular events in question do not correspond with English syllables, but rather with *stressed* syllables (lending support to the notion that English is in some salient sense a stress-foot-timed language). So it remains unclear what physical definition might be given for the syllable; indeed, it appears that there is no single articulatory gesture that corresponds to syllables, just as there is no single acoustic or auditory correlate.

However, there *is* strong evidence of the salience of syllables in speech production, in the cognitive-processing realm.

2.1.1 Speech production

A recurring theme in studies of speech production is the fact that not all segments in the speech stream are equal — there are significant asymmetries based on the position of a segment within the syllable. One example is that in English-speaking aphasics (Blumstein 1978), errors involving phoneme substitution (the most common error in aphasic speech) tend to maintain the syllable structure of the intended word. Segmental substitution occurs more frequently with single consonants (as in (2a)) than with clusters (2b), suggesting that a sequence of two consonants forms a more cohesive programmed articulatory unit than a consonant followed by a vowel.

(2) (a) teams → [kimz] think → [sɪŋk] 77.1% of cases
(b) flood → [tlʌd] Crete → [trit] 22.9% of cases

This argues for the syllable onset as a constituent. When aphasics show segment deletion, it results predominantly in cluster simplification (as in (3a)) or loss of a coda consonant (3b), not loss of an onset consonant.

(3) (a) pretty → [pɪti] (b) fall → [pɔ]

These deletion errors, as well as segment addition errors of the sort shown in (4), overwhelmingly tend toward the production of more canonical syllables (CV):

(4) (a) help → [heləp] (b) army → [ʤaɹmi]

In (4a), a vowel is added to make a CVCC sequence into the more canonical CVCVC; while in (4b) a consonant is added to a VC syllable to make it CVC. Finally, there are almost no aphasic substitution errors that produce violations of phonotactic constraints: only 3.3% of errors in the Blumstein (1978) study produced sequences that are phonotactically ill-formed in English (such as *pm or *ml onset clusters). Since many of these are syllable-based (section 1.4), it appears that the syllable remains an important element of production even in faulty articulatory programming.

The same is true in English speech errors by normal speakers (MacKay 1978): interchanged segments occupy the same syllable position, and errors involving clusters point to the constituency of the syllable onset.

(5) suit → [tut] (*[tus]) throat cutting → coat thrutting

Reaction-time data in the MacKay (1978) study show that syllable-initial consonants are more "available" (more quickly accessible) than syllable-final consonants, indicating that the syllable onset is a perceptually more salient position than the coda. Japanese speech error data (Kubozono 1989) show that the mora is more salient in production of Japanese than the syllable. The errors in (6) indicate some kind of processing equivalence between half of a long vowel, half of a geminate consonant, a coda nasal, and a CV sequence:

(6) a. se-ka.i re.n-po.o si.n-bu.n → se-ka.i re.n-bu.n si.n-bu.n
"World Federation Newspaper"

b. pe-ni.i "penny" / pe.n-su "pence" → pe-ni-su

c. ku.u-bo mi.d-do-we.i → ku.b-bo-mi.d-do-we.i
"Aircraft Carrier Midway"

d. zi.n-ke.n mo.n-da.i de ko-ma.t-te i-ru → ...ko-ma.n-te i-ru
"troubled with the problem of human rights"

First, bimoraic syllables are almost always replaced by another bimoraic syllable or by two monomoraic syllables; second, long vowels and geminate consonants are often split — something that does not happen in English speech errors — suggesting that they involve two units (moras), not one.

Child language acquisition data also show patterns that point to the importance of prosodic units (Ingram 1978). For one thing, segments develop differently in different syllable positions:

(7) a. bed → [bɛt] b. paper → [be:bə]
bib → [bɪp] pelle → [be:] (Fr. "shovel")
egg → [ɛk] poule → [bu:] (Fr. "hen")

The examples in (7a) show that coda consonants tend to get devoiced in early child language, while those in (7b) show that onset consonants tend to get voiced. Phenomena such as reduplication and deletion in children's speech also make use of the syllable unit:

(8) a. banana → [nænʌ] b. cracker → [kækæ]
potato → [dedo] apple → [bæbæ]
granola → [owa] water → [wʌwʌ]

In (8a), syllables that precede main stress are deleted, while in (b) a single syllable of a word is reduplicated to match the number of syllables in the adult target.

So data from aphasic speech, speech errors in normal speakers, and child language acquisition all indicate the importance of prosodic units in speech production. It is to be expected, then, that the perceptual end of speech processing will also show sensitivity to such units.

2.1.2 Speech perception

A number of perceptual studies point to the existence of an optimal 150-250ms window for chunking speech into cognitively usable units. Experiments by Miller and Licklider (1950) and Huggins (1975) show that the ear can bridge gaps of under 200ms and successfully perceive speech; longer gaps than this seem to extend beyond the capacity of short-term memory buffers. Other sensory systems display a similar temporal preference for chunks of approximately 200-250ms, such motor reaction times and visual image decay (Erickson 1965).

To investigate this ~200ms-window effect,[15] I performed a pilot study of compressed and interrupted speech, hypothesizing that listeners more successfully process speech information if it comes along at an expected rate. The prediction was that if a speech signal is compressed to a fraction of its original duration, then re-expanded with interspersed periods of silence or noise, it becomes more intelligible than the compressed version — even though there is no more acoustic information present in the re-expanded signal. With LPC resynthesis it is possible to compress speech signals without altering their pitch: for this experiment I compressed a set of monosyllables to one-half and one-

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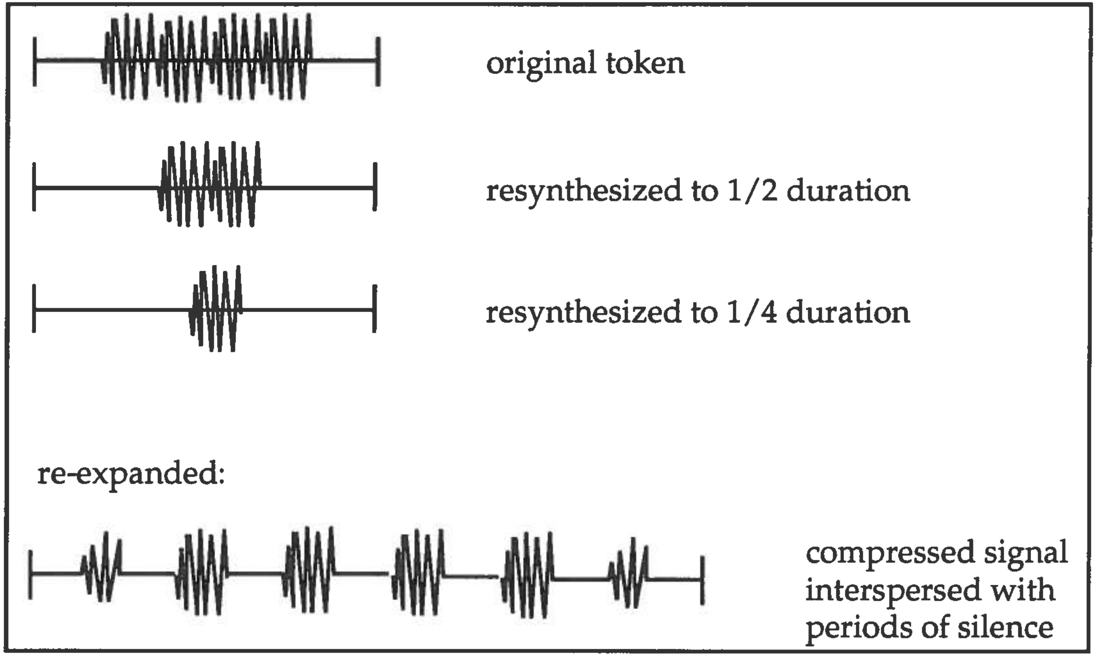
[15] The potential importance of this perceptual phenomenon was suggested to me by Steven Greenberg.

quarter their original duration. I then created two sets of distorted signals by alternating 100ms of speech with 100ms of silence, or 100ms of white noise. The syllables used are given in (9); the stimuli were created as schematized in (10):

(9)

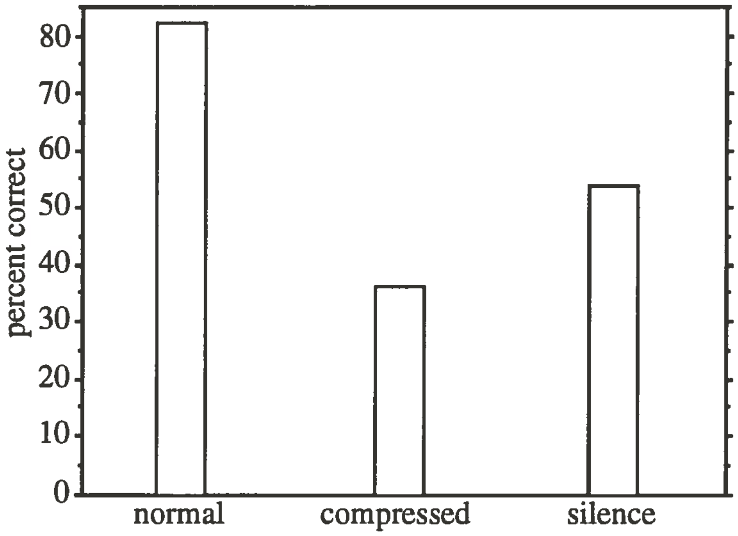
[ba]	[bæm]
[da]	[dæm]
[ga]	[gæm]
[ma]	[mæm]
[na]	[næm]
[ra]	[ræm]
[la]	[læm]

(10)



One linguistically naive subject performed a shadowing task in which he heard three to four tokens at a time and then repeated what he had heard. Intelligibility dropped sharply when the signal was compressed to one-quarter duration: from 82% intelligibility with the undistorted tokens, the quarter-duration comprehension rate dropped to 36%. When silent intervals were inserted, intelligibility rose to 54%.

(11)



Since there was no additional signal content in these "re-stretched" syllables, the results suggest that the expected rate of acoustic information flow is an important component of speech processing. This is further evidence that the syllable, appropriately timed, is a perceptually important unit for purposes of integrating information from a continuous speech stream.

This apparent perceptual integration constant may well result from the basic architecture of the auditory system: nerve fibers in the auditory periphery, the cochlear nucleus, and the auditory cortex fire in patterns that suggest a 200ms window is mechanically optimal for transmitting information (Greenberg 1994 and pers.comm.). Moreoever, there are nerve cells in the auditory system that are specialized for registering the beginnings of acoustic events, indicating that the phonological status of onsets — as non-weight-bearers, as perceptually more salient and historically more stable than codas, and as a less phonotactically restricted position — has its roots in the neurobiology of hearing.

In sum, evidence from diverse areas of speech production and perception points to prosodic units as important factors in mediating between the continuous speech stream and the discrete elements of linguistic meaning. I now turn to the acoustic study of timing in speech.

2.2 Investigating phonetic timing

Since duration is one of the easier acoustic features to measure, there is a fairly sizeable literature on it in various languages. What is chiefly of interest for moraic theory is the *linguistic* use of duration, i.e. phonologically distinctive quantity — but we need to know about the non-distinctive characteristics of duration as well, in order to learn about the mapping of phonological timing to surface realization. Lehiste (1970) offers a valuable survey of phonetic data on suprasegmentals: following the conventional usage of the term, she takes these to be pitch, duration, and intensity (loudness), and not other features that can operate at a suprasegmental level (such as nasalization, pharyngealization, vowel harmony).

This is an interesting distinction, partly justified by the fact that the three elements at issue are inherently present in all speech, and are often used as distinctive linguistic features (tone, quantity, and stress), yet are also regularly used for non- or para-linguistic purposes, i.e. to express affect (unlike segmental features like point of articulation). Fromkin (1987) points to a variety of neurolinguistic evidence that the suprasegmental features of pitch, duration, and intensity are localized differently in the brain from segmental features. So the non-linear representation of these phonological elements is justified on several levels.

But the special nature of suprasegmentals also makes them difficult to quantify: with a feature such as [+voice] or [+nasal], it is possible to say when its realization is there and when it is not. Since duration is always part of the speech signal, and is subject to both rule-governed and affective variations, it is difficult to separate it out as a linguistic feature. Much of the literature on duration addresses the issue of contextual variation: what influence does sound X have on the duration of neighboring sound Y; to what extent is the duration of vowels/consonants predictable given stress, syntactic boundaries, and other information (see among others Peterson and Lehiste 1960, House 1961, Klatt 1976). From this type of work we know that, for instance, high vowels are inherently shorter than low vowels, fricatives are longer than stops, vowels are slightly longer before voiced stops than voiceless (this has been systematized in English to such an extent that vowel duration is a major cue to following stop voicing, but the same is not true of all languages), syntactic boundaries are often signaled by lengthening of syllables/segments in phrase-final position, etc.

2.2.1 Isochrony: the root of the unit "mora"

Most of these durational effects, both mechanical and rule-governed, do not immediately bear on the question of moraic timing. The durational issue through which moraic theory is related to low-level phonetic effects is *isochrony*: the usual notion of isochrony (see Lehiste 1970), undoubtedly arising from the distinct acoustic impressions of different languages, is that certain events occur at regular intervals in the speech stream (we can think of this as the rhythmic aspect of speech). It has been claimed that this event is main word stress in English, the syllable in French, and the mora in Japanese — in other words, there is in English a regular durational interval between main stresses (regardless of how many syllables intervene), while in French each syllable takes up roughly the same durational span, and in Japanese the regular durational unit is the mora (CV, moraic N, or first half of a geminate C). Thus these languages are described as stress-timed, syllable-timed, and mora-timed, respectively.

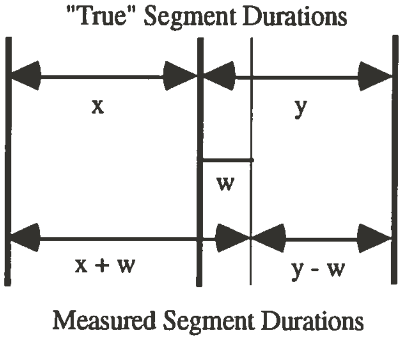
But phoneticians have long since demonstrated that this notion is incorrect — at least insofar as the acoustic reflexes of stress and syllable/mora boundaries indicate. It is simply not the case that every main stress in English comes along with metronome-like regularity, and that the duration of intervening syllables is adjusted to compensate. The paradox, however, is that isochrony *does* exist perceptually — listeners report that rhythmic speech events (stress, syllable, mora) are occurring at regular intervals even when the acoustic signal clearly shows otherwise. The reason we tend to hear isochrony even when it is not present in the speech signal may be found in articulatory evidence: some studies show that the action of certain muscles *is* isochronous, but the execution of the articulation takes varying lengths of time to achieve depending on the nature of the segment (Fischer-Jørgensen 1964 [cited in Lehiste 1970], Lehiste 1984). In other words, the gestures that originate an articulation may indeed be programmed at regular intervals, but because (for example) the tongue tip can move far more quickly than the tongue root or the lips, the completion of the speech gesture misses the rhythmic target. So it has been suggested that as listeners we may correct for the differing mobility of the various articulators; we extract from a non-isochronous acoustic signal a percept of isochronous articulatory triggers (though it is not clear how).

The reason this is important is that the abstract timing unit "mora" owes its existence to the assumption of timing equivalence: if for phonological purposes CV, V, and CVC are equivalent in quantity in some languages, while in others the quantity system groups together CVV with VV and CVC, we need to know whether this relationship holds in phonetic realization or whether it is a fact that only the underlying prosodic system cares about. And if abstract moraic representations do have a non-arbitrary relation to surface duration, then we can and should look to phonetic data to weigh in favor of or against our models. One of the central questions in this enterprise will be whether there is temporal compensation for inherent differences in segment duration in order to maintain a broadly isochronic timing scheme.

2.2.2 Segmental compensation

The study of compensation can be problematic: first, apparent temporal compensation based on the fact that durations of adjacent segments are negatively correlated may in fact result from measurement error (Ohala and Lyberg 1976). If a segment boundary is inaccurately measured, a falsely negative correlation can be introduced between adjacent measurements, as in (12).

(12) Measurement error (Ohala and Lyberg 1976)



If the timing of segment X is truly independent from that of segment Y, but an inadvertently misplaced segment boundary causes the investigator to log the duration of X as X+w (the difference between the true boundary and the false one) and Y as Y-w, then statistically there will appear to be a negative correlation between the durations of the two segments where none actually exists. Thus, since measurement error is impossible to eliminate entirely, a claim of timing compensation based on such negative correlations may be unjustified. For this reason, I take a different approach to segmental adjustment: I perform multiple ANOVA's (analysis of variance) to determine what factors affect the duration of a given segment or segment type, and how those factors are ranked with respect to each other.

A second complicating factor is that of coarticulation (Browman & Goldstein 1986). If a difference in the duration of a particular segment is observed in various environments, it is difficult to know how much of the difference results specifically from compensation to maintain a higher-order timing scheme (e.g. a moraic or syllabic constant), and how much arises accidentally from the coarticulatory effects of overlapping gestures. I will have little to say about this issue, since my data are acoustic and not articulatory, but one point is in order: the means for achieving compensation for timing maintenance must be the availability of overlapping gestures. The challenge is to determine how much of the durational effect of coarticulation is automatic, and how much of it is "intentional" in the service of mora maintenance. Cross-linguistic data will help answer this question, which I set aside for now.

2.3 Examining timing organization phonetically

In this section I return to the question posed in section 1.5.2: what is the most appropriate representation for onset consonants within the syllable? If we take seriously the notion that relationships between segments in a string in some way reflect the overall timing scheme of the language, then we can hope that phonetic data will help to answer this question. My hypothesis is that there is a regular enough mapping between phonological representation and phonetic realization that we can use phonetic data to support the choice of one representation over another. The phonological issue is whether onset consonants should be linked to moras (as in (13a)) or to syllables (as in (13b)).

(13)


(a) (b)

The phonetic question is whether the duration of nucleus vowels in English is affected by the complexity of the syllable onset. In other words, as more and more onset consonants are added as in (5), does the vowel get shorter, or does it maintain its duration?

(14) ta ~ tra ~ stra

When phoneticians have examined the effect of consonants on following vowels, they have looked primarily for the influence of consonant type, not number of onsets[16] — and the evidence is unclear even for single onsets. Peterson and Lehiste (1960) and Umeda (1975) found no significant effect of a preceding C on V duration in English, but the results are difficult to interpret because of the issue of aspiration after voiceless stops (a recurring problem in this kind of

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[16] As Sharon Inkelas has pointed out (pers.comm.), these two issues -- consonant type and consonant number -- are not completely separate, since the identity of consonants in complex onsets is so restricted in English. My point here is simply that there is no information in the literature bearing on the question of onset complexity affecting vowel duration; I would also note that a comprehensive treatment of the issue requires work in languages where there is greater freedom in onset clusters (e.g. Russian or Polish).

study). Ren (1985), however, did find that consonant type significantly affected following V duration in Mandarin, and others have found the same for French and Danish (Maddieson, pers.comm.). It seems likely that some effect will be seen in any language, because of the universal differences in inherent duration of different consonants. (Likewise, the inherent durations of vowel qualities must enter into the final calculation of syllable-level duration effects.) But there is still no clear answer to the question of how much durational effect there needs to be before the line of distinctive quantity is crossed; that is, if an inherently long-duration consonant such as /s/ causes a following vowel to shorten, can it cause what was intended as a long vowel to be perceived as a short vowel? Data from different languages give different results on this perceptual issue, and the overall effect is unclear (Lehiste 1970). For the moment, I will leave aside the issue of automatic effects of consonant type on vowels. What has not been examined previously is the effect of onset complexity on vowel duration, which I now turn to in hopes of illuminating the representational status of onsets in English.[17]

2.3.1 English onset complexity

In this pilot study it is assumed that there is a systematic relationship between the moraic representation that is the output of the phonology and the phonetic timing that appears on the surface. It is further assumed that the mora has a constant target duration (which will obviously be adjusted for segmental content and other factors), and that timing is chiefly driven by moras (rather than syllables, segments, or some combination of the above).[18] In principle, then, *if*

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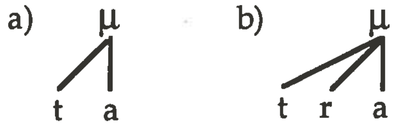
[17] A pilot study on coda clusters has also been attempted, but difficulties in eliciting data clouded the results (especially the frequent deletion of consonants in clusters, which did not occur in onset position). It appears that larger coda clusters do shorten a nucleus vowel, as would be predicted by the moraic models used here, but it is not possible at present to make this claim strongly.

[18] These assumptions will be justified, at least for certain languages, in Chapter 3.

onsets are linked to the mora (as in (15)), and *if* the mora is taken to be a unit of approximately constant duration[19], *then* a CV syllable and a CCV syllable should have the same duration — i.e., the vowel in the CCV syllable should be shorter than that in the CV syllable (and a vowel after a CCC onset would be shorter still).

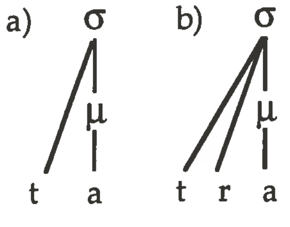
(15) *Hypothesis I*: onset consonants detract from vowel length



total duration of CV = CCV,
thus Vb is shorter than Va

Hypothesis I states that if all onset elements are linked to the mora, and the mora is a timing constant, then we expect to find cumulative shortening of the vowel as onset complexity increases. Hypothesis II, on the other hand, states that if onsets are linked directly to the syllable node (as in (14)), the phonetic prediction appears to be that rather than eating into the duration of a nucleus vowel, onset consonants merely add to the total length of a syllable, while vowel duration remains the same.

(16) *Hypothesis II*: onset consonants merely increase total syllable duration, and do not affect vowel duration.



mora has constant duration,
thus Va = Vb

In order to test these hypotheses, a study of English monosyllables was carried out in which minimal sets such as *sit* - *spit* - *split* were compared. In other

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[19] This hypothesis refers to stressed monosyllables, avoiding the issue of stressed vs. unstressed syllables in English.

words, minimal sets were used in which the only difference was one vs. two vs. three onset consonants. The aim was to measure segment durations in these words and compare them to see what affects the duration of a nucleus vowel.

(17)
sick
lick
tick
slick
stick

sit
lit
pit
spit
split

pot
plot
spot
splot

not
snot

say
pay
play
pray
slay
splay
spray

news
snooze

pa
spa

Target words were embedded in carrier sentences, randomized into three sets. Two male speakers of American English read the tokens, which were then digitized at 10kHz and durations were measured from waveforms and wide-band spectrograms. The total duration of each utterance was noted in order to check consistency of tempo for each speaker; anomalous sentences were discarded. Thus the values for each word are taken to be accurate within a given speech rate. Vowel durations were logged with and without aspiration included, and statistical tests were run twice to check both segmentations. In the statistical analysis of the results I controlled for open vs. closed syllable type, between-speaker differences, and vowel quality effects.

The first issue is aspiration after voiceless stops: the present data suggest that aspiration in English should be excluded from the measurement of the vowel. If aspiration is included, vowels of all qualities are much longer in aspirated than unaspirated contexts (40-90msec longer, which is strongly statistically significant in all cases); the reverse test shows that vowels in all contexts are much more consistent in duration if aspiration is excluded (vowels in aspirated vs. unaspirated environments show no significant difference, and standard deviations for all calculations come within normal range for the total data set). Other phonetic studies have reached the same conclusion; Umeda (1975) and House (1961), for example, exclude aspiration from vowel duration in English. The decision whether to look at the onset effect with or without aspiration is of course important: if aspiration is included in the vowel measurement, then vowels after single aspirated onset consonants are going to look much longer than vowels in certain multiple-onset environments where there is little or no aspiration (i.e. *pit* would appear to have a much longer vowel than *spit*, simply because there is no aspiration on the /p/ after /s/). So the numbers presented here represent vowel measurements excluding aspiration.

The greatest factor affecting vowel duration is vowel quality: as expected, low vowels are longest, high vowels shortest. Speaker identity is also significant, though the overall results are comparable for both speakers. For this reason, pooled measurements are followed by speaker breakdowns. In (18) we see mean durations:

(18) (a) Vowel duration (in milliseconds) by number of onsets (pooled)

vowel quality	*1 onset C*	*2 onset C's*	*3 onset C's*
/ɪ/	90.9	95.0	84.3
/a/	180.4	173.9	139.3
/ei/	210.0	189.8	182.8

(b) Speaker 1: Vowel duration by number of onsets

vowel quality	*1 onset C*	*2 onset C's*	*3 onset C's*
/ɪ/	87.3	86.4	84.3
/a/	147.9	137.1	120.7
/ei/	198.2	184.9	173.0

(c) Speaker 2: Vowel duration by number of onsets

vowel quality	*1 onset C*	*2 onset C's*	*3 onset C's*
/ɪ/	94.8	106.1	
/a/	187.3	181.1	158.0
/ei/	221.7	198.3	202.4

In the pooled data, /ɪ/ clearly shows no effect of onset complexity, while /a/ and /ei/ have a unidirectional tendency to shorten slightly as onset complexity increases. Speaker 1 consistently shows this same directionality (i.e., vowels in CCVC syllables are slightly shorter than those in CVC syllables, and vowels in CCCVC syllables are slightly shorter still). But Speaker 2 does not have this regular directionality: in some cases his two-onset syllables have longer vowels than the minimally corresponding single-onset syllables. This disparity indicates that no consistent effect of onset complexity is likely to be found across speakers. Moreover, even the unidirectional differences are small, and do not stand up under analysis of variance.

(19) (a) ANOVA's: Effect of Onset Complexity on Vowel Duration (overall)

F-value	*degrees of freedom*	*p-value*	*Fisher's PLSD*
1.196	2,196	.3046	none sign.

(b) Speaker 1: Onset Effect

vowel quality	*F-value*	*degrees of freedom*	*p-value*	*Fisher's PLSD*
/ɪ/	.788	2,27	.4651	none sign.
/a/	2.927	2,12	.0922	1vs.3 sign.
/ei/	.819	2, 20	.4552	none sign.

(c) Speaker 2: Onset Effect

vowel quality	*F-value*	*degrees of freedom*	*p-value*	*Fisher's PLSD*
/ɪ/	.254	1, 22	.6192	none sign.
/a/	.984	2,16	.3952	none sign.
/ei/	2.082	2, 12	.1674	none sign.

Finally, two-factor analysis of variance shows that both the speaker identity effect and the vowel quality effect are overwhelmingly more influential than number of onsets in determining a vowel's duration.

(20) (a) Interaction of speaker effect, onset effect

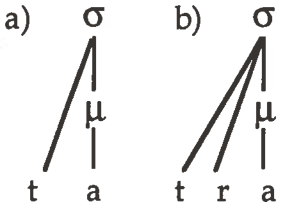
	df	*Sum of Squares*	*Mean Square*	*F-test*	*P value*
speaker (A)	1	18762.612	18762.612	10.439	.0016
# of onsets (B)	2	1729.427	864.714	.481	.6193
AB	2	5049.113	2524.556	1.405	.2495
Error	120	215693.181	1797.443		

(b) Interaction of vowel quality effect, onset effect

	df	*Sum of Squares*	*Mean Square*	*F-test*	*P value*
V quality (A)	4	145668.77	36417.192	48.999	.0001
# of onsets (B)	2	2693.138	1346.569	1.812	.1666
AB	8	4554.714	569.339	.766	.6331
Error	163	121145.525	743.224		

This pilot result requires confirmation with a larger number of speakers. But it strongly suggests that no reliable vowel shortening occurs after consonant clusters in English. Thus, the negligible effect of onset complexity on vowel duration argues for onsets linked directly to the syllable node in phonological representation (as in (21)).

(21)



Using techniques of measurement and statistical analysis similar to those employed here, I now move to a more detailed examination of moraic timing in Bantu languages.

2.4 Methodology of the present study

The experiments reported in Chapter 3 address four issues: (1) establishing a systematic link between the abstract entity "mora" and a phonetic interval, (2) correlating phonological differences between languages with patterns of phonetic realization, (3) identifying the nature and location of segmental compensation to maintain mora timing on the surface, and (4) exploring the range of timing behavior across languages in order to establish baseline measurements for typological comparison.

It is the second of these four issues, the linking of phonological patterns with phonetic patterns, that is at the center of this entire program: in no way do I suggest that moras can simply be read off of milliseconds, or that a naive understanding of the mora as a durational constant is correct. If this were my underlying assumption, I would simply present measurements of segments and argue from them for one phonological representation or another. Instead, I look for independently evident phonological phenomena involving moraic structure — differences in tone assignment, or in lexical distribution of quantity patterns — and then I examine the phonetic timing of the strings in question and test for the correlation of those measured differences with abstract differences in proposed phonological structure.

2.4.1 Data collection

For each of the languages identified in Chapter 1, data were collected from one to three native speakers in a controlled setting (elicitations were done at various university campuses in the U.S.). There were minor differences in the conditions for some experiments, but in general the methodology was as follows. A word list representing as diverse and balanced a phonological inventory as possible was constructed and reviewed with the informant; the list typically included between 100 and 200 items. For most of the experiments, the word list consisted of minimal pairs and triplets of verbs with varying quantity structures in the root: -CVC-, -CVVC-, -CVNC-, etc. (22a) is a typical minimal set of this sort in a language that has lexical vowel length distinctions; (22b) is a typical set including geminates, taken from Luganda.

(22)	a.	CVC	-gab-	b.	CVC	-kag-
		CVVC	-gaab-		CVVC	-kaag-
		CVNC	-gamb-		CVNC	-kang-
					CVCC	-kagg-

Words were embedded in carrier sentences of the type "Say ______ again", and the sentences were randomized three times into different blocks (i.e. each target word appeared three times in the sentence list, in a different order in each block). Speakers read the list onto audiotape in a soundproofed room; they were instructed to read "at a comfortable rate of speed" and asked to maintain a consistent tempo throughout the list.

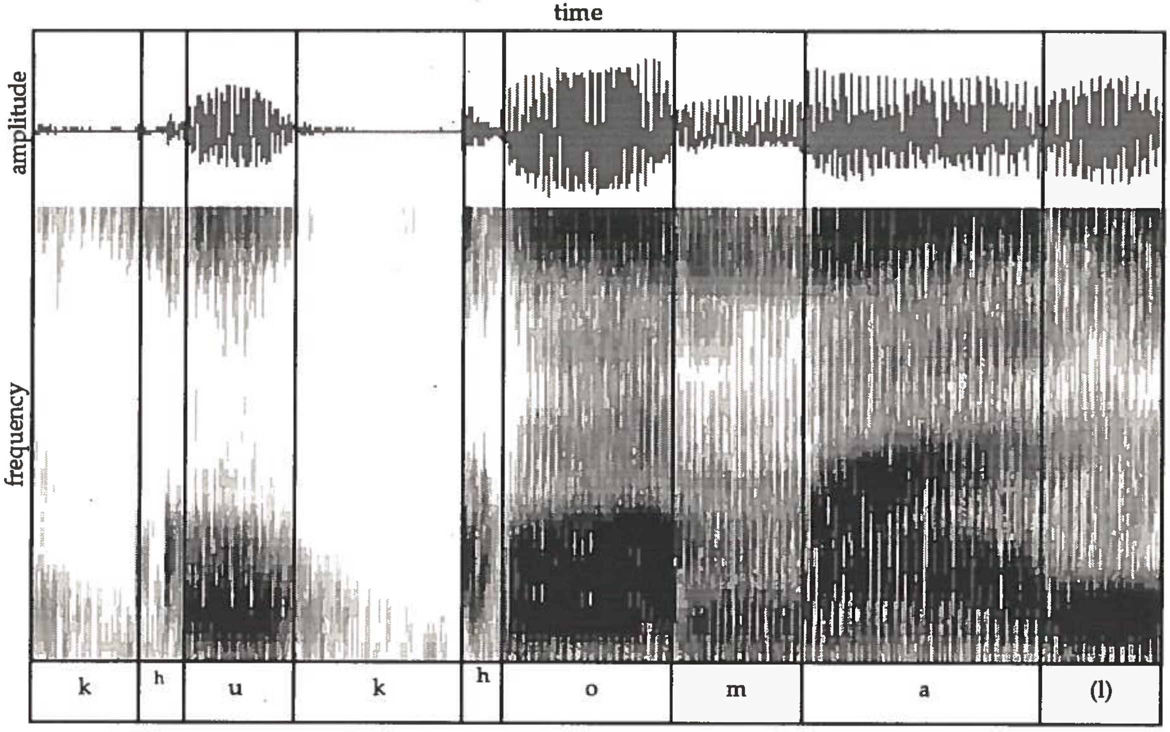
2.4.2 Measurement

Target words were digitized at 10kHz with 16-bit quantization, using the Kay Computerized Speech Lab. A crude method was used to control for speech rate: if a target word or a sentence was anomalously long or short, by an arbitrary criterion chosen on the basis of average duration, that token was discarded. In this way I satisfied myself that the tokens used for statistical purposes represented a uniform speech rate, and that differences in durations did not result from changes in tempo.

Segment durations were measured from waveforms and broad-band spectrograms; the criteria for determining segment boundaries followed general conventions (as described in Peterson and Lehiste 1960). For the boundary between a stop and a following vowel, the center of the release spike is taken to be the end of the consonant, and the beginning of periodic striations in F1 indicates the onset of voicing (the issue of aspiration or VOT is discussed below). After a nasal, the vowel was measured from the point of formant transition, after a voiceless fricative the vowel onset was identified as the beginning of voicing in F1, etc. The boundary between a vowel and a following voiceless stop is located at the point of cessation of all formants. For following voiced stops and fricatives, the boundary point is where energy drops rapidly. For /l/ and /r/ boundaries, rapid change in F3 is usually a reliable cue (note that /l/ and /r/ are non-distinct in many Bantu languages).

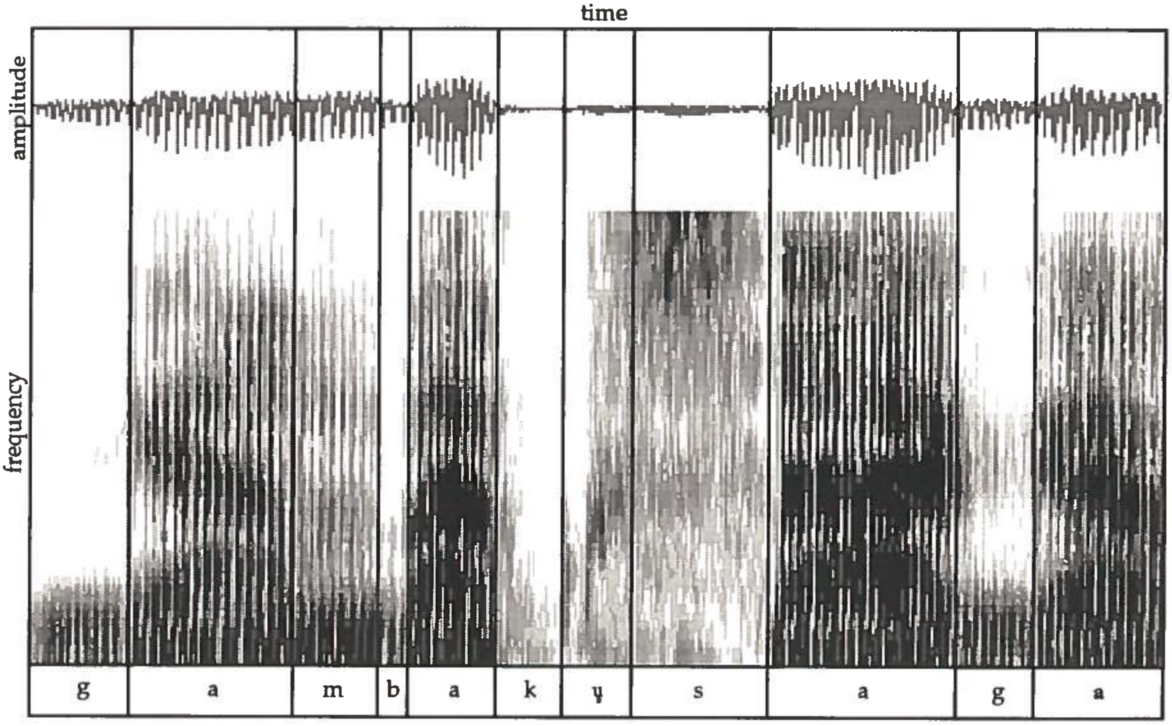
A few examples will serve to illustrate the segmentation issues at hand. In (14), segment boundaries are marked on an utterance from Kilega; these are examples of segmentation decisions that are relatively straightforward. The token is *kukoma* 'to plant', followed by the /l/ of the next word in the carrier sentence (*lengo* 'again'). We see that the voiceless stop and the intervocalic nasal are, as expected, quite clearly demarcated.

(23) Kilega *kukoma l*



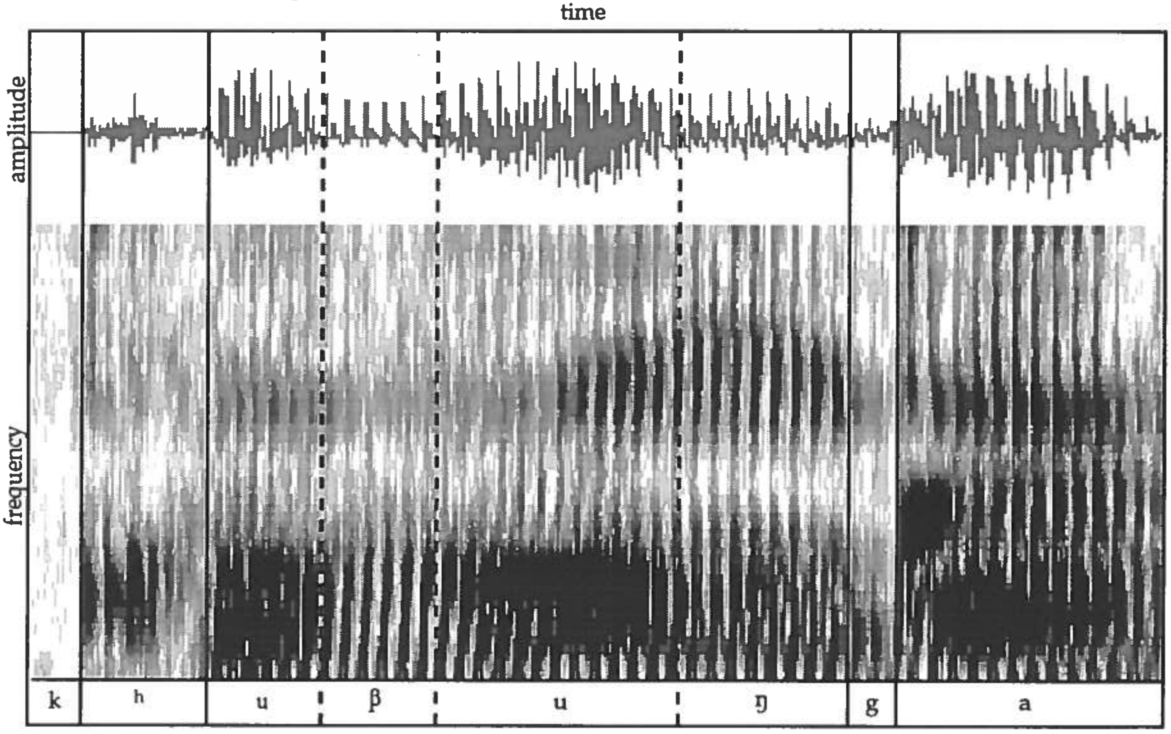
In the following example from Runyambo, the utterance is *gamba kusaaga* 'say "to be left over"', and the next word in the carrier sentence is *rumo* 'once' (hence the transitions out of the final /a/). The /u/ of the infinitive prefix *ku-* is devoiced in this token — but once again, the segmentation is quite straightforward. The voiced stops and voiceless fricative seen in this token are typical.

(24) Runyambo *gamba kusaaga*



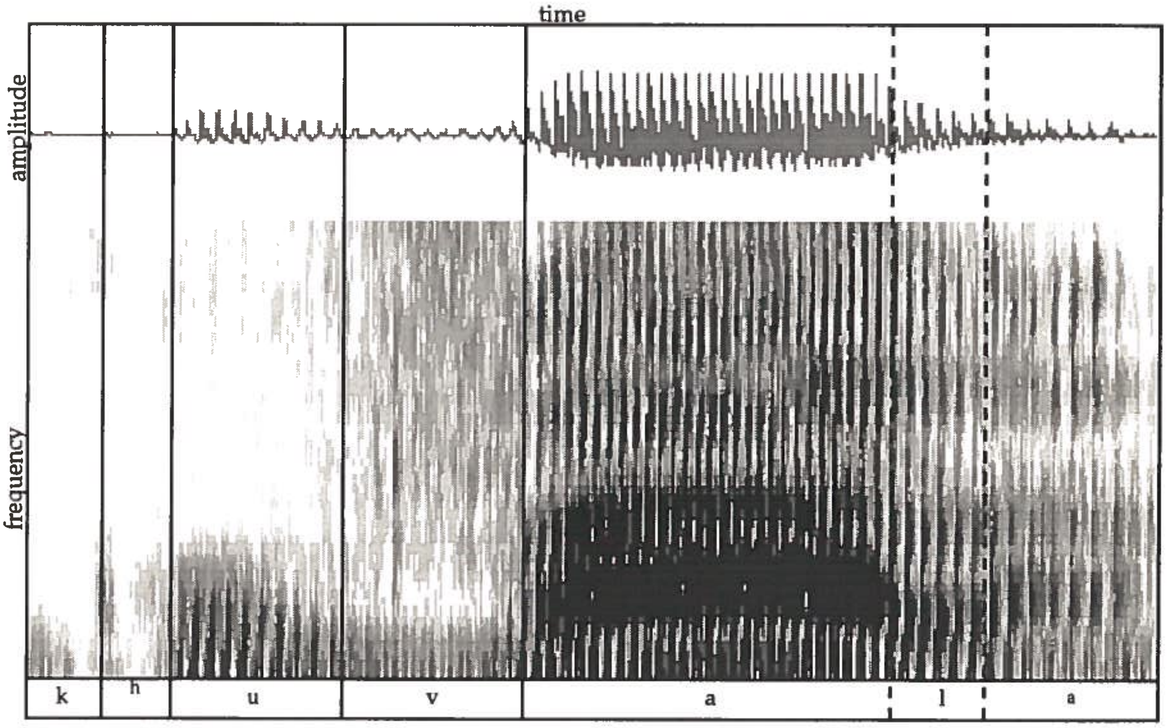
Some segmentations were more difficult, as in this example from Kikerewe: in *kubunga* 'to shed dust', the root-initial consonant is realized as a /β/, which between two occurrences of /u/ is somewhat difficult to identify, and the transition from the high back vowel to the velar nasal is also slightly ambiguous.

(25) Kikerewe *kubunga*



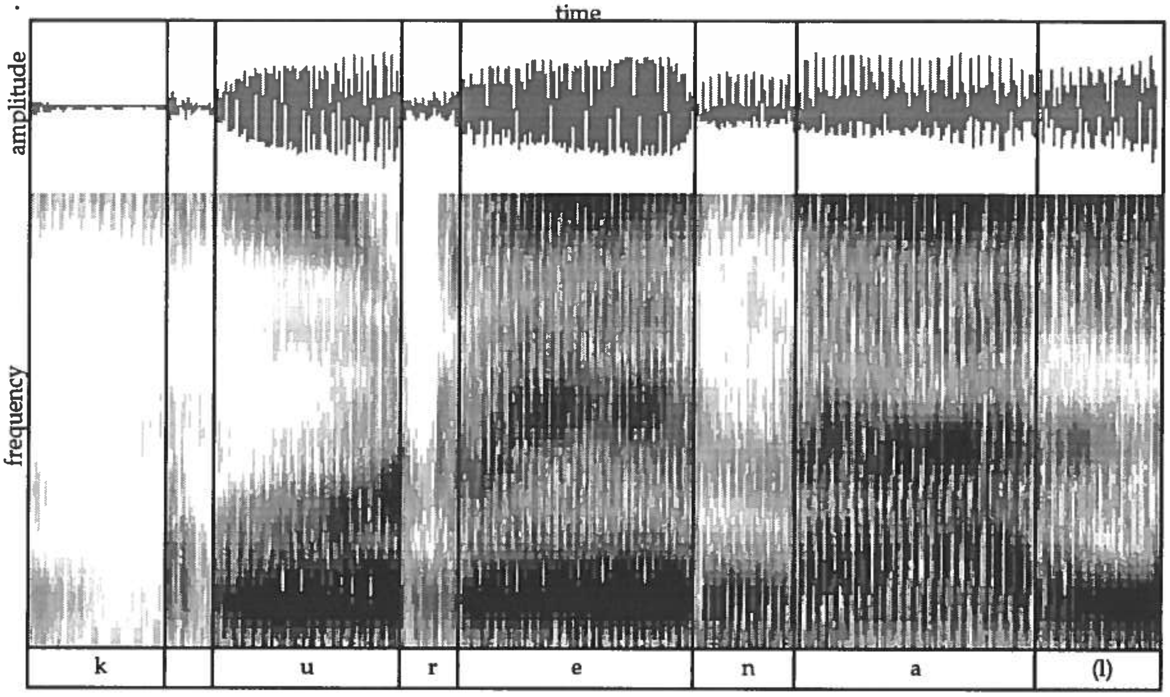
Liquids are notoriously difficult to segment in American English, but they tend to be somewhat clearer in the Bantu languages examined here. In (26), the Chichewa word *kuvala* 'to clothe' shows an /l/ between low vowels; the trickier boundary is the one after the /l/, where the vowel is slightly creaky and the transitions are not as clear as on the /a-l/ side.

(26) Chichewa *kuvala*



The languages in this study generally have a tapped /r/, which is much easier to measure than the retroflex found in American English, as seen in the Kilega token *kurena* 'to run away'.

(27) Kilega *kurena*



Of course, there is a subjective element to segmentation decisions, since no list of criteria is unambiguous: not only are some boundaries consistently harder to distinguish than others, there is also the problem that some speakers simply have fuzzier segment boundaries than others. But by checking my segmentation decisions with other researchers, having a sizeable data pool for each language including multiple tokens for each type, and completing all measurements for a given language before examing any statistical tendencies, I hope to have achieved as unbiased a result as possible. Given that the measurement equipment can place boundaries at intervals as small as one hundredth of a millisecond, and given a greater preponderance of clear segment boundaries than ambiguous ones, I estimate that the magnitude of measurement error averages 1-2ms, and rarely exceeds 5ms.

One segmentation issue that I have treated differently from some other researchers (e.g. Browman, pers.comm.) is that of voice onset time. In measuring the duration of vowels and consonants, it is important to decide whether to mark the beginning of a vowel at the release of the preceding consonant or at the onset of regular voicing. Voiceless stops typically have a significant period of aspiration following their release, and voiced stops often have a short span of non-periodic energy following release before the vowel voicing becomes regular. In all of the experiments reported here, I logged aspiration or VOT separately, and ran statistical analysis of vowel durations twice: once with aspiration included in the vowel duration, and once without.

There was no significant difference in categorial results when aspiration was included or excluded from vowel duration. Thus, reported values for vowel duration are generally those without aspiration (except where noted). It is important to note that while the treatment of aspiration in this group of languages is not crucially important to the measurement results or the phonological claims I make, this is not the case for all languages: in English, for example, data I have examined suggest that aspiration is indeed significant, and that it should be excluded from the calculation of vowel duration.

2.4.3 Analysis

Duration measurements were logged on the Kay CSL and transferred to Macintosh for statistical analysis. Means were calculated for each segment type and category (e.g. each vowel quality and consonant identity, nasals as a group, vowels as a group, etc.), and analysis of variance (ANOVA) was performed to test for significance of various influences on segment duration. Vowel duration, for instance, was typically tested in one-way ANOVA's against length category, vowel identity, position in the word, identity of preceeding and following consonant, etc. When the most significant factors were identified, pairwise two-way ANOVA's were run to determine the relative importance of their effects on the durational pattern in question.

This technique, namely testing a wide range of factors to see which if any show statistically significant influences on duration, is a fairly rudimentary method of sifting through large amounts of data. However, it is a useful one in a situation of limited data collection such as this: since I only had access to one, two, or three speakers of any language, it was not possible to obtain a securely speaker-independent critical mass of repetitions of each token, such as are needed for robust statistical testing. But in cases where I did have multiple speakers, I found that quantity categories and patterns of effects on segment duration were always consistent across speakers. Thus the results reported here point to important generalizations about the timing structure of the languages.

2.5 Summary

In this chapter I have outlined the acoustic, articulatory, and perceptual bases for prosodic units, and have argued that it is possible to look for answers to questions about prosodic structure in the realm of phonetic realization. I have shown on the basis of preliminary experimental data that the phonological unit "syllable" may derive from the perceptual optimization of information arriving in roughly 200-ms chunks. With another pilot study, I have suggested that since the duration of nucleus vowels in English is not reduced as onset complexity increases, it is appropriate to link onsets to the syllable node rather than the mora in phonological representation. Finally, I have detailed the instrumental techniques used to measure and analyze duration. In the following chapter, I look at nine Bantu languages with a range of prosodic behaviors, and compare their durational measurements with their phonological quantity and compensatory lengthening characteristics in order to discover the nature of mapping from underlying structure to surface timing.

CHAPTER THREE: TIMING IN BANTU LANGUAGES

In this chapter I present durational evidence from nine Bantu languages to show that moraic structure is systematically reflected in surface timing, and to explore the range of variation in phonological timing across these related languages. First, in §3.1 I outline the general prosodic characteristics of the Bantu family, focusing on quantity and lengthening, as well as tonal and morphological evidence for the mora as a phonological unit in many of the languages. Then the bulk of the chapter is devoted to reporting results of experiments designed to identify the relationship between moraic structure and surface timing.

I begin in §3.2 by establishing a correlation between mora count and word duration in two of the languages where moras are phonologically relevant (Runyambo and Luganda), which suggests that phonetic timing is importantly dependent on abstract structure. Next in §3.3 I discuss languages with canonical Bantu compensatory lengthening (Runyambo, Luganda, Kikerewe, CiYao), showing that CL operates in different ways across languages. Turning in §3.4 to Bantu languages that have no CL at all, I show that — in accordance with the claims of moraic theory — it is languages that lack lexical long vowels which do not show CL (KiNdendeule, KiLega). The converse, however, appears not to be true; in §3.5 I examine languages that appear to have long vowels but no CL (CiTonga, Chichewa): I demonstrate that these languages do not in fact have bimoraic, tautosyllabic vowels — instead, their apparent long vowels are heterosyllabic vowel sequences, and thus no structure for CL exists in the language. Finally, in §3.6 I present an example of a language with *both* true long vowels and bisyllabic vowels (Bukusu).

3.1 Prosodic structure in Bantu languages

The typical Bantu language has a robustly CV.CV syllable structure, with two exceptions involving nasals and glides (discussed below). Normally, there are no consonant clusters involving obstruents or liquids. This can be seen in the treatment of borrowed words with clusters:

(1)	English	*driver*	→	Swahili	*dereva*
		school	→	Xhosa	*i-sikolo*
		trousers	→	Chichewa	*thaláuza*
		steamer	→		*sitíma*
		test	→		*tésiti*

All of the languages except Swahili and its closest relatives are tone languages, the most common type of system possessing two tones (High and Low). As shown by Kisseberth (1984) for Digo, and Hyman and Byarushengo (1984) for Haya, it is desirable in many of these languages to mark only High tone underlyingly and to assign Low tone to lexically toneless vowels by default.

(2)	Runyambo	/o-mu-kóno/	'arm'	→	[òmùkónò]
	Ikalanga	/ku-lim-a.../	'to cultivate'	→	[kùlìmà]
		/ku-tól-a.../	'to take	→	[kùtólà][20]

Many of the Bantu languages have a contrast between long and short vowels; a few, such as Luganda, also have a long/short contrast in consonants (i.e. single vs. geminate).

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[20] The ... indicates that the token is not phrase-final.

(3)	Runyambo	-goba	'reach, arrive'	-tana	'fester'
		-gooba	'bend'	-táana	'go separate ways'
(4)	Luganda	-bíka	'report a death'	-yíga	'learn'
		-bbika	'dip, submerge'	-yígga	'hunt'

Among roots reconstructed to Proto-Bantu, long vowels are the marked case: few roots with long vowels can be securely reconstructed to that stage (Meeussen 1979[1954]). It is also notable that long vowels almost never surface word-finally. Much of the present-day vowel length in languages that have a length contrast has arisen secondarily from morphological concatenation, coalescence at vowel junctures, etc.

The prosodic status of tone is usually straightforward: in languages with no vowel length distinction, the unit of tone assignment is the syllable; in languages with long and short vowels, the tone bearing unit is the mora. Tone is normally realized on vowels, though when nasals are syllabic they may also bear tone. Luganda is unusual in having phonological tone borne by consonants (even stops):

(5) Luganda	-`ggala	'close'
	-´dduka	'run'

There are two general exceptions to the CV.CV structure of most Bantu languages (seen above in Chapter 1), one involving nasals, the other involving glides. The sequence VNC, in which the NC is usually said to be a prenasalized consonant, often triggers compensatory lengthening of the preceding vowel (as in (6)).

(6) Runyambo pre-NC compensatory lengthening

/ku-jend-a/ 'to go' → [kujeenda]
/o-mu-ntu/ 'person' → [omuuntu]
/tibákoma#nte/ 'they don't tie up the cow' → [tibákomaante]

The pre-NC compensatory lengthening process, in the languages where it occurs, can be seen not only within roots (where there is no long/short vowel contrast before NC), but also across morpheme boundaries and word boundaries. CL, then, is a pervasive synchronic process in Runyambo as in many Bantu languages.

The other exception to CVCV structure is the occurrence of glides after consonants in a syllable onset, arising from the concatenation of a high vowel and a following non-high vowel. Most Bantu languages do not permit sequences of vowels; if vowels end up adjacent at morpheme junctures or across word boundaries the hiatus is resolved by deletion of one vowel, coalescence of the two vowels, or glide formation.

(7) vowel deletion
(a) /kubóna úmukázi/[21] 'to see the woman' →
[kubónúmukázi] Runyambo
(b) /kulába omukázi/ 'to see the woman' → [kuláboomukázi] Luganda

Deletion can be complete, as in Runyambo (7a), with the surviving vowel remaining short (indicating that both the melodic and skeletal elements of the /a/ are eliminated), or it can result in a surface long vowel, as in Luganda (7b) (indicating that only the melodic unit is deleted, while the timing slot remains and is filled by the adjacent vowel).

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[21] The word for 'woman' in Runyambo is *omukazi* in isolation, but the augment vowel is underlyingly /u/, and always surfaces as /u/ when not phrase-initial.

In the case of coalescence, the vowel that surfaces is neither of the underlying vowels, but a blending of the two.

(8) vowel coalescence

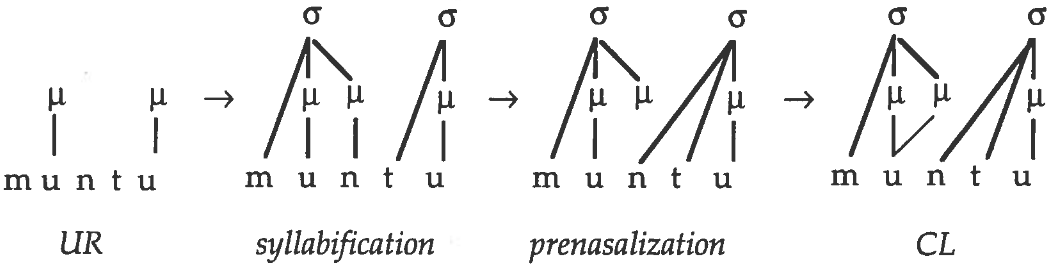
/ma-ino/	'cl.6-tooth'	→	[meno]	'teeth'	Swahili
/ma-ingi/	'cl.6-many'	→	[mengi]	'many (cl.6 things)'	Swahili

If a high vowel is preceded by a consonant and followed by a non-high vowel, it becomes a glide and triggers compensatory lengthening in the nucleus vowel. This is the process of interest here, because of the parallel to pre-NC lengthening.

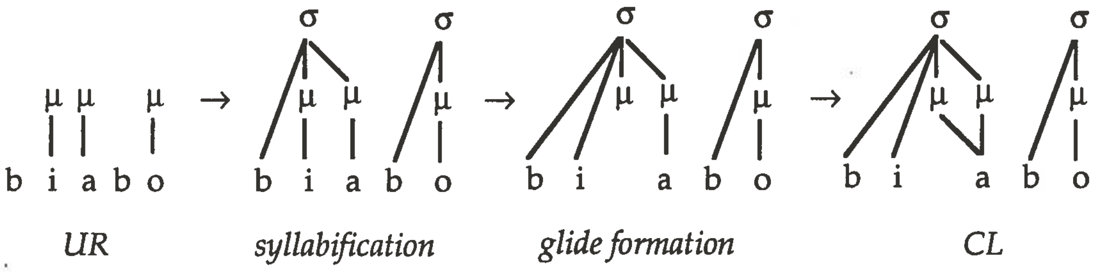
(9)	/bi-abo.../	'cl. 8-their'	→	[byaabo...]	'their (things)'	Runyambo
	/mu-ána.../	'cl.1-child'	→	[mwáána...]	'child'	Runyambo

Both the pre-NC and the post-CG compensatory lengthening processes are framed in modern phonological analysis as the loss of weight or timing status by one segment and the transfer of that quantity element to the neighboring vowel.

(10) CL from prenasalization



(11) CL from glide formation



This conservation of mora count is indeed observable in the phonetic timing, as well as in the abstract structure of these languages (discussed in §3.2). But recall that not all languages in this family have underlying vowel length distinctions: while VNC and CGV sequences do occur in such languages, I show in §3.4 that there is *no* vowel lengthening in these environments. This indicates that (a) when the phonological structure of long vowels is not available in a language, compensatory lengthening does not take place, and thus (b) the CL observed in VNC and CGV contexts is in fact phonological, and not a mechanical phonetic effect.

Recall that other phonological evidence for the salience of the mora in many Bantu languages includes tone assignment, reduplication, and suffixal allomorphy (§1.5). So when we examine the phonetic realization of moraic structure in Bantu languages, we have more to compare to than simply abstract timing facts such as lexical quantity and compensatory lengthening. The experiments that follow show that phonological facts correlate in a significant way with surface output, an important discovery that makes it possible to use phonetic data as evidence to support proposed phonological representations.

3.2 Correlation of phonological and phonetic timing

This data in this section show that mora count in the phonological word is respected as an approximate timing constant in Runyambo and Luganda. Earlier studies of the mora-duration relationship are mostly on Japanese, where the mora is often said to be an isochronous timing unit (e.g. Bloch 1950, Vance 1987), such that a CV syllable, a moraic nasal, and the first half of a geminate consonant are supposed to take up the same amount of time. The mora is a unit that all literate speakers are conscious of, since the *kana* writing system and the long poetic tradition both make use of it (and thus it is taught in school). Phonetic studies such as Beckman (1982), however, claim that the mora cannot be the kind of unit it is traditionally thought to be: for one thing, the inherent durations of different segments cause sequences that count phonologically as a mora to have very different durations. Other evidence in Beckman's study against the mora as a constant unit of phonetic timing includes the behavior of geminates and of devoiced (or deleted) high vowels.

But a later phonetic study of Japanese, Port, Dalby and O'Dell (1987), shows that looking just at long consonants or devoiced-vowel syllables or plain CV's in isolation restricts one's view to a stretch of speech that is too narrow for investigating moraic timing. Port et al. conclude that the mora is in fact a phonetically real timing unit in Japanese, but that segmental adjustment to maintain mora count is done at the level of the *word*. That is, if a sequence of segments is extended by units that count phonologically as one mora at a time, the duration of the word increases by roughly constant increments. Likewise, all phonologically-three-mora words fall into the same range of duration, regardless of syllable structure or segmental content, as do all four-mora words, five-mora words, etc.

This is precisely the conclusion I came to in a pilot study of Runyambo syllable timing: an examination of segment and syllable duration also revealed that the corpus of words sorted neatly into groups by total word duration, and that those groups corresponded to phonological mora count. Since those tokens were not balanced for the counting of moras and syllables, I performed a new experiment that was more carefully controlled to look for exactly this effect.

3.2.1 Runyambo

Bantu languages provide a natural way to extend a sound sequence by one mora or syllable at a time, namely verb affixes. I elicited a number of Runyambo verb infinitives with different numbers of prefixes and suffixes, as well as roots of varying shapes. These included long vowels, vowel-nasal-consonant sequences, and plain CV sequences, such that mora count and syllable count matched in some cases and not in others. The corpus is given in (12):

(12)

(a)*roots + affixes*

ku-nógoor-a	'to mold'	ku-guruk-a	'to jump'
ku-nógoor-er-a	'to mold for/at'	ku-guruc-ir-a	'to jump for/at'
ku-ji-nógoor-a	'to mold it (clay)'	ku-ci-guruc-ir-a	'to jump over it for/at'
ku-ji-nógoor-er-a	'to mold it for/at'	ku-ci-tu-guruc-ir-a	'to jump over it for us'
ku-ji-tu-nógoor-er-a	'to mold it for us'		
ku-jeend-a	'to go'	ku-kóm-a	'to tie'
ku-jeend-er-a	'to go to'	ku-kóm-er-a	'to tie for/at'

(b) *roots of minimally different shape*

ku-gob-a	'reach, arrive'	ku-kub-a	'fold'
ku-goob-a	'bend'	ku-kuub-a	'polish'
ku-gomb-a	'desire'	ku-kumb-a	'tilt, fall over'
ku-sib-a	'to imprison'	ku-tan-a	'fester'
ku-siib-a	'pass time at'	ku-táan-a	'go separate ways'
ku-simb-a	'erect sthg'	ku-táng-a	'forbid'
ku-sáag-a	'be left over'	ku-son-a	'sew'
ku-sang-a	'come upon'	ku-sond-a	'peck'
ku-bon-a	'to see'		

The hypothesis was that total word duration would correlate closely with mora count, and that as phonological sequences were extended mora by mora, their duration would increase by approximately the same amount each time.

Mean values for each item are given in (13); pooled values by number of moras are shown in (14). Analysis of variance to determine the correlation of word duration with mora count is compared with syllable count in (15).

(13) Runyambo: mean word durations

word	*moras*	*syllables*	*duration*
kuguruka	4	4	572
kugurucira	5	5	677
kucigurucira	6	6	807
kucitugurucira	7	7	874
kunogoora	5	4	675
kujinogoora	6	5	779
kunogoorera	6	5	772
kujinogoorera	7	6	849
kujitunogoorera	8	7	957
kusaaga	4	3	548
kusanga	4	3	562
kusona	3	3	476
kusonda	4	3	549
kukuba	3	3	488
kukuuba	4	3	562
kukumba	4	3	575
kutana	3	3	468
kutaana	4	3	528
kutanga	4	3	561
kusiba	3	3	448
kusiiba	4	3	528
kusimba	4	3	546
kukoma	3	3	484
kukomera	4	4	581
kubona	3	3	469
kugoba	3	3	464
kugooba	4	3	529
kugomba	4	3	549
kujeenda	4	3	513
kujeendera	5	4	621

(14) Runyambo: duration by mora count

mora count	*duration*
3	476
4	550
5	658
6	786
7	859
8	957

(15) Runyambo: ANOVA's - significance of mora count vs. syllable count

	F-value	degrees of freedom	p-value	PLSD test
mora	452.814	5, 79	.0001	yes
syllable	185.253	4,80	.0001	yes

The total duration of a word in Runyambo is more closely correlated with mora count than with syllable count. In addition, we can see that (for example) a four-syllable word containing a long vowel, such as *kunogoora* (675 ms), is much closer in duration to a five-syllable word with all short vowels such as *kugurucira* (677 ms) than to a four-syllable all-short word such as *kuguruka* (572 ms). Likewise *kukumba* (575 ms) is much closer in duration to words like *kukomera* (581 ms) than to words like *kusona* (476 ms). This relationship holds throughout the data set.[22]

The same patterns were visible in the data from the earlier pilot study, even though that experiment was not controlled specifically for this effect. Thus it is possible to conclude that although Runyambo does not have a rigidly isochronous mora-timing scheme, some kind of segmental compensation is taking place that is sufficent to override large inherent durational differences between segment types and roughly maintain a weight constant. So even though syllable boundaries do not line up neatly across different words (as was implicitly claimed in Herbert 1975 for Luganda), there is some higher-order timing pattern such that (for instance) four-mora words containing inherently long-duration consonants like /k/ and /z/ are not radically longer than four-mora words containing short consonants like /r/ and /b/. The question of how this compensation is achieved is broached in Chapter 4.

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[22] Assessments of greater and lesser significance cannot, of course, be made by directly comparing p-values; througout this study when I make a claim about relative significance I have examined a range of statistical tests and have run pairwise two-way ANOVA's to compare the effects of given factors on word or segment duration.

3.2.2 Luganda

A set of Luganda utterances elicited for another study contained a number of minimal sets that vary only by syllable and/or mora count; I examined these to see if the same sort of mora effect appears in Luganda as in Runyambo. The tokens were elicited with no carrier sentence, and each subset of four to eight items was read twice in the same order (which may have resulted in some rhythmic and order effects on duration). The tokens selected for this measure are as follows:

(16)	bálìma[23]	'they are cultivating'		
	bámùlima	'they are cultivating it'		
	bálìmira	'they are cultivating for/at'		
	bámùlimira	'they are cultivating it for him'		
	bálìmaalima	'they are cultivating here and there'		
	bámùlimaalima	'they are cultivating it here and there'		
	bálìmiralimira	'they are cultivating for/at here and there'		
	bámùlimiralimira	'they are cultivating for him here and there'		
	bágùlirira	'they are bribing'		
	bámùgulirira	'they are bribing him'		
	báágùlirira	'they bribed'		
	báámúgúlírìra	'they bribed him'		
	tebágúlírìrà	'they are not bribing'		
	omulimi	'farmer'	abalimi	'farmers'
	omupákàsì	'porter'	abapákàsì	'porters'
	omusélíkálè	'soldier'	abasélíkálè	'soldiers'
	omugóbâ	'driver'	abagóbâ	'drivers'
	mùlamuzi[24]	'judge'	mùsígìle[25]	'deputy'
	múngélézà	'Englishman'	mùvúbúkâ	'adolescent'

---

[23] Acute accent marks High tone, grave accent Low tone, unmarked = lexically toneless -- these vowels receive their tone specification from the surrounding environment (Hyman and Katamba 1993).

[24] Phonetically [m(u)lamudzi]. These four tokens have no augment (initial vowel) because they were elicited after a negative verb, an environment in which nouns lose their augment.

[25] Phonetically [musiʤire].

One puzzling result was that the nominal augment or initial vowel, sometimes said to be long, was actually phonetically long only for one lexical item: *omulimi* and its plural, *abalimi*. Although it is possible that this is a lexical fact, it may also be an order effect: the utterances beginning with *omulimi/abalimi* occurred at the beginning of their repetition set. Another unexpected result was a difference in the final vowels of the words *omugóbâ/abagóbâ* and *mùvúbúkâ*: though both are represented as short vowels with a falling contour tone, the first two items always had the duration of a short vowel with either a level High tone or a minimal contour; while *mùvúbúkâ* had phonetically very long vowels (as long as the lexical long vowels) and a fully realized contour. (Because it was difficult to know what representation to assign to *mùvúbúkâ* for comparison against its duration, I excluded it from the statistical tests.) Again, context is the key factor: *omugóbâ/abagóbâ* were always utterance-initial, thus the final vowel was utterance-medial, while *mùvúbúkâ* was always utterance-final. The source of both of these unexpected asymmetries can probably be found in the phrasal timing rules of Luganda, which should be further explored in the future.

These issues aside, the main effect is the same as that for Runyambo above. Mean durations for a representative sample of words and for pooled data are shown in (17) and (18). Analysis of variance for correlation of word duration with mora count and syllable count follow in (19).

(17) Luganda: mean duration of verbs in isolation

word	*moras*	*syllables*	*duration*
balima	3	3	426
bamulima	4	4	553
balimira	4	4	538
bamulimira	5	5	599
balimaalima	6	5	769
bamulimaalima	7	6	869
balimiralimira	7	7	817
bamulimiralimira	8	8	901
bagulirira	5	5	610
baagulirira	6	5	852
baamugulirira	7	6	914

(18) Luganda: word duration by mora count

mora count	*duration*
3	426
4	545
5	604
6	810
7	867
8	901

(19) ANOVA's: significance of mora count vs. syllable count

	F-value	*degrees of freedom*	*p-value*	*PLSD test*
mora	45.646	5, 97	.0001	yes
syllable	12.368	5, 105	.0001	yes

As in Runyambo, mora count in Luganda is a more consistent word-timing predictor than syllable count. The results are not as clean as those for Runyambo — standard deviations are greater, and categories are not as distinct — but this is at least partly because the tokens were not elicited in the same way. For example, there is a large durational effect of position within an utterance: a given word is longer in isolation or utterance-finally than utterance-initially, and is shorter as the first of two words than as the first of three words. In the Runyambo elicitation, all target words occurred in the same position within the utterance, so this effect did not interfere with other timing factors.

The main results are repeated here for comparison:

(20) Runyambo results
(mean diff. = 96ms)

moras	*duration*
3	476
4	550
5	658
6	786
7	859
8	957

Luganda results
(mean diff. = 95ms)

moras	*duration*
3	426
4	545
5	604
6	810
7	867
8	901

(21) ANOVA's: Correlation with mora count vs. syllable count

Runyambo

	F-value	*df*	*p-value*
mora	452.814	5, 79	.0001
syllable	185.253	4, 80	.0001

Luganda

	F-value	*df*	*p-value*
mora	45.646	5, 97	.0001
syllable	12.368	5, 105	.0001

As with Beckman's (1982) results for Japanese, it is not the case that every phonologically moraic sequence has the same duration:

(22) Runyambo:

one mora	*two moras*	
/ku/ = 194 ms	/tana/	= 351 ms
/go/ = 136 ms	/gom(b)/	= 300 ms

But it *is* the case that words with the same mora count have very comparable durations. These patterns show that languages like Runyambo and Luganda employ segmental timing adjustment of a degree that successfully maintains an approximate moraic constant.

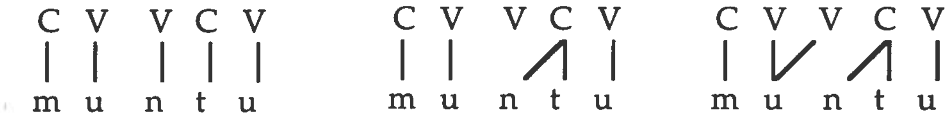
On the strength of these results, which suggest a systematic link between phonetic timing and phonological structure, I now examine the status of vowel length and compensatory lengthening in a range of Bantu languages.

3.3 Languages with canonical compensatory lengthening

In this section, I show how cross-linguistic differences in the phonological nature of compensatory lengthening are reflected in surface timing. I focus here on the prenasalization type of CL rather than CL resulting from glide formation, because VNC sequences can be more straightforwardly measured than CGV sequences.

To review the phonological claims about CL: Clements' (1986) representation of Luganda CL has a preconsonantal nasal underlyingly linked to a V slot, then reassociated by rule to the following C slot if it is non-initial; as a result the preceding vowel lengthens by linking to the vacated V slot.

(23) Prenasalization and compensatory lengthening in Luganda (Clements 1986)

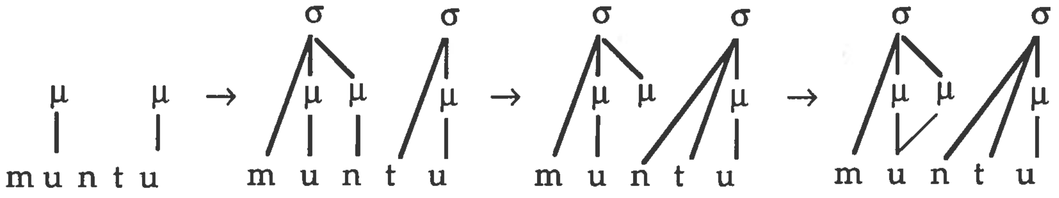


underlying representation *Prenasalization* *Linking Convention*

(stipulated: no CC sequences are permitted on the timing tier)

In moraic phonology, CL is similarly represented as a consequence of demorification of the nasal.

(24) Moraic representation of CL (Maddieson 1993)



UR *syllabification*[26] *demorification* *CL*

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[26] This syllabification process includes the (language-specific) Weight By Position rule by which a nasal that does not precede a vowel projects a mora, which then gets associated as a coda to the syllable on the left (Hayes 1989).

In the CV analysis of Luganda, the representation of prenasalization and compensatory lengthening falls out only because it has been stipulated that there are no CC sequences on the timing tier (reflecting the Bantu generalization that there are no surface consonant clusters), and thus a nasal or the first half of a geminate consonant gets linked to a V-slot. It leaves open the question of whether such models have any phonetic reality. The CV tier is supposed to represent timing, but Clements maintains that it is strictly a phonological representation — so while it is expected that the relative value of C and V slots will stand up under phonetic measurement (i.e. a segment associated to two timing units should in fact turn out to be longer than a segment associated to just one), we are cautioned not to take this to be absolute. The same caveat applies to the moraic model, in which timing slots are assigned not to every segment but rather to weight-bearing elements. As a phonological representation, moraic theory makes no explicit claims about the surface timing of segments — but the framing of CL as timing preservation begs the question of the relationship between the two. Given the evidence above that moras do in some way drive phonetic timing in moraic languages, let us now see how phonological compensatory lengthening is manifested durationally.

In the following sections I discuss the languages CiYao, Luganda, Kikerewe, and Runyambo, in order from most canonical compensatory lengthening to least.

3.3.1 CiYao

The version of CiYao (Guthrie P.21) described here is the dialect spoken in Mozambique. It has a lexical vowel length distinction, and a garden-variety five-vowel inventory:

i u

e o

a

There is no vowel hiatus in the language (i.e., no sequences such as *ae).

The verb roots in the measurement corpus are as follows:

(25) CiYao verb roots

ciga	jinx a trap	puuga	get fresh air
ciima	pant	puuta	hit, beat up
cima	hate	saala	say, inform
cinga	defend	sala	split
coma	burn (tr)	siga	chop
cooma	cry loudly	singa	make a string
gona	sleep?	soma	pierce
guma	bark	sooma	read, study
gumba	mold	suga	spot?
guuma	scream	sunga	keep
paata	rub down	suuga	swim
pata	obtain	taaga	pour
peeta	sift flour	tanga	tell (story)
peta	decorate	tega	set trap
puga	blow (wind)	tenga	roof
punda	exceed	timba	hit
puta	rub off	wona	see?

Mean vowel durations in milliseconds are shown in (26):

(26) V duration by length category

	mean	*SD*
short	60.8	(22.8)
long	131.5	(18.7)
pre-NC	130.4	(15.7)

(27) CiYao: length ratios

	lengthened	*long*
ratio to short V	2.14	2.16

Vowels in pre-NC position are indeed compensatorily lengthened; in fact they are the same length as lexical long vowels, while short vowels are approximately half this duration. This is just what would be predicted by a direct mapping of moraic structure to phonetic timing: lengthened vowels, like long vowels, have twice the timing count of short vowels (two moras as opposed to one).

Unlike many of the other languages in this study, CiYao has almost no difference in vowel length by identity.

(28) Vowel duration by identity and length category

	short	*long*	*pre-NC*
a	69.5	136.4	146.8
e	64.0	122.5	128.8
i	48.0	129.0	126.3
o	80.8	136.9	
u	53.4	127.6	129.2

There is a somewhat significant difference in short vowels between /o/ and /u/ and also between /o/ and /i/; but other short vowels are not significantly different, and none of the long or lengthened vowels show meaningful identity differences. A two-factor analysis of variance shows that phonological category (as opposed to identity) is overwhelmingly the determining factor in the duration of a vowel.

(29) CiYao: ANOVA - significance of V identity and length category

	df	*sum of squares*	*mean square*	*F test*	*P value*
vowel identity (A)	4	2325.96	581.49	1.622	.1767
length category (B)	2	82727.601	41363.801	115.414	.0001
AB	8	1116.919	139.615	.39	.9232
Error	80	28671.565	358.395		

(30) CiYao

(a) C1 durations

	Mean:	*s.d.*
p	101.7	15.7
t	92.3	12.2
g	83.9	20.0
c	153.9	33.7
s	123.4	19.1

(b) C2 durations

	Mean:	*s.d.*
t	68.7	9.5
g	66.3	12.3
m	72.7	10.1
n	61.1	2.1
l	75.1	8.4

(31) CiYao: aggregate C durations

	Mean:	*s.d.*
p	101.7	15.7
t	79.8	16.0
g	71.5	17.0
m	72.7	10.1
n	61.1	2.1
c	153.9	33.7
s	123.4	19.1
l	75.1	8.4

In this data set not enough consonants occurred in both C1 and C2 position to directly compare the effects of consonant identity and position. However, aggregate measurements of consonants by position and comparison of /t/ and /g/ show that, as in many other data sets presented here, consonants are significantly longer in C1 than in C2 position.

An interesting fact about nasals in CiYao is that there are two types of nasal prefix: the first is represented by the first person singular object marker (1sg OM) on verbs and the Class 9/10 noun prefix; the second by the second person singular object marker (2sg OM). As seen in (31), the 1sg OM prefix causes mutations to some following consonants (voiceless stops become voiced, voiced stops become nasals) and it drops out before other consonants (fricatives and nasals). In all these cases, the 1sg OM prefix causes the preceding vowel to be long. The 2sg OM, on the other hand, never drops out and never causes a following consonant to become voiced (therefore the sequences *-mp-*, *-nt-*, *-nk-*, *-nc-* are legitimate in CiYao, unlike some other languages). The vowel preceding the 2sg OM is never long, but the nasal prefix itself is long.

(32) 1sg vs. 2sg OM prefixes

kuu-m-ba	1sg	kuu-menda	1sg
ku-m-pa	2sg	ku-m-benda	2sg
kuu-n-duma	1sg	kuu-nyicila	1sg
ku-n-tuma	2sg	ku-n-nyicila	2sg
kuu-n-jima	1sg	kuu-mila	1sg
ku-n-cima	2sg	ku-m-mila	2sg
kuu-n-gaana	1sg	kuu-nona	1sg
ku-n-kaana	2sg	ku-n-nona	2sg
kuu-medudila	1sg	kuu-naaya	1sg
kum-bedudila	2sg	ku-n-naaya	2sg
kuu-n-ditila	1sg	kuu-n-yasa	1sg
ku-n-ditila	2sg	ku-n-jasa	2sg
kuu-n-yigala	1sg	kuu-n-dimila	1sg
ku-n-jigala	2sg	ku-n-dimila	2sg
kuu-nava	1sg	kuu-numa	1sg
kun-gava	2sg	ku-n-numa	2sg
kuu-soma	1sg	kuu-n-didila	1sg
ku-n-soma	2sg	ku-n-didila	2sg

Following are the durations of the two types of nasal prefix:[27]

(33) CiYao: two types of nasal prefix

	mean	*SD*
1st sg OM	71.8	17.0
2nd sg OM	90.5	17.2

The 2sg OM, the one that does not voice a following consonant, is syllabic and is phonetically longer.

What does this reveal about the root-internal preconsonantal nasals in the verb-root corpus above? The root-internal nasals are more like the 1sg OM (and Cl.9/10) nasal, i.e. non-syllabic. (There also are no voiceless consonants following nasals root-internally.) Because of the vowel length facts, we can conclude that these root-internal nasals give up *all* of their mora to the preceding vowel in a process of compensatory lengthening. This, then, is the default case. The 2sg OM prefix, however, comes with its own mora in the lexicon, which it does not lose.

(34)

2sg.OM

Meanwhile, the moraic representation in (35) is valid for the normal CL situation in CiYao (within lexical items and across morpheme boundaries, i.e. all VNC sequences except those involving the 2sg.OM):

---

[27] Here for comparison are the durations of nasals in stems, in VNC and intervocalic position:

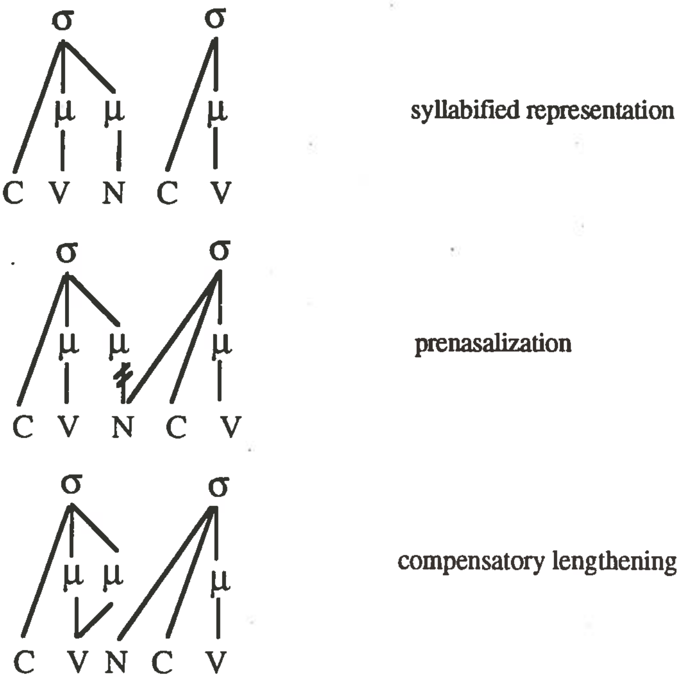
(a) CiYao: N's before C's in stems

	mean	*s.d.*
pre-C nasal	83.1	12.1
pre-C /m/	77.9	7.1
pre-C /n/	77.2	6.3
pre-C /ŋ/	85.6	13.5

(b) CiYao: intervocalic nasals in stems

	mean	*s.d.*
intervocalic nasal	71.3	10.2
intervocalic /m/	72.7	10.1
intervocalic /n/	61.1	2.1

(35)



In sum, CiYao is the prototypical sort of Bantu language with respect to compensatory lengthening; it will serve as a benchmark for the other languages with varying CL characteristics.

3.3.2 Kikerewe

Kikerewe is a Tanzanian language spoken on the island of Ukerewe in Lake Victoria (J.24). Kikerewe has the standard five-vowel system, andpossesses lexical long vowels in roots where long vowels are reconstructed to Proto-Bantu. It is very similar to Runyambo, lexically, morphologically, and segmentally; its chief differences from Runyambo are tonal. The present data were elicited from one adult male speaker of Kikerewe; the corpus is given in (36).

(36) Kikerewe corpus

baága	skin
bába	make itch
bamba	peg out (skin)
bemba	be undercooked, watery
benga	dance
bíba	spread, sow
biga	fish w/ maze trap
biíka	put away, keep
bíka	announce (death)
binda	hide sthg. away
bóna	get
bonda	be overripe (of fruit)
bumba	make pots
bunga	wood: shed dust from weevils
fuba	tie knot
fúnda	not fit (e.g. too many in room)
gaba	distribute, dish out
gaga	go bad
gamba	say
gana	tell a story
gimba	make rain
goba	to land (boats) / be at helm
goma	lose voice
gomba	buy snuff / insult, abuse
gona	snore
hémba	blow on fire
hénda	break (e.g. stick)
higa	to defend
hiíga	hunt
hika	arrive
hinga	gather, of clouds
kánga	startle, frighten
kaka	have acidic taste
kama	coagulate
kamba	be sour
kana	become numerous
kanda	treat bruise
kinga	be in one's way, obscure
kómba	lick food with finger
kúba	bend
kumba	sweep along like water
kunga	be headman on a site / shriek
liíla	eat for (someone)
lima	cultivate
mema	of potato: be starchy
panga	plan (v.)
pima	weigh, measure
pinda	hem(v)
poona	cultivate, till
saága	remain be extra, left over
sánda	woo
saasa	become painful, be sick
saba	ask for
samba	make trouble, disturb peace
sana	cut (w/ panga or hoe)
sanga	to meet
seega	ask for, beg for (beer)
seka	laugh
semba	wrap up
siba	kick
síga	leave (tr.)
siiba	fast
siiga	to smear, rub
siíka	put partition in house
siima	thank, praise
sínga	overcome
simba	uproot, dig out
sinda	use secret language
singa	apply oil, lotion
soba	tangle, be entangled
soma	read
somba	go fetch and bring repeatedly
sona	sew (usu. w/ machine)
sonda	be stingy, give niggardly
songa	hunting: throw second arrow
suka	plait (hair, mat)/pour
sumba	gather (of people)
sunga	hang from the ceiling
taána	let go of each other
tanga	brew beer
tánga	hamper
tana	expand
teega	throw a curse at
téga	lay trap, fish w/nets
téma	cut (down)
tenga	harass, be a burden
tína	fear (v)
tóna	ooze, drip
tuga	score, in a game
túma	send

tuna	be open (enough to not hide)	túnga	govern, keep animals
tunda	buy	kuuta	rub millet, corn from ear
tuuma	(heap up, of a swelling)		

Vowel measurements are as follows (in milliseconds):

(37) Kikerewe vowel durations

	mean	*s.d.*
short	70.9	19.2
long	128.8	17.8
pre-NC	118.0	19.5

The category distinctions are statistically significant, but the difference between long and pre-NC vowels is much smaller than the short/long and short/pre-NC differences:

(38) Kikerewe: length categories

	mean diff.
short vs. long	58.0
short vs. pre-NC	47.1
long vs. pre-NC	10.9

The mean difference of 10.9ms is substantially smaller than the standard deviations for each category (see above). So Kikerewe has pre-NC compensatory lengthening much like that of CiYao.

(39) Kikerewe: length ratios

	lengthened	*long*
ratio to short V	166%	182%

The ratios of long and lengthened vowels are not exactly as in CiYao; we will see that this difference is even more pronounced in Luganda.

As shown in (40), the effect of length category on vowel duration is much stronger than that of vowel identity.

(40) Kikerewe: ANOVA - vowels by length category, identity

	df	*sum of squares*	*mean square*	*F test*	*P value*
length category (A)	2	156758.136	78379.068	**326.327**	**.0001**
vowel identity (B)	4	22976.527	5744.132	**23.915**	**.0001**
AB	8	2240.888	280.111	**1.166**	**.3202**
Error	247	59325.818	240.185		

(41) Kikerewe: vowel duration by length category, identity

	short	*long*	*pre-NC*
a	82.1	140.9	132.4
e	67.1	136.8	122.1
i	60.1	120.4	112.5
o	83.4	143.0	121.4
u	51.9	121.9	102.3

Notice that for the vowels /e/, /i/, and /u/, long vowels are twice as long as short vowels or longer. In all cases, lengthened vowels are almost but not quite as long as their long counterparts.

Consonant durations in Kikerewe are as follows (C1 = root-initial consonant, i.e. onset of target syllable; C2 = root-final consonant, onset of following syllable):

(42) Kikerewe: nasals in VNC

	Mean:	*s.d.*
n	49.8	8.1
m	58.7	7.1
ng	43.8	10.6

(43) Kikerewe

(a) C1 durations

	Mean:	*s.d.*
p	80.5	17.1
t	72.5	14.6
k	82.7	15.6
b	44.4	7.0
g	59.3	11.2
m	61.1	6.5
h	61.7	18.3
f	127.0	12.9
s	113.0	17.2
l	25.5	10.0

(b) C2 durations

	Mean:	*s.d.*
t	57.9	2.1
k	49.4	9.1
b	46.9	8.3
g	46.5	7.9
m	68.1	7.3
n	50.6	8.7
s	87.8	3.4
l	35.3	4.7

When the consonants are analyzed in aggregate, they look much less consistent than consonants in any of the other languages discussed here. C1 vs. C2 position does appear to be important, but the directionality of the effect is not the same for all consonants (i.e. it is not the case that C2's are all longer than their C1 counterparts).

(44) Kikerewe: aggregate C durations

	Mean:	Std. Dev.:	Std. Error:
p	80.5	17.1	4.9
t	72.6	14.1	2.1
k	80.6	23.1	3.2
b	61.7	30.9	3.7
g	70.7	28.7	3.7
m	74.8	24.7	4.4
n	72.0	21.5	3.7
h	61.7	18.3	6.9
f	127.0	12.9	5.8
s	112.2	17.7	1.9
l	25.1	8.2	3.1

Note that the variance around the means is much greater than in comparable measurement sets in the other languages presented here. With the present data set it is not possible to determine what is affecting consonant duration in this way, except that it does not appear to be the identity of the neighboring vowel.

In sum, Kikerewe is a canonical CL language in which lengthened vowels are just slightly shorter than long vowels — as opposed to CiYao, a prototypical CL language in which lengthened vowels have the same duration as long vowels. In Luganda, we see yet another different surface interpretation of the same phonological process of CL.

3.3.3 Luganda

Luganda (J.15) is spoken in Uganda; it is similar to CiYao in segment inventory but is notable for also having geminate consonants. The corpus used for this section is as follows:

(45) Luganda verbs

baaga	to skin	kama	to milk
baga	to fasten loosely	kamba	to urinate
bbika	to dip	kana	to compel
bega	to serve (food)/sneak	kanda	to insist/weave
benga	to fill	kanga	to startle
biika	to lay (eggs)	kema	to try/whine
bika	to announce a death	kenda	to walk feebly
gaana	to refuse	kenga	to observe
gaga	to spoil	kuba	to strike, beat
gamba	to say to, tell	kuma	to make, keep up fire
ganga	to cure/put tobacco in pipe	kumba	to walk w/ airs
gema	to immunize	kunga	to cry out/be amazed
genda	to go	kuuba	to plane, polish
ggula	to open	kuuma	to watch
goba	to drive away	kuuta	to rub
gomba	to tie crosswise	liima	to spy
gooma	to bend over	lima	to cultivate
guba	to be stunted	saaba	to smear
gula	to buy	saaga	to say in jest
guma	to be solid	saaka	to beat cloth/get warm
kaaka	to shake	saana	to join/sink
kaka	to force	saba	to pray

sagga	to drive away
saka	to forage
samba	to hurry
sanga	to come upon
siba	to tie up
siga	to sow
siiba	to spend the day
siiga	to smear
siima	to be pleased with
sika	to pull
sima	to dig
simba	to plant
sina	to nauseate
sinda	to groan
singa	to pledge
sita	to plait
soba	to be over & above
sogga	to spear to death
soma	to read
somba	to bring 1 by 1
sona	to stitch
sonda	to gather
songa	to prod
sooba	to go carefully
soona	to disconcert
sotta	to crush
suba	to miss out
sukka	to pass
suna	to pinch
sunda	to churn
sunga	to jeer at
suuba	to swing to & fro
suuta	to praise
teeba	to aim
teega	to lie in wait
teeka	to be clear
tega	to strain
tema	to chop
tenda	to praise
tenga	to wag (tail)
tiba	to caress
tiga	to handle
tikka	to put load on s.o.'s head
timba	to bind
tinda	to hop over
toga	to crush in hands
tona	to tint/make a present
tonda	to be in embryo
ttuka	to break out again (sickness)
tuga	to choke
tugga	to tie
tula	to become sharp
tuma	to send
tunda	to sell
tunga	to sew
tuuka	to arrive, reach
tuuma	to give name to/heap up

Vowel durations are as follows:

(46) V duration by length category

	mean	*SD*
short	96.6	24.1
pre-NC	195.6	28.4
long	239.7	31.0

(47) Vowel duration by identity and length category

	short	*pre-NC*	*long*
a	121.0	219.7	268.4
e	111.7	209.8	233.3
i	77.2	160.1	224.8
o	105.5	197.6	240.5
u	88.0	170.1	217.1

Note that the relationships between surface vowel categories in Luganda is different from that of CiYao:

(48) Luganda: length categories

	mean diff.
short vs. long	143.1
short vs. pre-NC	98.9
long vs. pre-NC	44.2

(49) Luganda: length ratios

	lengthened	*long*
ratio to short V	2.0	2.5

As in CiYao, a compensatorily lengthened vowel is fully twice the duration of a lexically short vowel — but unlike CiYao, Luganda's lexical long vowels are two and a half times as long as short vowels. Still, these two categories of vowel (long and lengthened) pattern together phonologically in Luganda, while they do not in Runyambo (as we see in the next section). Runyambo shows much more dramatic differences between lengthened and long vowels; with respect to the durational output of CL, Luganda patterns together with CiYao and Kikerewe, and apart from Runyambo. I will claim that the differences between CiYao-type CL and Luganda/Kikerewe-type CL are phonetic, while the Runyambo-type CL differs from the others phonologically.

3.3.4 Runyambo

The data in this section were elicited from three native speakers of Runyambo, one adult female and two adult males. Speakers read tokens three times, in isolation, without a frame sentence. The corpus is given in (50).

(50) Runyambo corpus

-gaba	'give away'
-gamba	'speak'
-goba	'reach, arrive'
-gooba	'bend'
-gomba	'desire'
-kooba	'climb'
-kômba	'lick'
-kúba	'fold'
-kuuba	'polish'
-kumba	'tilt, fall over'
-sáaga	'be left over'
-sanga	'come upon'
-siba	'to imprison'
-siiba	'pass time at'
-simba	'erect sthg'
-síga	'leave behind'
-siiga	'smear'
-singa	'scrub'
-sînga	'beat (in contest)'
-sona	'sew'
-sonda	'peck'
-tana	'fester'
-táana	'go separate ways'
-tanga	'forbid'
-téga	'shave'
-teega	'cast magic spell'
-tenga	'excommunicate'
-tuga	'choke'
-tûnga	'become rich'

Because penultimate syllable position in Runyambo is prosodically prominent (all syllables in this position are somewhat lengthened, and it is the only position in which falling tones are licensed), each verb was elicited in two different contexts: in infinitive form, where the target syllable was penultimate; and in inflected form with a following clitic, where tonal distinctions were neutralized and the target syllable was antepenultimate.

An important result is that the surface contrast between short, long, and compensatorily lengthened vowels is consistent across speakers and prosodic environments. Prosodic position has the strongest secondary effect; vowels of all three length categories are typically 20-40ms longer in penultimate position than elsewhere. However, the interaction of this effect with phonological length is not enough to obscure the categorial distinctions.

Pooled data are shown in (51-52):

(51) Runyambo vowel durations

	mean	*s.d.*
short	110	35.4
long	215	38.3
pre-NC	168	31.6

(52) Runyambo: length categories

	mean diff.
short vs. long	105
short vs. pre-NC	58
long vs. pre-NC	47

Though the differences between categories do not look very large compared to the standard deviations, analysis of variance shows that they are statistically significant to at least 99% (by pairwise one-way ANOVA's and post-hoc significance tests). The apparent magnitude of the standard deviations in the pooled data results from effects of prosodic position, vowel quality, and between-speaker differences. But statistical tests also ruled out significant interference from any of these factors, as well as effects of tone, place of articulation of consonants, and list intonation.

After length category, the most significant effect on vowel duration was that of prosodic position: penultimate vowels were significantly longer for all speakers. However, since the *ratio* of short:lengthened:long vowels was comparable in the two environments, values reported here are means for the total data set. There were only two other effects of interest: between-speaker differences, and inherent differences in vowel quality. (Effects of tone, place of articulation of following consonant, and repetition number were negligible.) Still, the perturbing effects of these two factors were not strong enough to obscure the categorial distinction of short vs. lengthened vs. long vowels. Tables (53) through (56) show the statistical results for these factors.

(53) Runyambo: vowel duration by speaker (in milliseconds)

Speaker	*V*	*V:*	*VV*
JR	101	174	219
AK	104	152	201
LR	130	180	222

(54) Runyambo: ANOVA - significance of speaker effect

	df	*sum of squares*	*mean square*	*F test*	*P value*
Speaker (A)	2	40206.363	20103.181	18.594	.0001
Length category (B)	2	659150.359	329575.18	304.833	.0001
AB	4	13606.606	3401.652	3.146	.0144

(55) Runyambo: vowel by identity, length category

	short	*pre-NC*	*long*
a	130	176	220
e	132	182	233
i	68	141	184
o	114	175	238
u	113	175	229

(56) Runyambo: ANOVA - significance of vowel identity

	df	*sum of squares*	*mean square*	*F test*	*P value*
Vowel identity (A)	4	156069.761	39017.44	45.358	.0001
Length category (B)	2	670385.257	335192.629	389.659	.0001
AB	8	13664.521	1708.065	1.986	.0467

A brief excursus on glides is necessary at this point: although CL from glide formation is not addressed systematically in this study, pilot measurements show that in Runyambo the lengthening of a vowel after CG is of the same degree as that before NC.[28] That is, in verbs such as *ku-byaama* and *ku-twaara*, the duration of the steady-state vowel — defining the boundary between glide and vowel as the point of rapid transition in formant structure and energy change in the waveform — is the same as that of the vowel in verbs like *ku-tanda* and *ku-simba*. This may be taken as evidence that the two lengthening processes are the same, and that they are phonological and not a matter of phonetic implementation.

Another Tanzanian Bantu languages shows CL characteristics similar to those of Runyambo: in (57), measurements from Sukuma (Maddieson 1993) are compared with Runyambo.

(57) Vowel durations compared (Sukuma from Maddieson 1993)

	short	*lengthened*	*long*
Runyambo	110	168	215
Sukuma	129	200	280

It is useful to compare not only the durations in milliseconds but also the ratios between the different vowel types in each language, as in (58).

(58) Ratio of vowel durations (to short vowel)

	short	*lengthened*	*long*
Runyambo	1	1.5	1.9
Sukuma	1	1.6	2.2

---

[28] Runyambo is the only language in this study in which I measured CGV sequences; when it became clear that they were much more time-consuming to measure than VNC sequences I decided to restricted my investigation to the latter. Still, it is significant that in Runyambo, all three speakers show exactly the same degree of lengthening in CGV environments as in VNC. I predict that the same will be found in other Bantu languages that have CL.

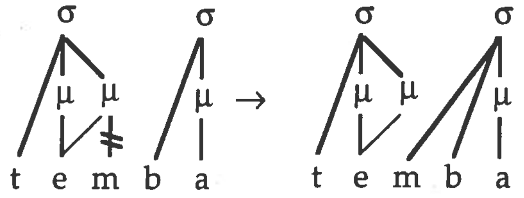
Clearly, the process of compensatory lengthening does not operate the same in way in these languages as in CiYao, Kikerewe, and Luganda.

(59) Ratio of vowel durations (to short vowel)

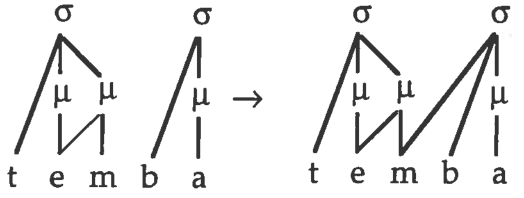
	short	*lengthened*	*long*
CiYao	1	2.1	2.2
Kikerewe	1	1.7	1.8
Luganda	1	2.0	2.5

In these other languages, a lengthened vowel is two to two and a half times longer than a short vowel, while in Sukuma and Runyambo it is approximately one and a half times longer. Comparison of Sukuma and Luganda led Maddieson (1993) to conclude that the compensatory lengthening rule in Sukuma differs from that of Luganda in that the nasal does not delink from its mora when the preceding vowel links to the same mora; rather the mora is shared between the two segments.

(60) a. Luganda:

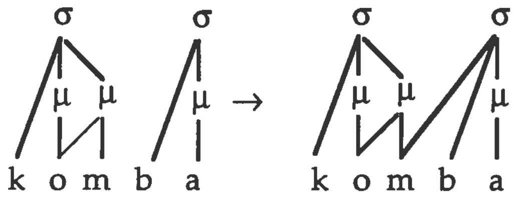


b. Sukuma:



Maddieson shows that the Sukuma lengthened vowel cannot derive from phonetic lengthening or from shortening of a long vowel; it arises from compensatory lengthening as in Luganda, except that the nasal remains linked to its original mora. The measurements of Runyambo reported here show that it is like Sukuma rather than CiYao et al. in this regard (a lengthened vowel is closer to one and a half times the duration of a short vowel), so the representation given for Sukuma in (60b) is taken to be valid for Runyambo as well:

(61)
Runyambo



In the case of Runyambo, however, it is possible to argue for this proposed representation not only on phonetic grounds, but for phonological reasons as well. If we compare Runyambo to Luganda, we find that the two languages assign different status to nasals at the level of tone assignment. Runyambo and Luganda have very similar two-tone systems (surface High and Low, of which only H is marked here),and both have a grammatical rule that assigns a H tone to the second mora of a verb stem in certain tenses (see section 1.5). As seen in (62), the inflectional H goes to the second vowel of the stem (in this case indistinguishable from the second syllable), whether that position is part of the root or a suffix.

(62) H tone assigned to second mora of verb stem in certain tenses:

Luganda	a-**jun-á**...[29] 3sg-help-FV	'he who helps'
	a-**gulúk-a** 3sg-gallop-FV	'he who gallops'
Runyambo	a-**jun-á**... 3sg-help-FV	'he helps'
	a-**gurúk-a** 3sg-jump-FV	'he jumps'

---

[29] The notation ... indicates that the form is not phrase-final.

In roots with long vowels, the grammatical H goes to the first syllable rather than the second, indicating that it is the mora that is targeted by the tone rule; since rising tones are not permitted in either language, a syllable with H tone on the second mora surfaces as all-H.

(63) Second mora in a long vowel (later H tone simplification)

Luganda	a-**siíg-a**... 3sg-smear-FV	'he who smears'	[asííga...]
Runyambo	a-**siíg-a**... 3sg-smear-FV	'he smears'	[asííga...]

So in both languages, the tone assignment rule in these verb tenses targets the second mora of the stem, whether that is in the first or second syllable.

The difference between Luganda and Runyambo arises when there is a nasal-consonant sequence internal to a verb root.

(64) Root-internal nasal:
counts as second mora in Luganda, but not in Runyambo

Luganda	a-**bíng-a**... 3sg-chase-FV	'he who chases'	[abíínga...]
Runyambo	a-**bing-á**... 3sg-chase-FV	'he chases'	[abiingá...]

In Luganda, the nasal counts as the second mora in the verb stem and receives the H tone (with simplification as in long-vowel roots); in Runyambo, by contrast, the nasal is not counted as a mora and the H tone goes to the next available tone-bearing unit, namely the vowel in the second syllable.[30]

---

[30] Phonetically, the tone of the nasal in this context continues that of the preceding vowel, in both languages.

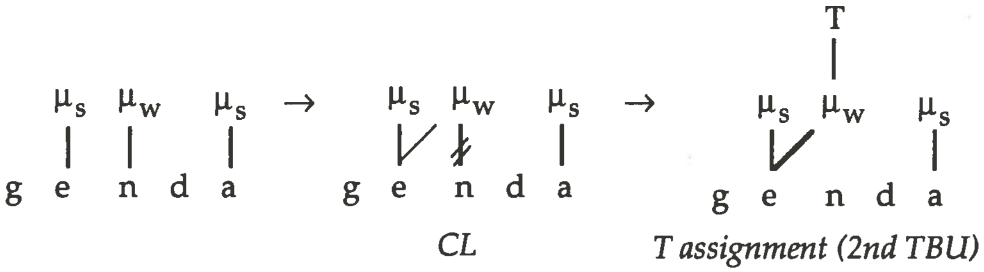
But does this finding account for the difference between Runyambo and Luganda with respect to tone assignment? Recall that the tonal difference was framed as one of moraic status of a nasal: the Luganda nasal "counts" as a mora, while the Runyambo nasal does not. But as Hyman (1992) points out, the Runyambo nasal must be a mora for purposes of compensatory lengthening — that is, a nasal in the sequence VNC must have weight in order to give it up to the vowel. Moreover, the nasal is also moraic in the morphological processes of reduplication and suffixal allomorphy (§1.5). Rather than positing two kinds of mora, one for quantity and another for tone, Hyman focuses on the tone-bearing potential of a mora, distinguishing head from non-head moras.

(65) Constraint on tone-bearing potential of the mora in certain languages (Hyman 1992):

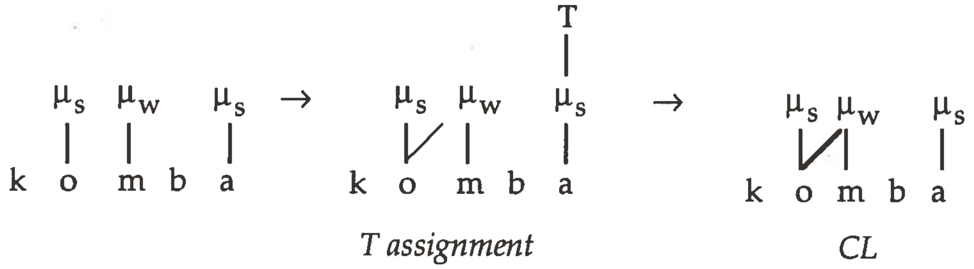
TBU = a. the head mora (μ_s) of a syllable
b. the non-head mora (μ_w) of a syllable, if it dominates a [-cons] root node

In other words, the first or only (therefore strong) mora of a syllable can always bear tone; if a syllable contains more than one mora, the second (weak) one may only bear tone if it is linked to a vowel. This accounts for the fact that in languages like Luganda and Runyambo, a word-initial nasal before consonant, which is fully syllabic (i.e. has long duration), also bears tone. But in non-initial position, Hyman says, a nasal cannot be a TBU — either in Runyambo *or* Luganda. The tonal difference in verbs is accounted for by ordering compensatory lengthening *before* tone assignment in Luganda, but *after* tone assignment in Runyambo.

(66) a. Luganda:



b. Runyambo:



In (66a), the H tone looking for the second tone-bearing unit finds it in the second mora, which has already been reassigned and dominates a vowel. In (66b), however, the H tone cannot dock on the second mora, because that mora is weak and dominates a consonant.

This account can now be simplified on the basis of the new durational evidence from Runyambo and Luganda: instead of positing a difference in rule ordering, we can say that the tone bearing unit in these languages is either (1) a strong mora or (2) a weak mora which is *uniquely* linked to a vowel. This solution to appeals to the Linking Constraint proposed by Hayes (1986), which states that association lines in structural descriptions are interpreted as exhaustive. That is, if the possible TBU's of Runyambo and Luganda are specified as in (67), then (68) does not count as equivalent to (67b) and it cannot be a site for tone docking.

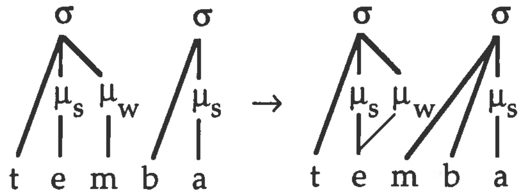
(67) a.

b.

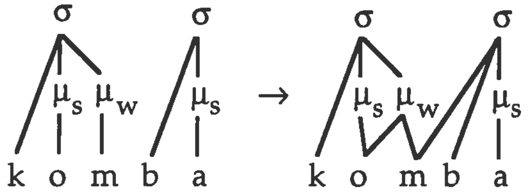
(68)

Since Runyambo CL differs from that of Luganda in not delinking the nasal, the weak mora ends up multiply linked (as in (69)), and cannot serve as a TBU.

(69) a. Luganda:



b. Runyambo:



Thus by slightly altering Hyman's constraint as in (44), the tonal difference between Luganda and Runyambo can be accounted for without any difference in rule ordering, in a way that accords with the durational facts.

(70) Revised constraint on potential TBU:
TBU = a. the head mora (μ_s) of a syllable
b. the non-head mora (μ_w) of a s, if it dominates no [+cons] root node

I have shown, then, that phonological differences between Luganda and Runyambo NC's are reflected in phonetic realization. The tone assignment asymmetry results from the difference in compensatory lengthening in the two languages; in Luganda a nasal gives up all of its moraic weight to a preceding vowel, while in Runyambo a nasal shares its mora with a preceding vowel — and this phonological claim is supported by the ~150% duration of lengthened vowels in Runyambo, as opposed to the much longer counterparts in Luganda.[31]

Of languages with the type of CL common in the Bantu family, then, CiYao represents the most transparent mapping of phonological timing structure to phonetic output. Kikerewe is nearly the same but shows a slightly greater difference between lengthened and long vowels, and the ratios of these to short vowels is not as great as it is in CiYao — i.e. the two-to-one phonological count is not fully manifested phonetically. Luganda goes in the other direction, with both long and lengthened vowels being *more* than twice the duration of short vowels, and with a still greater disparity between long and lengthened vowels. All of these have the same phonological output from CL and vary in the phonetic details of how this phonological output is interpreted phonetically; Runyambo, meanwhile, differs from them all in having a *phonological* distinction between lengthened and long vowels, which is reflected in the half-length added to lengthened vowels phonetically. In the following sections, we turn to languages that possess neither lexical length distinctions nor compensatory lengthening.

3.4 Languages with no length contrasts

3.4.1 KiNdendeule

KiNdendeule is spoken in southern Tanzania; it is classified by Nurse (1988) in the Rufiji-Ruvuma group, which also includes Kingindo (Guthrie P.14)

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[31] There *is* a mora-counting rule in Sukuma that moves an underlying H tone two moras to the right; interestingly, a preconsonantal nasal may either count as a landing site for this tone or not (in free variation). This may be taken as evidence that the mora is split, since the nasal has both moraic and non-moraic properties (Batibo, p.c. with Ian Maddieson).

and Kimatuumbi (P.13). The corpus used here was drawn from work with a native speaker at UCLA in 1992.

KiNdendeule has seven vowels:

1	i		u
2	I		U
3	e		o
4		a	

For typographical convenience, height 2 vowels are represented as I and U. It is often difficult to distinguish the height 1 and height 2 vowels; /i/ and /u/ (height 1) are very high, and the slight difference between them and /I/ and /U/ (height 2) is primarily a lowering of the tongue root. On these grounds, it would seem best to describe the height 1 vowels as [+ATR], but for distributional reasons (they are the unmarked elements), and because there is no apparent ATR harmony (i.e. the feature does not seem to be an operative part of the phonology), I represented them here as /i/ and /u/.

KiNdendeule has no contrastive vowel length, very limited vowel hiatus,[32] and no penultimate lengthening of the sort found many languages to the south. For this reason, Kindendeule provides an important baseline in the study of Bantu quantity. Two questions are immediately relevant: first, how much variability is there is vowel duration in a language with no quantity distinction (and what factors determine that)? And second, what is the duration of vowels before NC sequences?

The KiNdendeule corpus is as follows:

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[32] In KiNdendeuli /h/ has replaced most of the other fricatives: for example, "laugh" is *kuheka* (< s), "come" is *kuhika* (< f), etc. Apparently for some speakers, those /h/'s are optional — so the language is on its way to having vowel sequences like those of Swahili.

(71)

báránga	count	kánga	push
bóna	see	kínda	close
bópóra	untie	kÍngúra	shave
bútúka	run	kíríma	smear
céga	dawn	kóma	kill
cénga	build	kónga	cheat
díndúra	open	kóngóla	pour wine
gÚrÚra	wash dishes	kÚnga	tie
híka	come	kúnga	butt, fight
hína	dance	léka	leave
húba	ferment	léta	bring
húca	throw	rángíha	show
húma	be deep (color)	róngéra	speak
hÚmba	jump	tába	tie
húna	harvest	tága	throw away
húnda	teach	tángátíra	help
hyíma	hunt	téna	castrate
jénda	go	ténda	do
jÍmba	sing	tyánga	walk

Mean durations for vowels in CVC and CVNC environments are shown below (all durations are in milliseconds).

(72) KiNdendeule vowel duration

	mean	*SD*
CVC	147.9	(33.7)
pre-NC	145.5	(26.6)

The most significant effect on vowel duration is vowel identity:

(73) KiNdendeule: V duration by identity

	mean	*s.d.*
a	166.4	(32.5)
e	161.9	(22.2)
I	147.7	(20.9)
i	130.7	(26.4)
o	149.8	(31.5)
U	150.6	(22.1)
u	131.5	(22.0)

Analysis of variance shows that the most significant differences are between /a/ and the high vowels (/a/ is at least 35ms longer than /u/ or /i/), and next most significant is the difference between /e/ and the high vowels (/e/ is at least 30ms longer than /i/, /u/). The vowel /o/ falls in the middle of this span. So position before NC does not affect a vowel's duration, but identity of the vowel does.

In fact, not only do vowels not lengthen in the pre-NC environment, but certain vowels are slightly *shorter* in that position (there were not enough I or U tokens to analyze in this test):

(74) KiNdendeule: V duration by identity and environment

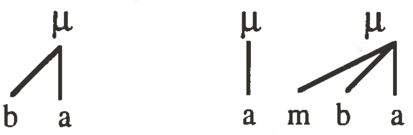
	CVC	*CVNC*
a	183.4	155.0
e	164.1	159.1
i	120.5	139.0
o	161.5	138.1
u	128.1	138.4

All but the high vowels, for this speaker at least, behave like vowels in many other languages that are shorter before a sequence of consonants than before a single consonant ("closed syllable vowel shortening", Maddieson 1985). The fact that there is no consistent directionality in vowel duration in these two environments argues against any phonetic explanation for the phenomenon of pre-NC lengthening found in so many other Bantu languages: if that lengthening were a strictly phonetic phenomenon, we would expect to see at least a small trace here, perhaps only a few milliseconds but always in the same direction (longer before NC). Since this does not occur, we can conclude that there is no phonological or systematic phonetic effect of pre-NC position on vowels in

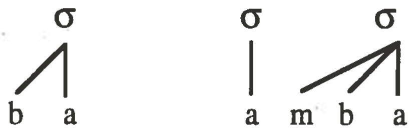
KiNdendeule, and we can argue that no phonetic lengthening in this position is likely for other Bantu languages.

Since there is no CL, how should the moraic structure of KiNdendeule be represented? Should we assume there is any process of prenasalization? While I have measured nasals and consonants (and gotten similar results to other Bantu languages, namely NC is not timed as a single segment), I have not yet identified any phonological information that shows whether a nasal in the VNC context can receive tone assignment (i.e., it is not possible to distinguish whether the tone-bearing unit is the syllable or the mora, because there is no opposition). Since there is no vowel length contrast, and no lengthening before NC that might suggest remorification, there is probably no need for both a syllabic and a moraic tier. Depending on one's theoretical viewpoint, there are at least three possibilities: (a) it might be sufficient simply to assign moras to vowels, then let consonants attach as onsets, and where the sequence arises, let nasals attach as codas (no need for syllables); (b) vowels could project syllable nodes directly, and then adjunction would proceed as in (a); or (c) nasals might project a syllable of their own (more phonological information is needed to decide this).

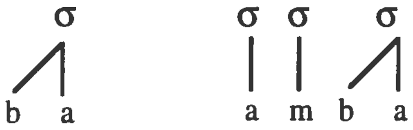
(75) a.



b.

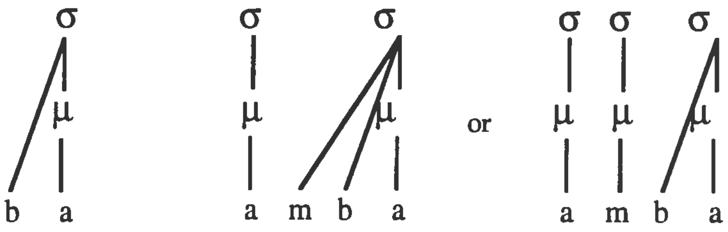


c.



The question of universality in phonological representation is an open one: if there is no evidence that a particular element of structure is relevant in the lexicon or rule system of a given language, should we include it in our grammar? One possibility is to posit known prosodic structures (at least at the level of syllable and mora) to universal grammar, not allowing individual languages to opt out of either layer of structure (e.g. Zec 1988, David Odden pers.comm.).

(76)



Under this view, languages like KiNdendeule would indeed have both syllables and moras, and there would simply be an exceptionless one-to-one correspondence between the two. This is the assumption I will maintain throughout this study.

3.4.2 Kilega

Kilega (Guthrie D.25), spoken in Zaire, has a seven-vowel system similar to that of Kindendeule. The height 2 vowels, represented here as *E* and *O*, are the marked set in the lexicon, and are difficult to distinguish from the height 3 vowels (*e* and *o*). There is no long/short distinction in vowels.

height 1	i		u
height 2	E		O
height 3	e		o
height 4		a	

Preliminary examination of formant structure indicates that in fact E and O are spectrally very similar to e and o, and that there may be a voice quality distinction at play, namely breathier voice on E and O (thanks to Robert Botne (p.c.) for first observing this). But since the present data set does not include enough tokens to perform detailed formant analysis, I leave this issue for future research.

The data were provided by two consultants, one adult female speaker (K) and one 15-year-old female speaker (J). While speaker J has all seven vowels in her speech, she did not produce the height 2 vowels (E and O) in this elicitation: the two are not distinguished orthographically (both are spelled *e* and *o*), and this speaker did not consult the glosses as speaker K did to produce the desired vowels. So values reported for E and O were obtained only from speaker K.

(77) Kilega corpus

baga	cut meat into pieces
bamba	catch
banga	copulate (of fowl)
bega	shave
benda	snap
benga	chase away
boba	copulate (of goats, etc.)
bomba	disappear
bonga	rub lotion
buga	break, smash
buluta	pull
bumba	shape, make
bunga	rub soap, lather
buta	"mettre au monde"
gaba	give in marriage (father)
gaga	spoil (of cooked food)
galuka	change
gamba	gossip, speak ill of s.o.
gana	to relate, tell tale
genga	spill (intr)
goga	grind
gomba	beat (drum)
gona	snore
gonda	tie, wrap
guba	keep liquid, food in mouth
gula	buy, sell
guma	be rich
gumba	roast (meat/fish) in leaves

kaga	place fetish to scare peo. away
kaka	burst (intr, of glass, calabash)
kama	dry (intr)
kamba	work, esp. in field
kana	pack
kanda	tie
kanga	scare
kega	make dam
kema	make palm wine
kéma	shock (electricity)
kenga	sharpen (knives, machetes)
keta	do
kinda	win
koka	be enough
kOka	chop
koma	plant
komba	wipe
konda	stoke fire, turn roasting food
kOnga	care for s.o.
kuba	be stunted
kuka	be many / bang
kumba	bend (tr)
lola	look at
mona	see
raba	burn (of venom)
raga	scoop liquid
ramba	become lukewarm
randa	crack open (nuts)
ranga	be first
rega	set traps
rema	drop
rena	run away
rEnda	be undercooked
renda	speak
renga	be alive
rera	be unstable
rima	jump, hop
rimba	circle
rinda	fall (tree)
roga	drip (intr)
roka	depart, leave
roma	claim from group
rOma	send
rona	deny
ronda	like, love
ronga	moan
rOnga	string beads
rora	be soft (mud)
ruba	be dull (blade)
ruga	farm animals
ruka	leave
ruma	jump up & down
runda	put aside
saga	grind tobacco
saka	make tattoo
samba	be mixed
sana	light up (tr)
sanga	to meet
sega	ask
seka	pick on (embêter qqn.)
semba	offend
siga	leave behind
sinda	cut (tree)
singa	rub soap, lather
soba	avenge
soga	wash (clothes)
soka	cross
sola	tell
soma	read
somba	hate
sOmba	swing
sona	sew
sOna	provoke
sonda	try, taste
songa	marry (man)
sunda	smell bad (e.g. meat)
sunga	mediate

Vowel durations are as follows:

(78) Kilega: V by identity

	Mean:	*Std. Dev.:*
a	125.1	23.7
e	119.8	26.6
i	103.5	22.8
o	113.6	25.8
u	107.5	27.9
E	*133.4*	*4.1*
O	*134.6*	*25.8*

(79) Kilega: ANOVA - significance of vowel identity

Source:	*DF:*	*Sum Squares:*	*Mean Square:*	*F-test:*
Between groups	6	32408.043	5401.341	8.244
Within groups	549	359689.416	655.172	p = .0001
Total	555	392097.459		

Excluding the height 2 vowels, we can compare the vowel identity effect with the speaker identity effect.

(80) Kilega: ANOVA - significance of vowel identity, speaker

Source:	*df:*	*Sum Squares:*	*Mean Square:*	*F-test:*	*P value:*
VQ (A)	4	27949.039	6987.26	12.846	.0001
spkr (B)	1	41522.333	41522.333	76.341	.0001
AB	4	2158.429	539.607	.992	.4113
Error	531	288815.611	543.909		

(81) Kilega: V by identity, speaker

	K	J
a	137.8	113.2
e	127.9	111.9
i	110.3	97.0
o	125.3	100.9
u	117.8	98.0

As expected, there is no lengthening of vowels in VNC environments.

(82) Kilega: ANOVA - significance of V identity, pre-NC environment

Source:	*df:*	*Sum Squares:*	*Mean Square:*	*F-test:*	*P value:*
VQ (A)	4	25869.491	6467.373	9.815	.0001
VC (B)	1	900.923	900.923	1.367	.2428
AB	4	2095.974	523.993	.795	.5286
Error	531	349903.201	658.951		

(83) Kilega: V by identity, environment

	CVC	CVNC
a	124.8	125.5
e	120.4	119.0
i	109.0	101.2
o	112.9	114.8
u	110.8	102.2

As in Kindendeule, identity is the chief determinant of consonant duration; speaker identity is not significant for C1 and is only slightly significant for C2. Aggregate C duration is significantly affected by speaker, but not enough to override identity. Consonant position is not significant, for either speaker, nor is vowel identity or any other factor.

(84) Kilega: C by identity, speaker

	K	J	aggregate
k	86.5	94.9	90.8
b	71.0	85.3	78.5
g	63.8	78.9	71.6
s	125.5	134.9	130.0
r	23.2	17.2	20.4
l	49.2	64.5	56.8
m	80.5	83.6	82.0
n	61.7	68.4	64.9

(85) Kilega: C by identity, position

	C1	C2	aggregate:
k	93.1	85.3	90.8
b	81.8	72.9	78.5
g	77.9	66.2	71.6
s	130.0	•	130.0
r	20.4	20.2	20.4
l	57.8	56.5	56.8
m	88.0	81.3	82.0
n	•	64.9	64.9

Pre-consonantal nasals, in contrast, do not differ much by identity: between-speaker differences overshadow the identity effect.

(86) Kilega: ANOVA - pre-consonantal nasal by identity, speaker

Source:	*df:*	*Sum Squares:*	*Mean Square:*	*F-test:*	*P value:*
identity (A)	2	677.716	338.858	3.173	.0437
speaker (B)	1	4971.668	4971.668	46.552	.0001
AB	2	20.781	10.391	.097	.9073
Error	230	24563.633	106.798		

(87) Kilega: N by identity, speaker

	K	J
m	77.4	87.4
n	73.9	82.5
ng	75.8	84.8

In short, Kilega is like KiNdendeule in having no lexical length contrast and no compensatory lengthening. In this type of language it seems likely that an algorithm for mapping underlying timing to surface timing will make greater use of segmental information than moraic information, while the languages in section 3.3 will give higher priority to moraic status. I now turn to the superficially puzzling phenomenon of languages that appear to have long vowels but do not have any compensatory lengthening.

3.5 Languages with length but no lengthening

3.5.1 CiTonga

CiTonga, spoken in Zambia (Guthrie M.64), has been primarily analyzed for its tonal system (Pulleyblank 1986, Goldsmith 1984, Meeussen 1963, Carter 1962); the dialect reported here is Valley Tonga, not the Plateau Tonga of previous studies. This language has a surface vowel length contrast, though minimal pairs are few. CiTonga has the usual five vowels; it also has vowel sequences in hiatus such as /au/ and /ai/: *kusundauka* 'to try in various ways', *kubbutaila* 'to parcel up'. The corpus used is as follows (double consonants are orthographic, not geminate; e.g. b = [β], bb = [b]):

(88) CiTonga verbs

baba	itch	cembaala	become old
bamba	make, take care of	cenga	deceive, cheat
bandika	converse	cetaala	become poor
banga	knock out teeth	cinga	go to meet
bbaatilwa	be busy	cita	do, act
bbadela	pay for	cumba	rub, polish
bbila	sink	diimana	become bent, stooped
bbindamuna	turn upside down (tr)	donkola	bore a hole
bbubbula	blow (wind)	donta	poke
bbutaila	parcel up	dooneka	doubt; set fire
benda	stalk game	duntauka	palpitate
beteka	judge	eeleba	have problems
binda	be in a hurry; deny	eema	be afflicted
binga	drive cattle	eepa	clean yard
bomba	be humble, soft, wet	fooma	hiss
bona	see	fuba	be half
boola	come	fubaala	act foolishly
bota	become good	fugama	kneel
bumba	mould pottery	fuma	get up early
bunda	become worn	fumpa	become blunt
bungana	gather (intr)	futa	rise (of bread)
butika	put a child to sleep	fwepa	smoke tobacco
bwentela	scold	fwinkila	sniffle, shiver
caala	remain behind	gama	go in the direction of

gamba	patch; wonder
ganka	sow
gonka	cut, chop
íimba	sing
íita	call
jana	find
jata	catch
jika	cook
joka	return
kamba	clap hands
kanana	speak, discuss
kanda	knead
kanga	fry
kanka	begin
kasaala	be warm
kkazika	set at rest
kolota	borrow
komba	plead
komena	grow, become big
konda	please
konga	frighten away
kopa	stir
kosoola	cut up
kumba	brew; incubate; rub
kumbila	ask for, request
kunka	stoke a fire
kwiila	scream
laba	flash; blink
lamba	smear the body
lampa	be long
landuka	cross stream
langa	look, look at
langaula	look for, look around
lemba	write
lenga	create
liiba	be free
limba	cover, fall down on
linda	wait
linga	beg
lingula	check on
lomba	ask for
londa	guard
londola	keep safe
longela	pack baggage
lumba	thank, pray
lundika	pile up
lunduka	run
lunga	pay fine; season w/ salt
lweela	be sweet
mana	finish
mena	swallow
mina	blow the nose
mita	conceive
myankuta	lick
nana	anoint
neneya	become fat
nenga	cut flesh
nona	taste good
nyaana	scramble for
nyanga	deprive of, take away
nyongana	become upset
nyonka	suck (of child)
pampula	cut out a piece
panda	break new ground
panduka	become split
pandula	split (tr); operate (med.)
panga	make, prepare
panuka	be clever
papa	go sour
peela	sweep
pembula	shave round head
penga	suffer, go mad
peta	roll, fold up
piila	spurt; sacrifice
pindula	twist
pompa	appear in view
pona	live, get well
popa	care, mind
puta	move about, be stubborn
saala	sack, ravage
sabaula	cut into small pieces
sabila	disturb by making noise
sakana	go far away
sama	put on clothes
sambala	trade, sell
sampuka	deteriorate
sanduka	invert (intr)
sandula	change (tr), translate
sanka	jeer
seba	sieve

seka	laugh
senda	make love to
senga	ask for
sengula	propose
siba	whistle
siila	leave for
sika	arrive
sima	get strong, grown up
simba	make mark
simbula	frown
simpa	plant
sina	throttle
sinda	prepare new land
singa	curse
sinka	obstruct, stop up
sinkuka	unstop
sinta	moan
soka	attack, provoke
solomba	toss in pain, writhe
somba	feed a stranger
somona	bear first child
sonda	divine (by witchcraft)
sondela	peep
sondoka	go mad
soola	scare off
soomona	have diarrhea
sotoka	leap, bounce, skip
suba	urinate
suma	sew, knit
sumpa	bore as insects
sunda	be a nuisance
sundauka	try in various ways
sundila	annoy
sunga	bind, tether
sunka	tempt, examine
swaana	meet each other
swaangana	meet each other
taaluka	step over
taanguna	be the first
taba	support; respond
tafuna	chew
takata	fuss, balk
tama	accuse
tamba	invite
tambula	take from, receive
tandaanya	pursue
tanga	begin (of rains)
tangala	crave
tanta	climb, mount
tebela	be relaxed
teelela	listen to, obey
teka	draw water
tekaana	shake, rock (intr)
tema	cut, chop wood
tenda	cut with knife
tenga	grumble
tenta	burn (tr)
teta	become wet, soft, easy
tijaana	run, run a race
tika	spill
tinga	throw wrestling opponent
tingaana	wrestle
tinta	change
tombayila	go reluctantly
tomoona	eat little of
tondeka	aim, point at
tondezya	show
tonga	groan
tongooka	complain
tonka	push
tonta	push
tontola	be cold; be quiet
toogwa	be dazzled
tuba	be white
tuma	send
tumbuka	give birth
tumpa	become septic
tunta	pour
tyanka	squeeze
tyompya	disappoint
vakaca	go about, visit
vuba	tame; possess
vuna	save
vunda	rot
vunga	fold
vuuma	roar
vuumuka	rush
vwenta	look for
vwiila	reply to
yaama	lean (intr)

yaamika	lean (tr)	ziima	be foolish
yandaula	look for	zima	extinguish
yandika	be beloved	zimba	swell
yuuna	shake, quake (intr)	zinga	attack
zabana	make mischief	zubuka	cross a river
zamba	wind, coil	zumbaana	swing from
zanduka	separate from (intr)	zunda	conquer
zeeleka	stagger	zunga	wander about
zeka	try case in court	zungaana	quake, shake (intr)
zemba	pace up and down	zunta	throb
zenta	wander about	zutuka	get broken, as rope
zeta	disappear		
ziba	castrate		

Vowel measurements are as follows:

(89) CiTonga vowel duration

	mean	*s.d.*
long	240.6	39.7
short	100.3	28.3
pre-NC	101.4	22.4

The identity effect on vowel duration is small:

(90) Vowel duration by identity and category

	long	*short*	*pre-NC*
a	282.4	121.1	110.5
e	232.2	112.8	106.4
i	239.2	73.2	92.9
o	235.1	106.6	104.8
u	207.9	77.3	91.7

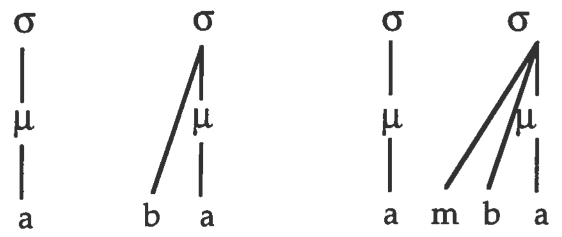
It is significant for the pairs a/u, e/u, and o/u, but not nearly as strong as the Kindendeule identity effect.

The surprising result here is that in CiTonga, vowels before NC are the same length as short vowels, while long vowels are more than twice as long. This is precisely the reverse of our most-canonical CL language, CiYao (where pre-NC vowels are the same length as lexical long vowels). So although a glance at the wordlists of CiYao and CiTonga might suggest that they have the same length categories, their phonetic timing is quite different.

It turns out that CiTonga does not preserve historical length: roots that are reconstructed to Proto-Bantu with long vowels have short vowels in CiTonga. After the Proto-Bantu length distinction was lost, new long vowels arose from consonant loss and morphological concatenation (sometimes no longer apparent). In reality, CiTonga has "regular" vowels (which, as in Kindendeule, are no different in CVC and CVNC environments), and it has "long" vowels that arose from vowel sequences. In fact, vowel hiatus sequences such as /ai/ (245.4ms) and /au/ (212.9ms) are quite comparable in duration to monophthong long vowels. Long vowels — which are highly marked in the language, and are much longer in relation to short vowels than the corresponding vowels in CiYao — are really bisyllabic, just like /ai/ and /au/. The reason CiTonga has no compensatory lengthening is that the structure for it does not exist: there are no vowels linked to two moras, so there is no rule that produces such a structure.

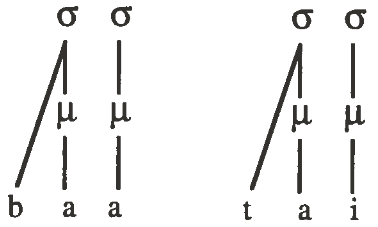
CiTonga thus has long syllables but not long vowels. A plausible representation of this has each vowel projecting a syllable (or mora and syllable, as in (91)). This would mean that V alone is a legitimate syllable.

(91)



The apparent long syllables, then, would be represented as follows:

(92)



More complex evidence for disyllabic representation of apparent long vowels comes from Chichewa, to which I now turn.

3.5.2 Chichewa

Chichewa is spoken in Malawi (Guthrie N.31). It has the usual five-vowel system, and a restricted number of "long" vowel roots which are clearly derived (as in CiTonga). There is a contrast between aspirated and unaspirated voiceless consonants. Voiceless stops are always aspirated after nasals, and aspiration may also mark morphological information (as in the class 5 noun prefix, which also involves other consonant alternations). Like many other languages in the southern zones of the Bantu region, Chichewa has regular lengthening of phrase-penultimate syllables (Watkins 1937).

(93)	/ku-lim-a/	[kuli:ma]	'to cultivate'
	/ku-lim-ir-a/	[kulimi:ra][33]	'to cultivate for'

The present data were elicited from two adult male native speakers of Chichewa. The two speak slightly different varieties — most of the differences being tonal — but the distinction between the two varieties is not signalled by any dialect labels. Speaker A is typical of Central Malawi; he comes from the Nkhotakota

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[33] The l~r distinction is purely allophonic, but is represented here as it is in the orthography.

region, which may show influences of the variety of Chichewa spoken in the Niassa Province of Mozambique, as well as influences from CiTonga and CiTumbuka, both spoken to the north. The variety spoken by Speaker B may be characteristic of the Chichewa spoken in the Pengapenga area, which borders with the CiYao-speaking area of Mangochi.

The verbs in the wordlist were elicited in two contexts: (1) as plain infinitives, such that the root syllable was penultimate (and therefore postlexically lengthened), and (2) with an applicative suffix on each verb such that the root syllable was antepenultimate and therefore not lengthened.

(94) /ku-bal-a/ 'to carry' [kubaala]
/ku-bal-ir-a/ 'to carry for/to' [kubaliira]

The applicative suffix was used because it can be productively added to any verb root; while its primary meaning is benefactive ('to do something for someone'), it also is used as a locative ('to do something at a place'). The lengthened set (1) was elicited from both speakers; the non-lengthened set (2) was read only by Speaker C. High tone marked on final -a in the corpus indicates that the root is high-toned (surface realization depends on morphological and phrasal context).

(95) Chichewa corpus

root (1)	*suffixed (2)*	*gloss*
bala	balira	bear, carry
bika	bikira	interlace
birá	birirá	dive
bisá	bisirá	hide
bizá	bizirá	immerse
boola	boolera	pierce
busa	busira	herd
chapa	chapira	paddle
chema	chemera	cry at a 'maliro'
chemba	chembera	notch, carve
chepa	chepera	be small
chesa	chesera	cut up animal
cheta	chetera	take one off from
cheza	chezera	talk
chima	chimira	strain
chinda	chindira	have sex
chinga	chingira	enclose w/ fence
chira	chirira	recover
choma	chomera	be filled up
chonga	chongera	contradict
dekhá	dekherá	settle

dika	dikira	plait
dinda	dindira	strike w/ elbow
dontha	donthera	drop
fala	falira	spread abroad
famba	fambira	seize
fana	fanira	be like
fesa	fesera	scatter
fooká	fookerá	weaken
foola	foolera	tire out
fotá	foterá	wither
fumpha	fumphira	rehoe old garden
funa	funira	wish, want
fupa	fupira	give reward
fuula	fuulira	shout
goná	gonerá	lie down, sleep
guga	gugira	be threadbare
gula	gulira	buy
gunda	gundira	knock, beat
guza	guzira	drag along ground
kama	kamira	milk
kamba	kambira	talk
kaná	kanirá	refuse, deny
kanda	kandira	knead
kankha	kankhira	push, shove
kapa	kapira	bail water
khula	khulira	rub, polish
koka	kokera	draw together
komba	kombera	scrape w/ finger
konda	kondera	please
konkha	konkhera	sprinkle water
kopa	kopera	persuade
kunga	kungira	lay stones for fire
kusa	kusira	hoe lightly
kuta	kutira	wrap up
maná	manirá	be hard, stingy
mata	matira	plaster
mema	memera	gather
mina	minira	blow nose
mirá	mirirá	go under water
nena	nenera	speak
nona	nonera	be fat (animals)
nunkha	nunkhira	smell (intr)
pana	panira	fix between 2 sticks
panda	pandira	beat, slap
panga	pangira	do, make
pempha	pemphera	ask
penda	pendera	try, test
phathá	phathirá	stick (into)
phika	phikira	cook
phoola	phoolera	pierce
phopha	phophera	beat
pima	pimira	be half-cooked
pinda	pindira	fold, bend
pinga	pingira	cross
ponda	pondera	tread
puntha	punthira	beat, thresh
pusa	pusira	be foolish
puta	putira	provoke
samba	sambira	wash
sankha	sankhira	choose
sasa	sasira	be sour
senga	sengera	cut, mow
sesa	sesera	sweep
sina	sinira	foment
sinkha	sinkhira	think
sintha	sinthira	change, exchange
sipa	sipira	eat w/o sauce
sosa	sosera	hoe lightly
suma	sumira	buy/get food
sumba	sumbira	fight w/ horns
sunga	sungira	keep, watch
supa	supira	pay wages
tamba	tambira	spread
tanda	tandira	extend
tantha	tanthira	cross along sthg. stretched across
tema	temera	cut
temba	tembera	rely on
tenga	tengera	be like
tentha	tenthera	be hot
tepá	teperá	bend
thasa	thasira	flourish
thera	therera	finish
thira	thirira	pour
tola	tolera	pick up
topá	toperá	be tired
tosa	tosera	poke
tuma	tumira	send
tumbá	tumbirá	capture
tumpha	tumphira	leap

tupa	tupira	swell
vala	valira	clothe
vama	vamira	take shelter
veka	vekera	clothe
vika	vikira	steep
vina	vinira	dance
vula	vulira	undress
vuma	vumira	hum
vumba	vumbira	rain on
vundá	vundirá	be rotten
vunga	vungira	rush (wind)
vuula	vuulira	take out of water
zembá	zemberá	disappear
zenga	zengera	tie
zika	zikira	stab
zimá	zimirá	quench
zinda	zindira	avoid
zinga	zingira	surround
zuká	zukirá	rise up
zula	zulira	pull up by roots
zuna	zunira	be sweet

Note that all of the long-vowel roots in this set have /k/ or /l/ as their second consonant, and /u/ or /o/ as their vowel:

(96)

-boola	pierce, pass through
-fooka	weaken
-foola	tire out
-phoola	pierce
-vuula	take out of water

These roots must originally have been morphologically complex — /vuula/ "take out of water", in fact, clearly shows the semantics of the Bantu -uk-/-ul- reversive suffix.

In the results for set 1, between-speaker differences were significant, but did not overshadow the main effects on segment duration. Speaker A in this set also had a significant effect of repetition number on speech rate: his first-block tokens were uttered at a faster rate than the second and third blocks. Again, while this effect is significant, it does not obscure the main effects.

Aggregated vowel durations are given in (97).

(97) Chichewa 1: V by environment

	mean	*s.d.*
short	164.1	30.9
pre-NC	161.0	25.4
long	294.4	47.5

In (98) we see that, just as in CiTonga, there is no significant difference between vowels in CVNC position and CVC position.

(98) Chichewa 1: comparison of vowel categories

	mean diff. (ms)	*Fisher PLSD*
short vs. pre-NC	3.1	4.522
short vs. long	130.4	10.224*
pre-NC vs. long	133.5	10.465*

*significant to at least 95%

Between-speaker differences do not obscure this effect:

(99) Chichewa 1: V by category and speaker

	spkr A	spkr B
short	178.6	148.7
pre-NC	176.3	145.1
long	310.2	272.3

Results for set 2 (in which the target syllables do not undergo penultimate lengthening) show the same patterns.

(100) Chichewa 2: V by environment

	mean	*s.d.*
short	90.2	21.1
pre-NC	89.1	13.9
long	190.5	40.2

(101) Chichewa 2: Comparison of vowel environments

	mean diff.	*Fisher PLSD*
short vs. pre-NC	1.2	4.28
short vs. long	100.2	9.943*
pre-NC vs. long	101.4	10.158*

*significant to at least 95%

Kanerva (1989) demonstrates on the basis of tone assignment and reduplication that Chichewa "long" vowels (as I have argued for those of

CiTonga) are actually bisyllabic, and that Chichewa has no bimoraic syllables. Hence there is no structure available for a vowel to be linked to two moras, and no compensatory lengthening.

Vowel identity is the most significant determinant of duration for Chichewa vowels, far more robust than any other influence. Below, durations are broken down by vowel category and identity:

(102) Chichewa 2: Vowel duration by category and identity

	short	pre-NC	long
a	98.8	96.6	•
e	86.3	93.2	•
i	80.0	78.5	•
o	96.8	93.1	181.3
u	92.7	84.5	207.3

Note that in most cases, vowels in pre-NC position are slightly shorter than their counterparts in CVC contexts, once again showing that pre-NC lengthening in other languages is not simply an automatic tendency throughout the family.

Comparison of the two sets elicited from speaker A allows us to examine penultimate lengthening in more detail. Monosyllabic vowels are shown in the following tables:

(103) Chichewa speaker A: ANOVA - significance of syll. position for V duration

	df:	Sum Squares:	Mean Square:	F-test:	P value:
V identity (A)	4	58852.989	14713.247	35.212	.0001
syll. position (B)	1	1357731.231	1357731.231	3249.301	.0001
AB	4	12464.101	3116.025	7.457	.0001
Error	721	301272.232	417.853		

The effect of syllable position is many times stronger than that of vowel identity for tokens uttered by this speaker. The breakdown of vowel durations by identity and position is given in (105):

(104) Chichewa speaker A: V by identity, position

	penultimate	*antepenultimate*
a	198.0	97.8
e	177.9	89.1
i	166.5	80.7
o	187.2	95.4
u	166.0	89.5

(105) Chichewa speaker A: Comparison of monosyllabic vowels by position

(a)

	Mean:	*Std. Dev.:*
penultimate	177.7	26.3
antepenultimate	90.0	18.1

(b)

	Mean Diff.:	*Fisher PLSD:*	*Scheffe F-test:*
penult. vs. antepenult.	87.7	3.284*	2748.343*

Bisyllabic vowels also lengthen in penultimate position; Kanerva (1989) shows that it is the second portion that undergoes lengthening, which further confirms the notion that "long" vowels are actually two syllables.

Lexically, Chichewa has only "regular" vowels and bisyllabic sequences of vowels, no true monosyllabic long vowels, and no canonical compensatory lengthening. However, there is a species of CL that occurs across morpheme boundaries (Mtenje 1986), which requires an excursus here. Phonological analysis of this phenomenon reveals further evidence that Chichewa has no bimoraic syllables, and shows that two moras linked to the same melodic element may belong to different syllables in output forms (contra Zec 1988).

The lengthening facts are as follows: Chichewa does not have CL anywhere in the lexicon; vowels after consonant-glide sequences (CG) and before nasal-consonant sequences (NC) are always short. Across prefix boundaries, there is lengthening after a high vowel becomes a glide (106), but never before NC (107):

(106)	/ku-athu.../	[kwaathu...]	'our'
(107)	/a-nthu.../	[anthu...]	'people'

Unlike CL from glide formation in Luganda, Kikerewe, or Runyambo, this CL happens anytime there is glide formation — whether or not there is a consonant before the glide.

(108)	/u-a-bwino.../	[waabwino...]	'good X'

So this fact, the asymmetry with NC environments (compared to other CL languages), and the fact that lengthening only occurs in derived environments are three crucial differences between Chichewa CL and "normal" Bantu CL.

A further complication is that Chichewa lengthening operates differently in different morphological environments. When /i/ follows a coronal consonant in a prefix (Mtenje's statement of the condition), instead of gliding, it drops and the following vowel lengthens.

(109)	/si-ena.../	[seena...]	'it's not others'
	/ndi-ena.../	[ndeena...]	'with others'
	/ti-u-peza.../	[tuupeza...]	'we will find it'

When a demonstrative follows a vowel, its first vowel (always /i/, /u/, or /a/) drops and the preceding vowel lengthens.

(110)	/nyumba-iyi.../	[nyumbaayi...]	'this house'
	/bambo-awa.../	[bamboowa...]	'this man/father'
	/gule-uyu.../	[guleeyu...]	'this dance'

So there are three possible outcomes when two vowels come together: V1 glides and V2 lengthens, V1 deletes and V2 lengthens, or V2 deletes and V1 lengthens (Mtenje states that this last case must be specified as occurring with the demonstrative). This is unlike any of the CL phenomena we have seen in previous sections.

Mtenje analyzes this lengthening in CV terms, without showing what syllables the C's and V's in question belong to. He argues that lengthened vowels are single segments linked to two V-slots; this is motivated by the fact that long segments show integrity and inalterability effects, and by the Obligatory Contour Principle. However, Chichewa itself shows no integrity or inalterability effects (thus there is no direct evidence of multiple linking), and since the segments in question are heteromorphemic, the OCP need not apply (Steriade 1982). This leads me to claim that the surface long vowels derived here are not contained within a single syllable, any more than the lexicalized sequences we see in roots are.

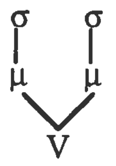
The process in question is indeed compensatory lengthening, but the function it performs is not, as it is in many languages, maintenance of syllable length: rather, the key here is that CL is maintenance of mora count. Since moras and syllables are always in a one-to-one relationship in Chichewa, CL does not create bimoraic syllables; it simply has the effect of preserving syllable count. Further evidence that Chichewa CL is concerned with length but with mora count comes from another prefixal process (an optional rule):

(111)	/a-ku-pita.../	[aapita...]	'as he/she was going'
	/u-ku-gona.../	[uugona...]	'as you were sleeping'
	/a-ku-koka.../	[aakoka...]	'as he/she was pulling'

Here, a whole syllable is deleted and the preceding vowel lengthens. Of course it is possible to represent this as the syllable node being lost but the mora being retained, and then gathered into the preceding syllable (though Mtenje does not show syllables, it seems clear this is the intention). But I claim this is evidence that Chichewa only cares about syllable "beats" or timing units, and that is what is being preserved here. There is no evidence that the input in these cases is four syllables but the output is three; it seems more likely the output is also four syllables, and the long vowels here are just like those in the lexicon — disyllabic.

There is no evidence to resolve the question of whether the features that get transmitted to the vacated syllable in this CL are a matter of a multiply-linked vowel, or some kind of feature-copying. In the absence of such evidence, the spreading solution seems more appealing; it results in the representation of a melodic element linked to two moras which belong to separate syllables:

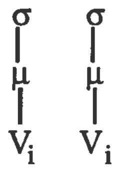
(112)



There is in principle no reason to rule out this representation. We already know that a crucial fact about Chichewa is that it has no multiply linked (bimoraic) syllables; a mora never comes without a syllable, and a syllable never has more than one mora. This constraint could force the representation above, when a mora loses its melodic element.

Given the caveat about the OCP above, there is also no *a priori* reason to reject the representation in (113):

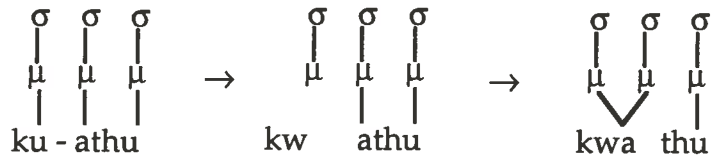
(113)



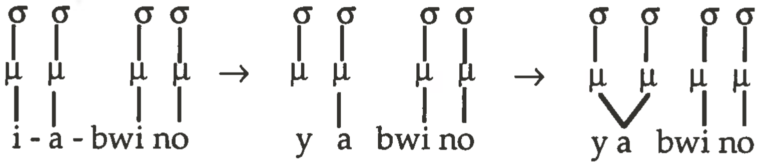
In this case, however, to get the features from an existing vowel to a vacated mora there would have to be copying, rather than spreading — a less desirable solution.

The representations for Chichewa heteromorphemic CL are as follows:

(114) /ku-athu.../ → [kwaathu...]

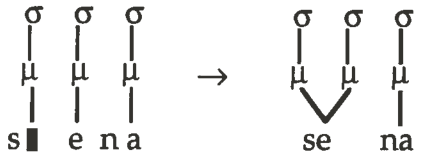


(115) /i-a-bwino.../ → [yaabwino...]

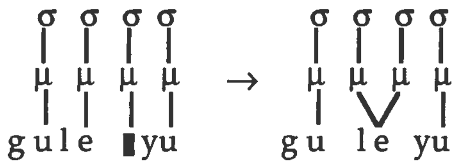


The processes in (116) and (117), which Mtenje states as a specific segmental rule and a specific morphologically-marked rule respectively, may both be handled with underspecification.

(116) /s▮-ena.../ → [seena...] (cf. 110)



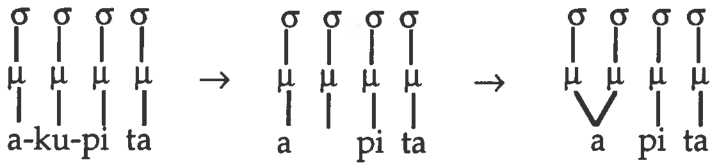
(117) /gule-▮yu.../ → [guleeyu...] (cf. 111)



In other words, the problem of directionality (V1 deletes in the first case, V2 in the second, and V1 when high does not glide as it does in (126-127)) is solved by representing the vowel of certain prefixes as underspecified (where it gets its /i/ features from the preceding coronal consonant if it must), and representing the first vowel of the demonstrative as underspecified (it gets its features from the other vowel of the demonstrative if it must). In both cases, if there is a neighboring full vowel after morphological concatenation, then the underspecified vowel gets its features from that vowel.

Finally, the phenomenon shown in (111) would be represented as follows:

(118) /a-ku-pita.../ → [aapita...]



It is possible to argue that in this situation it is not the syllable node itself being deleted, because this only ever happens to /-ku-/ of this particular tense, and so must be highly specified anyway (e.g. segmentally).

The fact that only gliding, and not a VNC sequence, produces CL in this case can be captured by having all vowels be unconditionally moraic (in the sense of Steriade 1991). Underlying glides never have a mora,[34] nor do nasals, so

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[34] Note that this analysis requires that /y/ and /w/ be independent phonemes in Chichewa, as Mtenje says they are.

adjacent vowels never get a mora from them. There is no assignment of "weight by position" (Hayes 1989) that creates weak moras (coda moras), since all syllables are monomoraic. Nasals, then, only get a mora when they precede a consonant *initially* — and thus they never give up a mora to anything. High vowels, on the other hand, may glide in certain derived environments — and they always have a mora, so they give it to the neighboring vowel. [35] Since moras in Chichewa are always in a strictly one-to-one relation with syllables, syllabification is entirely redundant (Kanerva 1989). Both levels are nonetheless represented, for reasons discussed in §3.4.1. In the lexicon, this one-to-one relationship also applies to the segment-mora relationship, but a two-to-one segment-to-mora representation can be derived by rule.

Having resolved the issues surrounding Chichewa vowels, I now conclude with a brief statement of consonant timing. Duration of consonants in set 1 (target syllable in penultimate position) are primarily determined by their identity, though speaker identity and C1 vs. C2 position are also significant.

(119) Chichewa 1: C by identity, speaker

Source:	*df:*	*Sum Squares:*	*Mean Square:*	*F-test:*	*P value:*
identity (A)	16	1141371.839	71335.74	225.869	.0001
speaker (B)	1	29914.073	29914.073	94.716	.0001
AB	16	22330.568	1395.661	4.419	.0001
Error	1211	382467.612	315.828		

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[35] The difference in Luganda can be stated as follows: instead of having underlying glides and having all vowels be unconditionally moraic, high vowels in Luganda are conditionally moraic. Morification examines adjacent segments that do not yet have a mora, compares sonority and assigns a mora to the rightmost segment if it is more sonorous than the leftmost. Thus a high vowel that precedes another vowel either initially or after another vowel never gets a mora (it glides because it ends up in onset position, but does not trigger any CL). High vowels after consonants, on the other hand, receive a mora by the sonority/morification algorithm, so when they glide they have a mora to give up.

(120) Chichewa 1: C by identity, speaker

	T	C
p	93.4	115.6
t	103.3	114.4
k	77.3	93.1
b	89.8	100.0
d	93.5	97.8
g	105.5	122.9
ph	99.1	110.2
th	102.4	112.8
m	101.1	101.7
n	91.4	87.1
l	71.9	75.0
r	24.9	35.4
s	148.3	171.2
f	149.2	171.7
z	134.5	151.6
v	122.2	140.7
ch	141.7	149.6

(121) Chichewa 1: ANOVA - significance of C identity, position

Source:	*df:*	*Sum Squares:*	*Mean Square:*	*F-test:*	*P value:*
identity (A)	11	493905.486	44900.499	153.543	.0001
position (B)	1	18552.921	18552.921	63.444	.0001
AB	11	10879.303	989.028	3.382	.0001
Error	923	269912.831	292.43		

(122) Chichewa 1: C by identity, position

	C1	C2
p	107.8	101.3
t	115.3	90.8
k	91.2	76.4
g	118.2	96.5
ph	105.3	105.3
th	111.0	92.9
kh	100.8	86.3
m	104.3	100.1
n	97.2	87.2
s	170.9	147.2
f	160.3	•
z	151.3	119.2

(123) Chichewa 1: C by position, speaker

(a) C1 position

	T	C
p	95.4	119.8
t	107.6	122.6
k	81.2	100.7
b	89.8	100.0
d	93.5	97.8
g	107.9	127.7
ph	97.0	111.6
th	102.4	119.5
kh	93.9	107.7
m	102.1	106.6
n	94.8	99.2
s	154.8	185.1
f	149.2	171.7
z	143.0	159.5
v	122.2	140.7
ch	141.7	149.6

(b) C2 position

	T	C
p	90.7	110.6
t	91.3	90.5
k	71.6	81.2
g	94.4	98.7
ph	105.6	105.0
th	•	92.9
kh	80.7	91.9
m	100.7	99.6
n	90.6	84.0
s	139.8	153.6
z	109.6	128.9
l	71.9	75.0
r	24.9	35.4

Consonant durations for set 2, in which the target syllable is antepenultimate are as follows (speaker A only):

(124) Chichewa 2

(a) C1 by identity

	Mean:	*s.d.*
p	35.3	39.3
t	58.9	27.0
k	34.8	27.1
b	75.1	21.4
d	68.6	9.1
g	88.7	10.6
ch	82.6	23.8
f	123.9	13.8
m	71.5	22.4
n	56.7	21.6
ph	82.9	11.3
th	75.2	10.7
kh	63.1	9.3
s	123.3	28.4
v	109.3	18.3
z	91.1	24.6

(b) C2 by identity

	Mean:	*s.d.*
p	86.4	12.3
t	72.6	16.8
k	60.3	11.6
g	77.8	10.0
m	89.1	8.4
n	86.3	9.6
l	26.2	4.8
r	36.0	8.3
ph	81.4	1.4
th	76.2	10.7
kh	73.4	6.2
s	146.1	16.2
z	112.3	14.6

For consonants that occur in both C1 and C2 position, comparison shows something interesting:

(125) Chichewa 2: C duration by position

	C1 position	*C2 position*
p	75.0	86.4
t	66.5	72.6
k	52.9	64.4
g	88.7	77.8
m	76.6	89.1
n	63.8	86.3
ph	83.5	81.4
th	75.2	76.2
kh	63.1	73.4
s	126.4	146.1

Here, consonants in C2 position in the verb stem are in most cases longer than in C1 position — the opposite of what happens in set 1 and in most of the other languages examined in this study. What this reveals is that at least for Chichewa, it is not root-initial position that causes consonants to be longer, but rather pre-penultimate position. That is, the syllable that receives prosodic prominence postlexically, the one that regularly has lengthened vowels, also has longer onset consonants. Penultimate lengthening, then, is a phenomenon realized within a syllable domain, not just on vowels. A question for future research is whether other Bantu languages that do not have the marked penultimate lengthening of Chichewa — such as Runyambo, which does have a significant effect of penultimate prominence, but nowhere near the degree of lengthening that Chichewa possesses — also show this consonantal effect. My prediction is that they do.

3.6 Long vowels and bisyllabic vowels together: Bukusu

Bukusu is a Kenyan language of the Luhyia group (J.31c). It has five vowels, lexically long and short in the expected places (i.e. the historical roots reconstructed as long in Proto-Bantu). In addition, Bukusu has homorganic vowel sequences (cf. CiTonga), in two environments: where an object marker ends in a vowel and a verb root begins with a vowel, and where a consonant was lost between vowels in a root.

(126)	long vowel root:	-beela	'forgive'
	object marker:	-bi-ila	'send them (cl. 8)'
	"double" vowel:	-bi.ila	'hate'

There are no heterorganic vowel sequences (of the sort found in CiTonga, such as /ai/ or /au/). The data presented here were elicited from one adult male speaker of Bukusu; the corpus is given in (127).

(127) Bukusu corpus

baka	skin
bamba	stretch (hide)
be.ela	accuse falsely
beela	forgive
beka	shave
bi.ila	hate
biila	send them (cl.8)
biipa	beat them (cl. 8)
biira	kill them (cl. 8)
biixa	keep
bimba	swell / cover
bira	pass
bomba	reduce in size
bona	see
bonda	become sour, curdle (milk)
bu.ula	overpower it (cl.14)
buka	abound, grow strong
bunda	grope
bunga	store (esp. grain)
buta	pick, gather
buula	reveal
buumba	mold
cexa	laugh
cuxa	pour
fuca	spit
fuka	stir
fuma	be renowned
fumba	bend
funa	harvest / break (snap)
funda	ferment
funga	close
funja	break down (tr)
fuuma	cover
ka.amba	hold them (cl. 6)
ka.axa	besmirch them (cl. 6)
kaama	catch
kama	honor w/gift
kamba	complain about small gift

kanda	make dough
kanga	do sthg. terrible to s.o.
kaata	slaughter
kaxa	go stale (of food)
keema	deny them (cl. 6) sthg.
keka	cut down (e.g. a banana)
kema	add
kenda	walk
ki.ika	overburden it (cl. 9/4)
kiima	deny them
kiipa	beat it (cl. 9/4)
kimba	predict rain
kinga	ward off (a blow)
kisa	hide
koka	strangle
komba	desire
kona	lie down, sleep
konga	knock (down)
kooma	pick up and go
koota	scrape out mud
kopa	borrow, imitate
kota	collapse, wither (person)
kula	buy
kumba	be barren
kuta	backbite
kuula	roof
kuuta	raise voice, sing in unison
kuxa	stink
laka	promise
langa	call
lasa	shoot
leka	despise
lenga	fill with liquid
lexa	leave
liima	deny it (cl. 5)
lila	cry
lima	cultivate
linda	wait
miina	press down
naba	sew
niina	go up
nuuna	suck
paasa	iron
panga	arrange
piima	measure
roora	dream
rora	pluck
ruma	send
ruuma	jump, skip over
saaba	wash hands
saba	beg
sama	bark
samba	kick
saxa	collect food (when lack)
seesa	winnow
senda	move
siika	sic dog on someone
siila	swell
siima	thank, like
siira	kill it (cl. 7)
sika	put meat on a skewer
sila	be silent
sima	burn out
simba	overgrow
singa	rub, wash
sira	block
soka	swim
soma	read
somba	carry in several trips
soona	sew
sumba	become a bachelor
sunda	do sthg energetically
sunga	hang
suta	carry, lift
suuka	plait / alight
suuna	become barren (dry up)
tamba	lack (w/o nec. being poor)
taxa	lack (be poor)
teeka	bless, give favor
teexa	cook
tiima	grope
tiixa	fill up
tima	run
timba	darken
tora	get wet
tuuma	surpass
xaka	try
xala	cut
xama	milk
xiina	waylay

xila	abound	xoora	hollow out
xina	dance	xula	grow
xola	do	xunga	pile up
xoma	nail, abuse	xuupa	beat
xomba	lick	xuuxa	come out of handle
xooca	make		

Vowel durations are as follows:

(128) Bukusu: vowel duration by length category

	Mean:	*s.d.*
short	65.1	17.5
long	133.4	30.2
pre-NC	124.4	23.3
object marker	185.8	69.5
double vowels	229.3	22.7

The categories are statistically distinct, but as in Kikerewe, the least differentiated groups are long and lengthened vowels: in other words, compensatory lengthening once again produces vowels that are just shy of the duration of lexical long vowels.

(129) Bukusu: comparison of length categories

	Mean Diff.:
S vs. L	68.4
S vs. N	59.3
S vs. O	120.8
S vs. D	164.2
L vs. N	**9.1**
L vs. O	52.4
L vs. D	95.8
N vs. O	61.5
N vs. D	104.9
O vs. D	43.4

The only pair here that is not robustly distinguished is long vs. lengthened (L vs. N); as in Kikerewe, the mean difference is much smaller than the standard deviations of the vowel durations.

(130) Bukusu length ratios

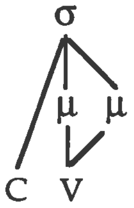
	lengthened	*long*	*OM*	*double*
ratio to short V	191%	205%	286%	353%

As in Kikerewe and Luganda, the surface difference between lengthened and long vowels is a matter of phonetic realization, not phonological representation. Both are bimoraic vowels.

The object marker sequences and double vowels of Bukusu, like the "long" vowels of CiTonga and Chichewa, are in fact separate syllables. What makes them different from one another is a 'ghost' or unfilled consonant slot in the syllabic structure of the double-vowel case, as opposed to zero onset in the OM case (cf. Roberts 1994, where this analysis is suggested for Kikamba on phonetic grounds). Recall that these are these empty-slot roots are the ones that lost a consonant between identical vowels historically.

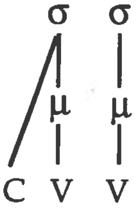
(131) Bukusu "long" vowel types

(a)



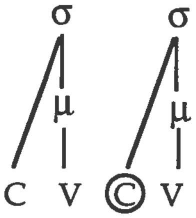
true long vowel syllable
(lexical or derived)

(b)



object marker
sequence

(c)



double vowel
sequence

Since the disyllabic vowel sequences are highly marked in the language, it is easier to examine other effects on vowel duration with these types excluded. The role of vowel identity in duration of canonical (short, long, lengthened) vowels is shown in (132).

(132) Bukusu: ANOVA - significance of length category, vowel identity

	df	*sum of squares*	*mean square*	*F test*	*P value*
length category (A)	2	323903.32	161951.66	418.906	.0001
vowel identity (B)	4	44902.95	11225.738	29.037	.0001
AB	8	6971.39	871.424	2.254	.0236
Error	313	121007.79	386.606		

Length category is a much greater influence on vowel duration than is vowel identity.

Consonant durations are as follows:

(133) Bukusu

(a) C1 durations

	Mean:	*s.d.*
p	112.8	22.1
t	104.4	12.7
k	90.2	16.7
b	74.5	11.9
m	101.1	10.4
n	76.8	7.2
f	126.9	18.7
s	125.1	17.6
x	116.7	21.2
c	131.8	16.0
l	31.6	12.2
r	30.6	9.4

(b) C2 durations

	Mean:	*s.d.*
p	91.1	18.7
t	71.9	9.6
k	69.6	12.2
b	56.7	5.9
m	79.0	9.2
n	69.4	9.0
s	98.4	14.3
x	90.3	15.1
c	113.7	17.3
l	37.2	12.6
r	29.9	5.8

Consonant position is a strong influence on duration; C2 consonants are regularly shorter (except for the shortest segments, /r/ and /l/, which are essentially the same in both positions). As in many of other languages here, the onset of the penultimate syllable receives extra duration.

In summary, Bukusu shows that bimoraic, tautosyllabic long vowels (of the sort found in CiYao, Luganda, Kikerewe, and Runyambo) and bisyllabic vowels (of the sort found in CiTonga and Chichewa) may exist in the same language. A further phonological distinction may be made, between these two categories and that of vowels separated only by a "ghost" or empty consonant slot. The contrast between these types is strongly marked phonetically.

3.7 Survey summary

A summary view of vowel duration in the languages discussed here is shown in (134) and (135):

(134) Vowel durations in three environments

	CVC	CVNC	CVVC
CiYao	61	130	131
Luganda	73	191	237
Kikerewe	71	118	129
Bukusu	65	124	133
Runyambo	110	168	215
Kindendeule	148	145	•
KiLega	117	115	•
CiTonga	100	101	241
Chichewa	90	89	190

(135) Ratios of vowel durations in three environments

	CVC	CVNC	CVVC
CiYao	1	2.1	2.1
Luganda	1	2.6	3.2
Kikerewe	1	1.7	1.8
Bukusu	1	1.9	2.0
Runyambo	1	1.5	2.0
Kindendeule	1	1.0	•
KiLega	1	1.0	•
CiTonga	1	1.0	2.4
Chichewa	1	1.0	2.1

The main patterns that emerge from this nine-language survey are as follows: languages with no vowel length at all do not have compensatory lengthening in the VNC environment (Kindendeule, Kilega). Likewise, languages that only have derived length have no canonical compensatory lengthening (CiTonga, Chichewa); apparent long vowels (and the heteromorphemic lengthened vowels of Chichewa) are in fact bisyllabic. Of the languages that have true bimoraic syllables, all have CL in VNC position (Luganda, Runyambo, CiYao, Bukusu, Kikerewe); however the amount of lengthening varies from one language to another.

These durational results have several implications for phonological analysis:

(a) Some languages may permit only a one-to-one correspondence of syllables and moras.

(b) Adjacent vowels in syllable-only languages may have restrictions on their featural content.

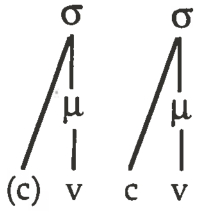
(c) A language may have both bimoraic syllables and adjacent-syllable vowels.

(d) If a language does not possess bimoraic syllables, it does not have compensatory lengthening.

(e) The process of compensatory lengthening may differ among languages either phonologically or phonetically.

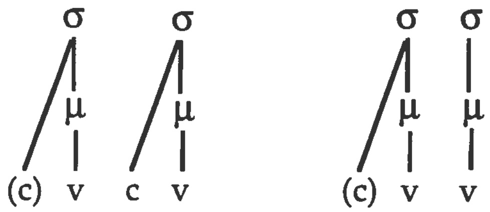
In some languages, ones with no length or weight distinction at all, syllables may only be monomoraic, and on the melodic tier no vowels may be adjacent:

(136)



In languages such as CiTonga and Chichewa, syllables are also required to be monomoraic, but on onsetless syllable may follow another syllable. So the possibilities are these:

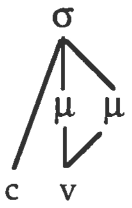
(137)



Languages that have true bimoraic syllables may also have bisyllabic vowels, as in Bukusu:

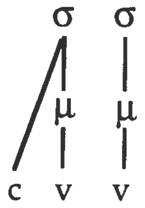
(138)

(a)



true long vowel syllable

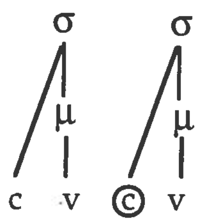
(b)



object marker sequence

In the case of Bukusu, there is a third possibility, namely a ghost consonant separating two vowels:

(139)



double vowel sequence

Thus I attribute the three phonetically distinct vowel durations in Bukusu to three different phonological representations (lengthened and long vowels have the same representation, that in (138a)).

The observation that compensatory lengthening only occurs in languages that have an existing vowel length distinction is here confirmed by instrumental evidence across several Bantu languages. The lack of compensatory lengthing in languages that superfically appear to have long vowels accords with lexical evidence that length in those languages is not a matter of bimoraic syllables, but of bisyllabic vowels.

Finally, I have shown that compensatory lengthening may differ across languages in two ways: the difference may be phonological, as in the case of Runyambo — where the structure must be different from that of the other four CL languages in the study, in order to account for an accompanying tonal difference between Runyambo and Luganda — or it may be phonetic, as in Luganda vs. CiYao, where (a) both lengthened and long vowels are longer with respect to short vowels than in the other three total-CL languages, and (b) lengthened vowels are not as long as long vowels, but these have no contrastive effect.

In my conception of the place of phonology and phonetics within a grammar, this means that Runyambo has a CL rule that is specified differently in the phonological component from the rule that operates in the other languages here. Luganda, on the other hand, has a rule in the phonetic component of its grammar that differs from the other languages in specifying a more exaggerated durational contrast between short, lengthened, and long vowels. As for CiYao, Bukusu, and Kikerewe, the differences in their ratios of lengthened to long are so close that it is impossible to tell from the present data just how much should be specified in the grammar and how much should be left to universal phonetic implementation. However, the ratio of short to long/lengthened, which is roughly 2:1 in CiYao and Bukusu but 1.7:1 in Kikerewe, may be significant enough to belong in the phonetic rule system of the grammar. Further cross-linguistic data will help to resolve this question.

CHAPTER FOUR: MAPPING PHONOLOGICAL TO PHONETIC TIMING

4.1 Mechanisms for mora maintenance

In Chapter 3 it was demonstrated that phonetic timing in a number of Bantu languages systematically reflects the phonological characteristics of moras and syllables. In this chapter, I take the first steps toward identifying the means by which this maintenance of prosodic structure in surface timing is achieved. The only way for the results seen in Chapter 3 to be visible is that segmental adjustment around inherent durational differences must be taking place (contra Nagano-Madsen 1992). The task, then, is to determine how and where this occurs in the phonetic string.

While that question is too large to explore fully in the present work, it is possible to look more closely at some of the acoustic data gathered for Chapter 3 and locate important factors in segmental adjustment. In the following sections, I examine Luganda durations in greater detail and lay out the foundations for what a systematic study of segmental compensation in moraic mapping will look like. Then I return briefly to Runyambo and identify similarities and differences from Luganda. I have already noted (in §2.2.2) the difficulties inherent in the study of compensation, and the methodological measures I have taken to minimize them. In what follows, I rely largely on multiple analysis of variance as described there to tease apart the influences on segment duration in Luganda and Runyambo. I show that there are a host of factors affecting the duration of consonants and vowels, that these are ranked differently in different languages, and that temporal compensation takes place both in vowels and consonants, both within and across syllable boundaries.

Finally, I draw on research in speech synthesis and articulatory phonetics to support a model of speech timing in which prosodic structure takes precedence over other features of an utterance in the computation of output durations, and I suggest how this model may account for the characteristics of Luganda and Runyambo (and by extension, the other languages examined in Chapter 3).

4.2 Segmental adjustment

4.2.1 Luganda

In this section I return to the Luganda corpus of §3.3.3 for more detailed analysis, first of vowel and then consonant durations. Luganda initial and medial vowels are treated separately in here, because of their different status: while medial vowels can contrast in all five vowel qualities and both phonemic quantity categories, initial vowels do not (only /e/, /a/, and /o/ appear initially, and they do not contrast in quantity). As described earlier, tests on medial vowels show that the effect of length category is much greater than that of vowel identity, though both are important.

(1) Luganda medial vowel durations

	short	*pre-NC*	*long*
a	122	218	270
e	110	210	242
i	79	161	225
o	108	198	247
u	87	172	217
total	98	192	240

The next most important factor turns out to be the identity of the preceding consonant, though this is much smaller than the vowel identity effect. Still smaller in its effect on medial vowels is the identity of the following consonant.[36] Other factors tested, such as grammatical category of the word, were not significant.

(2) Factors correlated with medial vowel duration (Luganda):

quantity > identity > preceding C identity > following C identity

Initial vowels in this data set were more difficult to measure because their onset boundaries were often unclear, so the results must be viewed more tentatively. It has often been claimed that in Luganda initial vowels are always long, except before geminate consonants — Katamba (1985) suggests that this length has a demarcative function. In the present data set, however, initial vowels are not consistent in duration: often they are shorter than their medial counterparts, sometimes longer, and the variation is enormous — but they are never as long as a medial phonologically-long vowel.

(3) Luganda initial vowel durations

	mean	*s.d.*
a	152	*(57.5)*
e	112	*(45.8)*
o	85	*(15.1)*
total	124	*(52.9)*

Recall that there is no phonological length distinction in this position (comparison of items where there should be a morphological contrast shows that

---

[36] Because of asymmetries in consonant frequency in preceding and following position in this corpus, it was not possible to run a two-way ANOVA to directly compare the C1 and C2 effects, but indirect comparison of other tests indicates that the C2 effect is much smaller.

the quantity is neutralized: initial /a/ of *a-gul-a* 'he buys' is 156ms, in *a-a-gul-a* 'the one who buys' it is 158ms), so quantity is not a factor. However, grammatical category surprisingly plays a large role: on verbs, initial vowels are significantly longer than on nouns.

(4) Luganda IV by grammatical category

	mean	*s.d.*
noun	105	*(38.7)*
verb	167	*(53.3)*

This may be because of the difference in morphological function: on the verbs in question, the initial vowel is the subject marker, while on nouns it is a pre-prefix redundantly determined by the noun class prefix. In any case, grammatical category is a much greater influence on initial vowel duration than vowel identity. The next most important determinant is the quantity of the following consonant — namely, vowels are shorter before a geminate than a single consonant.

(5) Luganda IV by C quantity

	mean	*s.d.*
single	136	*(41.8)*
geminate	77	*(18.6)*

The effects on Luganda initial vowels, then, are ranked as follows:

(6) Factors correlated with initial vowel duration (Luganda):

grammatical category > identity > following C quantity

For Luganda consonants, there is a significant difference between root-initial (C1) and root-medial (C2) position, as there was in CiTonga, Bukusu, and

Chichewa above. Given the patterns for Speaker A in Chichewa, where when each verb was elicited with and without a suffix it proved to be penultimate syllable position and not root-initial position that was causing a consonant to be lengthened, it is likely that the factor at work in Luganda is also penultimate position (not root-edge). When C1 and C2 consonant durations are analyzed separately, the ranking of certain factors is different for the two sets. For both types of consonant, though, the most significant effects on duration are quantity (single vs. geminate) and identity.

For C1, there is a small effect of preceding vowel identity, and an even smaller effect of following vowel identity. C2, on the other hand, is affected somewhat by the identity of the preceding vowel,[37] but moreso by the identity of the preceding *consonant* — that is, C1 has a distinct effect on the duration of the onset consonant of the next syllable.

(7)

$$\begin{tikzcd}[column sep=tiny] \text{-}C_1 \arrow[rr, bend left] & V & C_2\text{-}V \end{tikzcd}$$

Voicing of C1 has the greatest impact on C2, place is somewhat less important, and manner is not significant. The effect does not occur in the reverse direction; none of these distinctions in C2 affects the duration of C1 (cf. Port et al. (1987), where voicing of C2 affects C1 in Japanese). This is a very interesting result; further study will be required to determine why this consonant effect only works in one direction, and why it is the opposite of Japanese. The answer may lie in the same penultimate prominence that causes C1 to have greater duration in this set.

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[37] Since the final vowel in this data set is invariably /a/, it is not possible to determine whether C2 is influenced by following vowel identity.

So the determinants of consonant duration in the present Luganda corpus are as follows:

(8) Factors correlated with C1 duration (Luganda):

quantity > identity > previous V identity > following V identity

(9) Factors correlated with C2 duration (Luganda):

quantity > identity > C1 identity > previous V identity

While this sorting of influences on vowel and consonant duration is a preliminary result, it gives us something to compare to other languages.

4.2.2 Runyambo

Testing for a wide range of possible factors as in Luganda, I ran further tests on the Runyambo corpus in §3.3.4. These tokens had more secure initial and final segment boundaries, but since there were no contrasts among initial vowels in this set, vowel results were obtained only for medial and final position.

Results for vowels were similar to those for Luganda.

(10) Runyambo medial vowel durations

	short	*pre-NC*	*long*
a	130	176	220
e	132	182	233
i	68	141	184
o	114	175	238
u	113	175	229

The most important factor for medial vowels is length category, then preceding consonant identity, then vowel identity. Unlike Luganda, the effect of following consonant identity is not significant. Of final vowels, which do not contrast in quantity, the only one present in this data set (for morphological reasons) was /a/; its duration is affected most by preceding consonant identity, and then by preceding vowel identity — again a trans-syllable effect, as seen in Luganda consonants.

(11) Factors correlated with medial vowel duration (Runyambo):

quantity > identity > previous V identity > following V identity

(12) Factors correlated with final /a/ duration (Runyambo):

preceding C identity > preceding V identity

As for consonants, the chief difference from Luganda is that Runyambo has no geminate consonants. Root-initial consonants are affected most by identity, and by following vowel identity. As in Luganda, C1 is not significantly affected by C2 identity. C2 duration is determined first by its own identity, then by C1 identity, then by preceding vowel identity, and somewhat by preceding vowel quantity — which was not a factor in Luganda. Also different from Luganda is the ranking of effects of C1 on C2: in Runyambo, as in Luganda, the greatest factor in this component is voicing of C1; but the next factor is C1 *manner* (which was not significant in Luganda), and C1 *place* is not significant.

(13) Factors correlated with C1 duration (Runyambo):

identity > following V identity

(14) Factors correlated with C2 duration (Runyambo):

identity > C1 identity > previous V identity > previous V quantity

4.3 General comparisons

The compensation results for the two languages are summarized in (15) and (16):

(15) Luganda: influences on segment duration

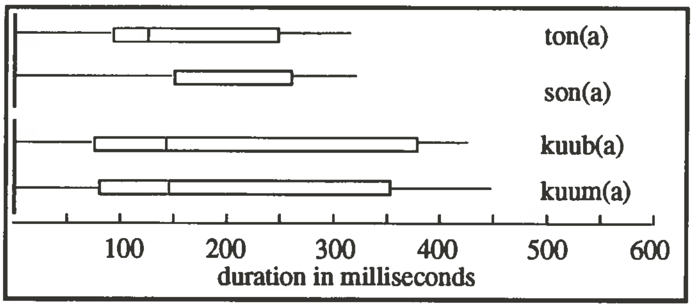
VOWELS		CONSONANTS	
V(med)	quantity (S, L, pre-NC) identity preceding C identity following C identity	C(rt-init)	quantity identity preceding V identity following V identity
V(init)	grammatical category identity following C quantity	C(rt-med)	quantity identity C1 identity (voice > place) preceding V i.d.

(16) Runyambo: influences on segment duration

VOWELS		CONSONANTS	
V(med)	quantity (S, L, pre-NC) identity preceding C identity	C(rt-init)	identity following V identity following V quantity
V(init)	preceding C identity preceding V identity	C(rt-med)	identity C1 identity preceding V identity

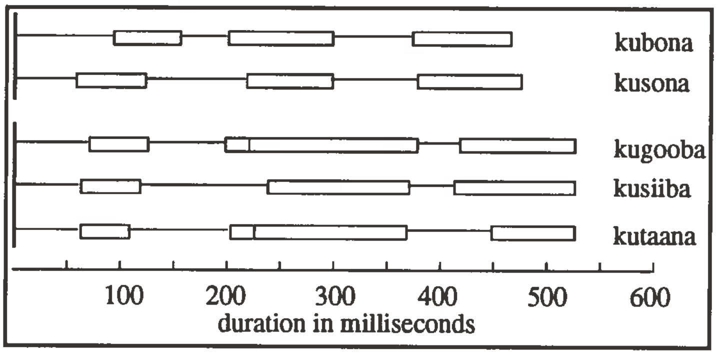
Evidence for compensation can be seen in the following diagrams (lines represent intervocalic consonants, boxes represent vowels and VOT, and narrow boxes represent nasals in the VNC environment). Each figure shows mean durations for the three utterances of each word. Since final vowel measurements in Luganda were unreliable, only the stem portion of those words is given.

(17) Luganda comparisons



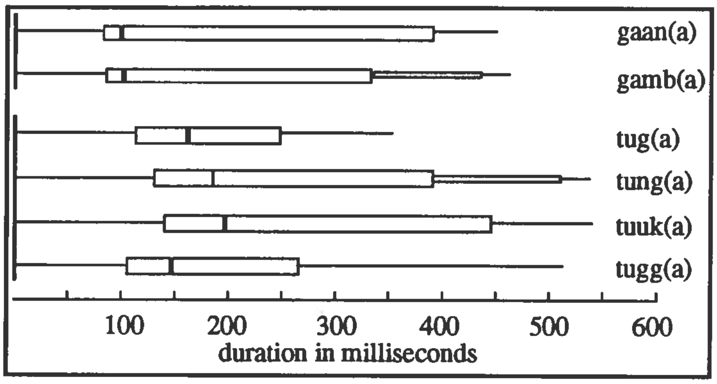
(17) shows minimal pairs in which vowel and consonant duration can be seen to adjust around different consonants; /o/ is shorter after /s/ than after /t/, /u/ is shorter before /m/ than /b/, etc.

(18) Runyambo comparisons



In (18), where whole words are given, the first pair shows adjustment around a minimal contrast (*kubona/kusona*); the next three show that even with widely different segmental content (*kugooba/kusiiba/kutaana*), the total duration of four-mora words is quite constant.

(19) Luganda comparisons



Finally, the Luganda set in (19) shows comparisons with lengthened vowels and geminate consonants. Note that mora maintenance is not exact — for instance, *-tugg(a)*, with a geminate consonant, is shorter than its CVNC and CVVC counterparts: this was true throughout the data set (and I have no story for it at present). Nonetheless, adjustment does appear to be taking place such that a general moraic constant is sustained.

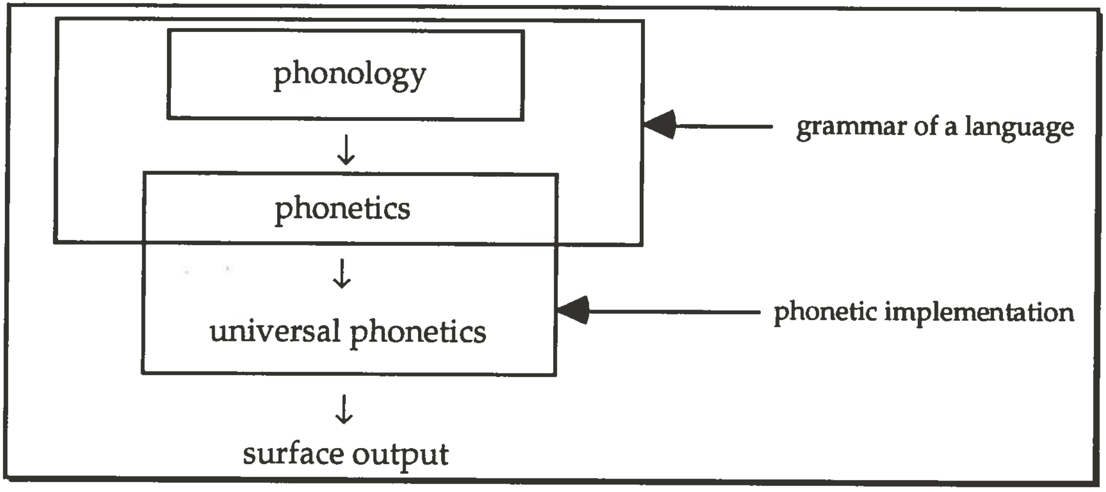
These findings for Luganda and Runyambo show four important things: (a) the specific mechanisms for segmental compensation may differ between languages; (b) when the same mechanisms are employed in different languages, their ranking may differ; (c) segmental compensation occurs both in consonants and in vowels; (d) the domain in which adjustment of segment duration occurs may be larger than a syllable.

4.4 Implications for a theory of timing

From what precedes it is clear that one obstacle in testing phonological representations is the lack of a model for how phonological timing gets mapped to surface realization. Models for other aspects of the mapping between phonological structure and phonetic output have been developed recently; see among others Beckman and Pierrehumbert (1986), Browman and Goldstein (1986), Keating (1988). These have dealt primarily with intonation, coarticulation, and the nature of phonetic targets and the trajectories between them. A study that builds on Keating's window model by examining the realization of a phonological feature is Cohn (1990) on nasals and nasalization; it offers a starting point for a theory of phonological and phonetic timing.

An important assumption in this enterprise is that the relationship between abstract phonological structure and concrete aspects of speech production is systematic. Cohn demonstrates that phonetic implementation is not simply the province of what is universal and mechanical, it also includes language-specific rule-governed behavior. Thus a plausible model of phonological-to-phonetic mapping will look something like the schema given in §1.1 (adapted from Cohn), repeated here:

(20)



Given this model of grammar, we can assume that there is a point at the output of the phonological derivation where duration is assigned to segments and syllables. In a language like English, the chief priority at this point will be assigning greater duration to stressed syllables. In a language like Runyambo, the highest priority will be to assign duration to segments dominated by a mora: these are the ones that determine distinctive quantity, and thus are subject to the constraint of maintaining a distinctive durational contrast, while other segments may receive their duration specification solely from other sources (such as their place and manner features). This contrasts with the usual assumption about the computation of timing (e.g. in Klatt 1979), namely that assigning target *segment* durations is the first step, and that these durations are then adjusted for location of stress and other factors.

There is some evidence for a timing model like the one described here, from research in speech synthesis. Campbell and Isard (1991), in an effort to find a workable algorithm for calculating duration in synthesized speech, examined natural speech corpora of British English and concluded that the syllable was the most relevant unit of programming for duration. Thus they consider the following factors in their model: (1) number of segments in the syllable, (2) nature of the syllable nucleus (tense/lax vowel, sonorant consonant, etc.), (3) position of the syllable in the foot, (4) position of the syllable in the phrase and clause, (5) stress, and (6) the function vs. content role of the word. The first thing to be calculated is not segment duration but syllable duration, taking into account stress, phrasal position, etc. and leaving out phonetic detail. Then the appropriate durations for individual segments are computed within that syllable span, considering factors like inherent durations, the nature of pre-boundary lengthening (whether it applies to all segments in a syllable or just the last ones), etc.

The durational data presented in this study argue for a similar process taking place in the mapping of phonological timing to phonetic duration. This means for a general theory of timing we would want to take into account at least the following:

- Does the language make phonological reference to moras?
    - Yes: assign minimum durations to maintain quantity distinction
    - No: next step
- Calculate appropriate duration for the syllable:
    - how many syllables in phonological word?[38]
    - how many words in phrase?
    - position in phrase?
    - location of stress?
- Calculate appropriate duration for each segment:
    - feature specification?
    - specifications of neighboring segments?

At this stage in the computation of timing, language-specific allophonic rules would apply (e.g. anticipatory nasalization in English), and their output would be subject to universal physiological constraints on relative timing. This means that a number of factors may influence the final realization of duration *after* the end of the phonological derivation. But this does not necessarily obscure underlying relationships; indeed in languages with distinctive quantity we know that it does not.

Articulatory evidence in Japanese and Italian (Smith 1992) also supports the primacy of prosodic structure in surface timing. X-ray microbeam data show that coordination of articulatory gestures in utterances with geminate consonants is based on vowel-and-consonant interaction in Japanese, while in Italian it is based on a vowel-to-vowel scheme. This accords with the traditional description of Japanese as a mora-timed language and Italian as a syllable-timed language: since in Italian consonants are not central to prosodic structure, they are integrated between vowel targets; while in Japanese, where consonants may

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[38] In Runyambo, for example, this step will assign greater duration to the penultimate syllable of the phonological word (see Hubbard 1992).

distinctively bear a mora, articulatory timing takes both vowels and consonant targets into account in programming gestures.

More abstract typological evidence also argues that different ranking of factors in the mapping of timing occurs across languages. Mary Beckman (pers. comm.) has observed that while Japanese has moras very saliently — in surface timing, in lexical access, etc. — English has moras only implicitly: for instance, the mora is implied in the contrast between tense and lax vowels of the same height, but low lax vowels are often much longer than high tense vowels, so the surface timing facts do not reinforce the salience of the mora. The same is true for the foot in Japanese: while the foot is clearly a very salient unit in English timing, it is only implicit in Japanese.

I have shown in this study that substantive evidence for the phonetic status of prosodic units can be found in acoustic durational data. Acoustic evidence is the easiest to obtain; it is a relatively simple matter to measure duration — compared to extracting pitch or formant values — and these measurements can be compared with known phonological structures, as I have done here. Data from acoustic measurements, however, do not tell the whole story: it is of little use to discover that the crucial durational difference between two syllable types in a given language is 25ms, if that difference is smaller than the perceptual threshold for such speech, or is not categorized as a difference by speakers of the language. Perceptual studies, then, must add an important dimension to the interpretation of acoustic data such as I have gathered: an important next step for this type of research will be cross-over listening experiments, in which tokens from a given language are resynthesized with increasing increments of vowel duration from canonical short to canonical long, and native speakers identify stimuli as one lexical item or another.

Further afield, articulatory studies can reveal a great deal about the production aspects of linguistic timing (as in Smith 1992). Data from speech synthesis efforts, which draw from observed prosodic patterns to construct algorithms that generate more- or less-natural sounding speech, are another important source of information on linguistic timing. And ultimately, further investigation of the auditory physiology of speech perception in humans will provide the fundamental biological information about how we parse continuous signals into perceptually useful chunks. All these types of evidence can illuminate the nature of surface timing and how it is related to underlying representations; by combining them we will be able to more fruitfully connect our multi-tiered models of phonological representation to the many dimensions of speech processing.

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